NUMERICAL SIMULATION OF THE SURVIVAL CHANCE OPTIMZIED SEARCH STRIP WIDTH

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ABSTRACT: When using transceivers (or avalanche beacons) to search for fully buried avalanche victims, the search strategy depends on the signal search strip width which influences the search time until the first signal from the buried subjects can be received by the rescuer. It depends on technical characteristics of the avalanche rescue devices, the avalanche scenario as well as the rescuer's behaviour. The larger the signal search strip width, the shorter is the search time and therefore the higher the survival chance of the buried subject. However, if the search strip width is chosen too large, the probability to miss a buried subject increases, which makes time-consuming multiple searches necessary – and decreases survival chances. Therefore, the search strip width needs to optimized. Only a few years ago, with the advent of digital transceivers, it was realized that the search strip width is not a universal constant but is a device specific property depending primarily on the range of the transceiver. Several approaches on how to determine the signal search strip width have been presented in the past. Most of them use rather conservative assumptions for the different input variables. A newly developed simulation approach for the optimization of the search strip width allows considering more realistic (rather than worst case) assumptions. Preliminary results suggest that the optimal signal search strip width is higher than previously assumed. In future applications, the simulation may be used to optimize a broad variety of search parameters or even entire search systems.

KEYWORDS: avalanche accident, avalanche rescue, numerical simulation

1. INTRODUCTION

Today most avalanche victims in Europe and North America are recreationists (e.g. Meister, 2002). When searching for an avalanche victim the primary issue is time since the survival chances decreases rapidly (e.g. Falk et al., 1994). To locate fully buried victims electromagnetic transceivers are therefore the method of choice when searching the avalanche debris. Transceivers allow a fast and efficient rescue – preferably by other members of the victim's party. The search strategy on the avalanche deposit depends among other things such as the number of rescuers available, on the range of the transceiver. This has been recognized at the very beginning when the first devices that were able to transmit and receive electromagnetic signals were developed in the 1960s.

The search strip width which is the lateral distance between individual rescuers, determines the area of avalanche debris that can be covered in a given time – given a certain search velocity. If the search strip width increases, the chances increase that a buried victim will not be detected (i.e. missed) when searching the debris area the first time, but if the victim is found 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). Therefore, the optimal search strip width is the result of solving an optimization problem.

Good (1972) illustrated the optimization problem with the two following extreme cases:

a) Probability of detection = 1 :
time → ∞ : Chance of survival = 0

b) Chance of survival → 1 :
time → 0 : Probability of detection = 0

It becomes obvious that the probability of detection cannot be 100%, since this would lead to a very narrow search strip width and increase the search time very much. In fact, all victims would be found – but most likely dead.

In summary, the search strip width needs to be chosen to maximize the chances of survival. Some thoroughness needs to be sacrificed in order to decrease the search time. Consequently, there is no need to determine the minimal range which tends to be zero (see below) with the

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consequence that the chance of survival tends to be zero as well.

The principles on how to determine the search strip width based on measurement statistics were described when the first transceivers came on the market (e.g. Good, 1987). Before the advent of digital transceivers towards the end of the 1990s it was common to use either 20 m or 40 m for the search strip width depending – one is tempted to say – on the country. The results of a comparative study on the performance of transceivers initiated by the International Commission of Alpine Rescue (ICAR) showed that the search strip width to be applied very much depended on the transceiver characteristics (Krüsi et al., 1981; Schweizer, 2000). Meier (2001) suggested a relatively simple method to approximate the search strip width. A further test, in particularly focusing on the search strip width, showed that the times where the search strip width were considered a universal constant in avalanche rescue were gone (Schweizer and Krüsi, 2003). Clearly, the search strip width has to be considered as a transceiver specific property. However, this fact was often oversimplified by suggesting a search strip width of 40 m for analog transceivers and of 20 m for digital ones (e.g. Winkler et al., 2006). Tough, results obtained with a method proposed by Meier (2001) had clearly shown that the search strip width is not very much lower than the maximal range that can be obtained in co-axial antenna position. As the further generations of digital transceivers had improved range, a search strip width of 20 m was clearly too narrow – in other words not at all optimized on the survival chance.

The aim of this study, is to present a novel simulation approach to obtain a survival optimized search strip width that takes into account the relevant factors that affect the search time based on realistic – rather than worst case – assumptions for these factors.

2. METHODS

2.1 Previous approach

In the past, four different methods had been proposed to determine the search strip width based on range measurements. The methods were related to the fact that the electro-magnetic field of a transmitting beacon at 457 kHz resembles the characteristics of a dipole in the near field (less than about 100 m), and that there are three typical antenna configurations between transmitting and receiving beacon (considering just one, the main and longest antenna which is most decisive for the signal search): a) co-axial, b) parallel and c) perpendicular (for details see Meier, 2001). The range in the three positions decreases from a) to b) to c). In configuration c) 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 one 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.

From the four methods, the first three methods were described in Schweizer and Krüsi (2003). In the following we only shortly summarize the methods. (1) The first method is based on a large number of range measurements with random antenna configuration (also called effective or usable range). The search strip width is then defined as twice the “98%”-effective range with the “98%”-range defined $r_{98} = \overline{r} - 2\sigma$. (2) The second method is known as the “40%rule” and will not be discussed here any further as it is completely outdated. (3) The third method was proposed by Meier (2001). The search strip width is based on measurements of the maximum range in co-axial antenna position, configuration a), and is equal to the “98%”-maximum range. 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. These assumptions yield a ratio of effective range to maximum range of 0.5. (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 fourth method does not make sense – for theoretical and practical reasons – and will not be further discussed.

2.2 Simulation approach

It is obvious that very many factors affect the search time and hence the optimal choice of the search strip width. This has been exemplified by the method proposed by Meier (2001) – which was a considerable milestone and already led to higher search strip widths than presently used. However, the method as all previous ones relies

partly on worst case scenarios. Given the large number of factors and recall that the search strip width has to be survival chance optimized, a simulation approach seems most appropriate. This allows incorporating a vast amount of variables from different fields of influence with various dependencies between the input variables

2.3 Input variables

Table 1 summarises the various input variables.

Table 1: Variables entering the simulation

Group of factor	*Variables*	*Assumption*
Rescuer	Suboptimal rotation of the receiving device in signal search	All rescuers rotate their device at least ±45°. The majority comes within 10-25° of the optimal rotation.
	Search velocity	1 m/s
Receiving device	"Realistic" maximum mange	For new definition see below
Transmitting device	Remaining battery capacity	Distribution of remaining battery capacity reflects experience of service centers.
	Temperature of the transmitter	Distribution based on carrying methods and outside temperature profile.
	Transmitted field strength	Distribution based on measurements of devices in use and field strength of devices sold today.
	Transmit frequency deviation	Distribution based on measurements of devices in use and field strength of devices sold today.
Avalanche scenario	Deposit size	Size distribution based on Swiss avalanche accident statistics for recreational accidents and buried subjects with no visible parts
	Location of victim	Randomly distributed in debris, (uniform distribution)
	Best possible transmitter orientation relative to center line of the search strip	In two thirds of the cases at least parallel coupling can be reached.
	Burial depth	1 m (median burial depth) according to Swiss accident statistics
	Excavation time	15 min

2.3.1 Rescuer dependent input variables

Rescuer dependent input variables show the performance of a rescuer. Performance may vary in many aspects: physical fitness (i.e. search velocity), level of training (i.e. is the rescuer aware of the fact that the receiver should be rotated in 3d during signal search) and discipline (to what extent the rescuer does follow the rules he is aware of in the field, i.e. does the rotation of the receiver in signal search really include all three dimensions). Not all rescuers are aware of the necessity of the

3d rotation of the receiver during signal search and out of those who are aware, not all comply in the full extent to the rules. However, some movement of the receiver is always existing while moving on the uneven surface of debris; corresponding assumptions and consequences on the loss of range are shown in Figure 1.

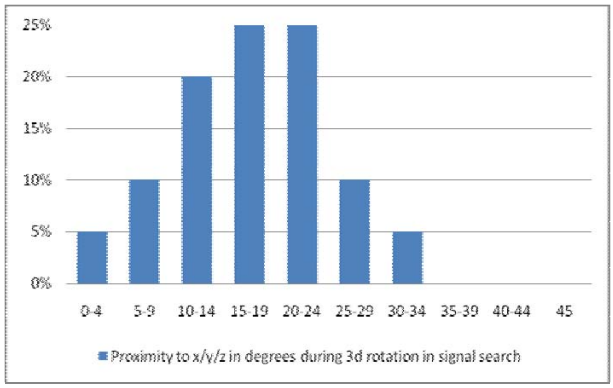

Fig. 1a:
Suboptimal 3d rotation of the receiving device in signal search.

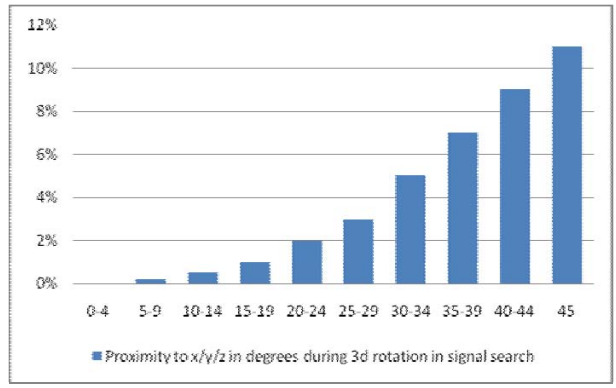

Fig 1b:
Loss of range due to suboptimal 3d rotation of the receiving device.

2.3.2 Receiver based input variables

Receiver based input variables show the technical performance of the receiver. Receiver sensitivity at 457 kHz and tolerance towards frequency offset are examples for variables taken into account. The key input variable is certainly the range of the receiving beacon. In the past, range was based on measurement statistics. We propose a new approach (Zurkirch, personal communication) and define the so-called “realistic maximum range” which fully characterises the range of the receiving beacon. The realistic maximum range is technically measured and therefore free of human-specific influences such as quality of human hearing or concentration of the test person during measurements. Due to the very low acceptable interference level, measurements need to be done outside of a building, but with some battery driven measurement devices. The “realistic maximum range” is defined as follows:

1. Test setting and transmitter: Transmitter at 457 kHz (± 10 Hz) and 2.1 μA/m in 10 m distance, co-axial antenna orientation, interference free environment, no conducting parts nearby.
2. Receiver setup: The measurement must be repeated with 10 receivers of the same brand and type. The mean value of the 10 results counts as the final result.

(a) Analog receiver setup: Receiver in co-axial antenna orientation. Signal to noise ratio must be at least 6dB. In practice, this means that there is a clearly audible, distinct search tone.
(b1) Digital receiver setup for distance criterion: Receiver in coaxial antenna orientation (main antenna). During 5 subsequent minutes, 80% of the pulses must be recognized and indicated in each one of the five 60 s windows. The variance of the measured distance must not exceed ±10% of the mean distance.
(b2) Digital receiver setup for direction criterion: Start at the distance evaluated as described above. Turn receiver 45° clockwise from co-axial position and turn it on. Then, turn on transmitter: Direction indications must be within ±30° within 60 s. Turn receiver off. Repeat procedure by turning receiver 45° counter clockwise to co-axial orientation and turn on transmitter: Direction indications must be within ±30° within 60 s.

2.3.3 Transmitter based input variables

Transmitter based input variables include the transmitted field strength (Fig. 2a,b), the temperature of the transmitter (Fig. 2c,d), the frequency deviation of the transmitter (Fig. 2e,f) as well as the remaining battery capacity (Fig. 2g,h) and the orientation of the transmitting antenna on the deposit (Fig. 2i,j).

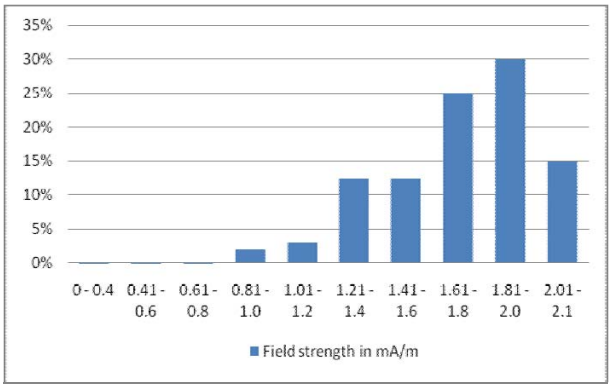

Fig. 2a:
Transmitted field strength

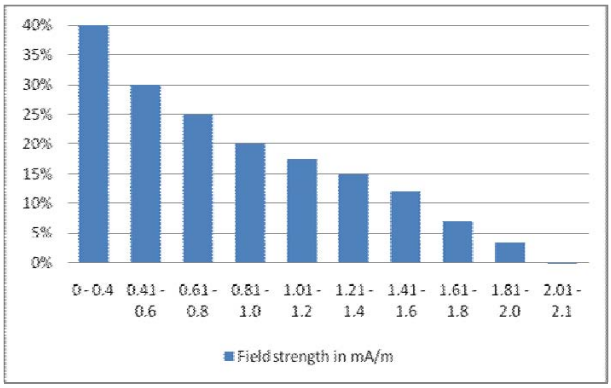

Fig. 2b:
Reduced transmit field strength related loss of range

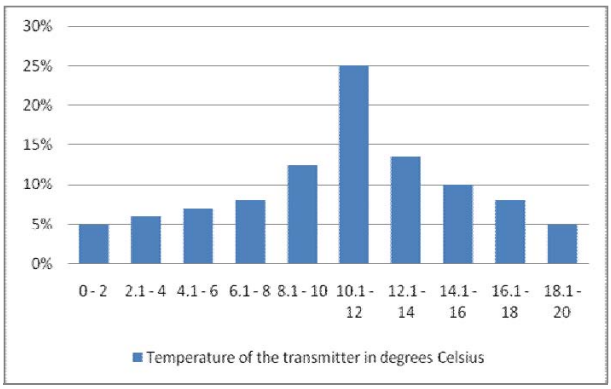

Fig. 2c:
Temperature of the transmitter

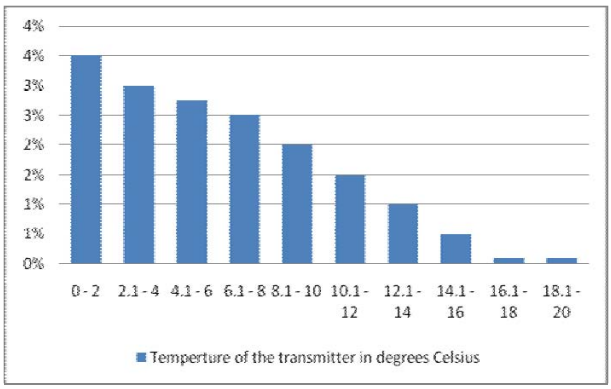

Fig. 2d:
Temperature related loss of range (transmitter)

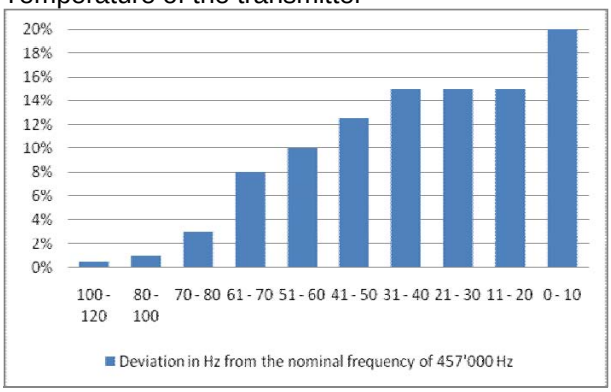

Fig. 2e:
Transmit frequency deviation

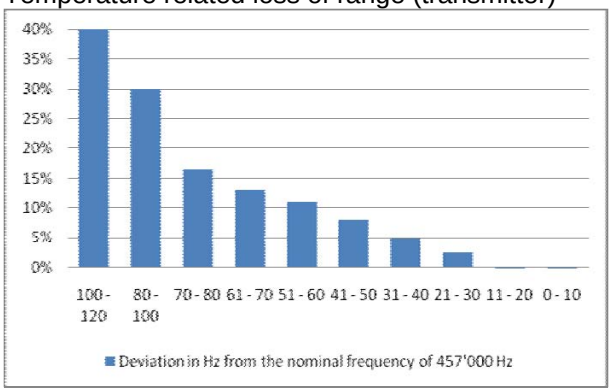

Fig. 2f:
Transmit frequency deviation related loss of range (within the shown frequency range, receivers with digital signal processing do not suffer from this effect)

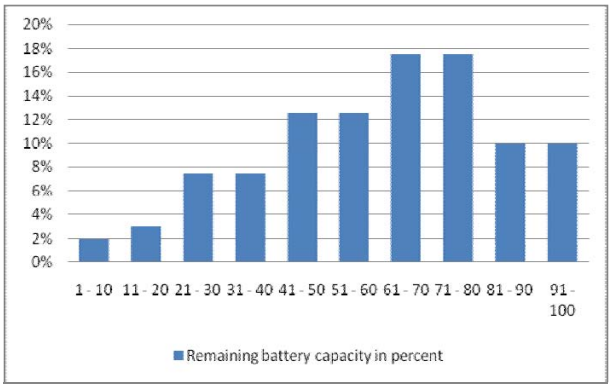

Fig. 2g:
Remaining battery capacity (transmitter)

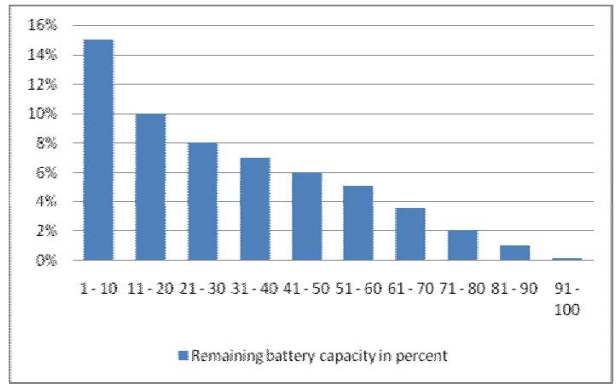

Fig. 2h:
Battery related loss of range
(valid for transmitters without constant output)

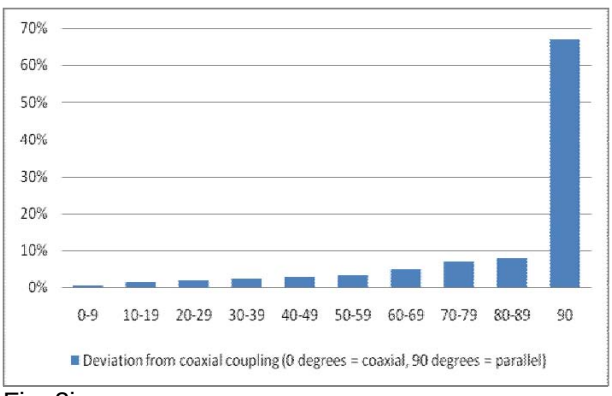

Fig. 2i:
Best possible transmitter orientation relative to center line of the search strip.

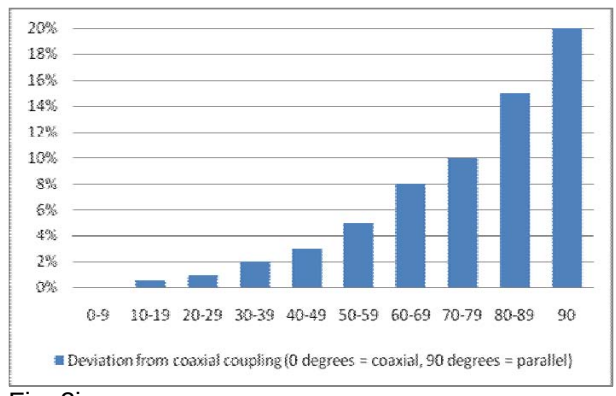

Fig. 2j:
Loss of range due to transmitter orientation

2.3.4 Avalanche scenario dependent input variables

Avalanche scenario dependent input variables include size of the debris, position of the buried subjects within the debris and within the search strip as well as foot penetration of the surface, a parameter which influences the rescuer's velocity. As avalanche accidents statistics usually do not provide information on location of the victim and as we do not want to make any assumption on the last seen point etc., we have assumed that the victim can be buried anywhere in the deposit (uniform distribution). The size of the deposit is based on avalanche accident statistics from Switzerland (1970-1971 to 2005-2006) (Fig. 3). The deposit size from all recreational avalanche accidents in the SLF database were extracted where at least one person was fully buried (no visible parts). The median avalanche size in the sample (N = 267) was 8400 m^2, with a range from 80 m^2 to 225,000 m^2. Three quarters of the avalanches had a size of less than 22,500 m^2, the lowest 25% were smaller than 2500 m^2. Hence, the sample contains very many small and a few very large avalanches – though it is representative.

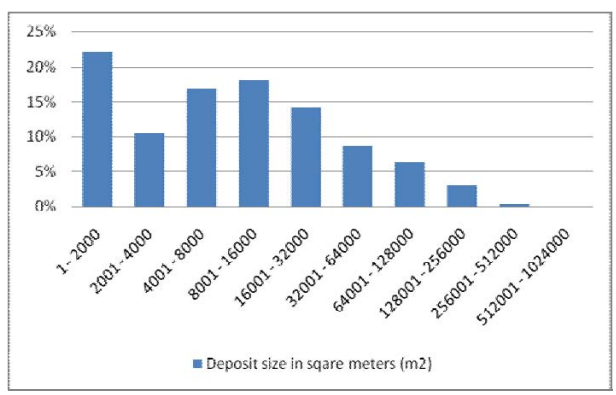

Fig. 3: Avalanche deposit size based on Swiss avalanche accident statistics.

2.3.5 Survival chance as a function of burial time

Based on the survival chance as a function of burial time published by Falk et al. (1994), it is decided whether the subject is alive or deceased at the end of the simulated rescue time.

2.4 Multiple searches

If the search of the debris with the initially applied signal search strip width does not lead to success, the debris need to be searched again by cutting the value for the search strip width in half. This approach of applying a finer search pattern in cased of misses is widely accepted in avalanche rescue and applied for decades in probe line search strategies.

In case multiple searches become necessary, the simulation includes a strong decrease of the rescuer's performance reflecting the decrease of physical performance and motivation usually associated with this occurrence. Therefore, the proposed values for a survival chance optimized signal search strip width make it very unlikely that the rescuer ever needs to search the debris more than once.

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2.5. Coarse search, fine search, probing and excavation

Times for coarse search, fine search, probing and excavation are implemented in the simulation. Whereas coarse search and fine search are implemented as part of the transceiver related search times, probing and the excavation process is taken into account by a 15 min addition to the transceiver search times. This is a realistic value taking into account that the median burial depth for completely buried avalanche victims is 100 cm (Harvey and Zweifel, 2008).

2.6 Simulation procedure

Based on a given maximum range (which can be varied) and assuming a certain initial search strip width (e.g. 10 m) the rescue time is simulated, and evaluated whether the subject is still alive or deceased (according to the survival curve). This procedure is then repeated 20,000 times, with different values for the various variables randomly chosen according to the distribution shown above. Within this sample then all possible combinations (also worst cases) exist according to their frequency. Finally, we receive for a given realistic maximum range and a given search strip width the average survival chance.

The search strip width is then increased more and more (still for the same realistic maximum range) and the above procedure is repeated. At the end, we receive the survival chance for a given maximum range as function of the search strip width. The curve will show a maximum (a minimum if the mortality is shown) which will indicate the optimal search strip width for a device with a given maximum range. The whole procedure is then repeated for different values of the maximum range.

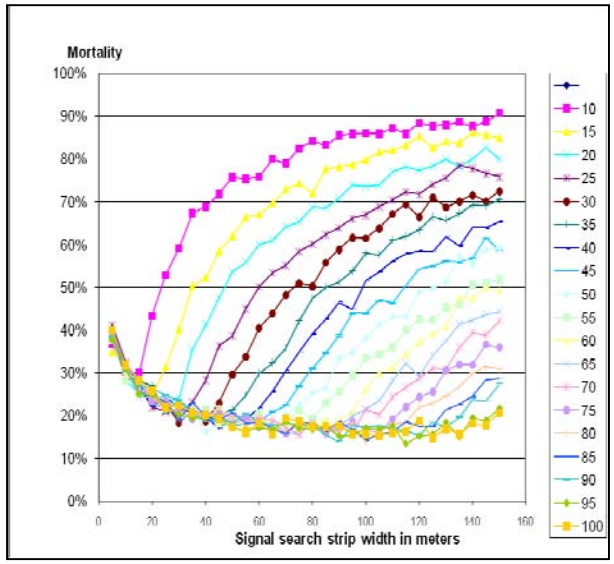

Fig. 4: Results of simulation showing the search strip width for different values of the realistic maximum range.

3. RESULTS

The simulation allows calculating the survival chance optimized signal search strip width for any avalanche rescue transceiver with a given realistic maximum range (as determined above).

Figure 4 shows the mortality as a function of the search strip width for various values of the realistic maximum range. For each curve (corresponding to a given realistic maximum range) a maximum exists. The maximum indicates the width of the signal search strip for which the survival chance is greatest (or the mortality lowest). As can be seen, for example for a realistic maximum range of 40 m, the optimal search strip width is about 40 m. The maximum values are compiled in Figure 5. The optimal search strip width increases with increasing realistic maximum range and is about equal to the maximum search

strip width. In Figure 6 the effect of the realistic maximum range on the survival chance is shown.

The mortality decreases with increasing range of the device indicating that a beacon with a large range allows short search times due to a large search strip width. For a receiver with a realistic maximum range of 20 m the mortality is about one third higher than for a receiver with 50 m realistic maximum range.

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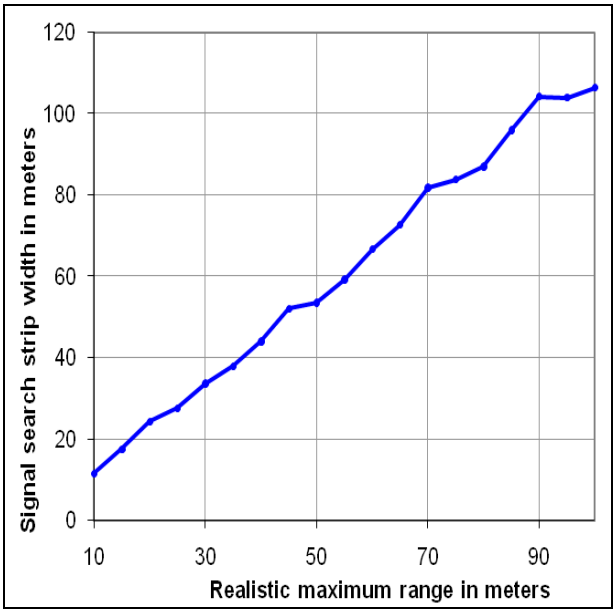

Fig. 5: Search strip vs. realistic maximum range

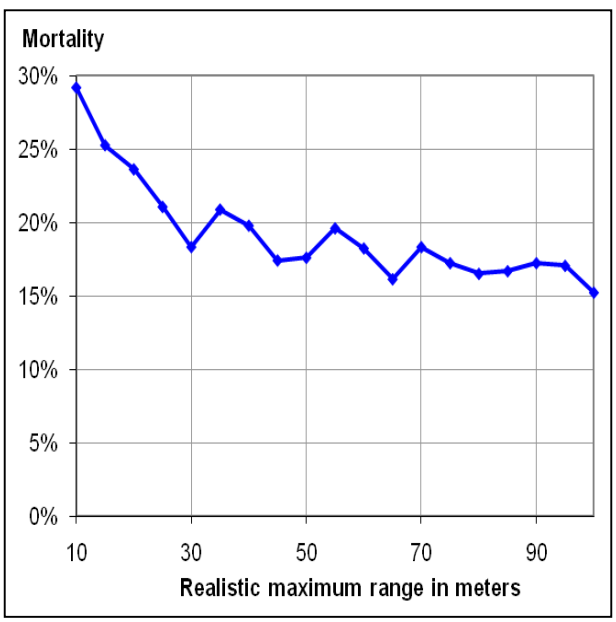

Fig. 6: Effect of realistic maximum range on the mortality.

4. DISCUSSION

The avalanche deposit size distribution contains many small avalanches. On very large avalanche deposits the optimal search strip width is therefore slightly larger. However, it seems not practical to make the search strip width dependent on avalanche size.

In most cases with a median deposit size of 8400 m^2 corresponding to a square of about 92 m × 92 m the search strip width is not a big issue if the rescuers have some hints where the victim might be buried (e.g. if the last seen point is known).

A surprisingly strong influence on the survival chance optimized signal search strip width (+ approx. 23%) was found between receivers with and without digital signal processing. The wider tolerance of receivers with digital signal processing towards transmitters with frequency offset seems to be important.

The 3d rotation of the receiving device is important for all devices with antennas of considerably different length. If all rescuers would perfectly rotate the device in all three dimensions, the signals search strip width would be approx. 9% higher. Contrary, if everybody would stop at all with actively rotating the device in all three dimensions so that only the unintended movement of the device due to the progress of the rescuer on the uneven avalanche debris would be left, the signal search strip width would have to be approx. 10% to 15% smaller.

The more antennas a receiver has (up to three) and the more simultaneously all antennas are (technically) receiving in the signal search phase, the more error tolerant is the receiver towards rescuers who do not optimally rotate the device in all three dimensions. Only a receiver with three antennas of the same length simultaneously on receive at all times completely eliminates the necessity of the 3d rotation. Such devices are today only applied in 3d external antennas for helicopter based transceiver search.

The shorter the realistic maximum range, the less error tolerant is the receiver towards underestimating distances in the field since the curve in Figure 6 becomes almost flat above a realistic maximum range of about 60 m.

Compared with the methods proposed by Meier (2001) or Good (1987), the simulation based approach takes a by far wider range of influencing variables into account. However, whereas the previous methods applied constant penalty factors for the range reducing factors, the simulation tries to reflect for each parameter as closely as

possible the real situation in the field, where accumulations of negative only factors have a very low probability. With the simulation approach, the search strip widths are similar, but slightly larger than the ones that can be determined with the method by Meier (2001), i.e. about 0-20% higher. Consequently, they are also comparable to those that have been determined with the first method described above. However, the simulation approach is more comprehensive and does not require time consuming and partly subjective field tests. A completely new approach of the simulation is to optimize the signal search strip width based on highest possible chances of survival.

5. CONCLUSIONS

We have presented a novel approach to determine a survival optimized signal search strip width. The simulation shows that survival chance optimized values for the signal search strip are about equal to the realistic maximum range – provided the receiver which has been simulated for the purpose of this study shows technical characteristics comparable to the leading products with digital signal processing which are today widely available on the market.

The values for the survival chance optimized search strip width are considerably higher than the standard recommendation within many countries and organizations. Narrowing the signal search strip width below the proposed values leads to an increase of the average signal search time and therefore directly reduces the survival chances of the buried subject.

Currently, the simulation is focussed on optimizing the survival chance optimized signal search strip width. However, in future applications, the simulation may be used to optimize a broad variety of search parameters or even entire search systems.

As a potential tool for transceiver manufacturers, the simulation allows to be adapted to their specific receiver related parameters. Applying this simulation allows a manufacturer to determine the signal search strip width with minimal field related testing.

ACKNOWLEDGEMENTS

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REFERENCES

Falk, M., H. Brugger, and L. Adler-Kastner, 1994: Avalanche survival chances. *Nature*, **368**(6466), 21.

Good, W., 1972: Optimaler Einsatz der Mittel zur Ortung Lawinenverschütteter. In: de Quervain, M. (Ed.), *Schnee und Lawinen in den Schweizer Alpen Winter 1970/71 (Winterbericht des Eidg. Institutes für Schnee- und Lawinen-forschung, Weissfluhjoch-Davos, No. 35)*, Eidg. Drucksachen und Materialzentrale, Berne, Switzerland, 154-162.

Good, W., 1987: Electronic transceivers for locating avalanche victims, an optimal strategy for the primary search. *Proceedings ISSW 1986, International Snow Science Workshop, Lake Tahoe, California, U.S.A., 22-25 October 1986*, ISSW Workshop Committee, Homewood, CA, USA, 177-182.

Harvey, S. and B. Zweifel, 2008: New trends of recreational avalanche accidents in Switzerland. *Proceedings ISSW 2008, International Snow Science Workshop, Whistler BC, Canada, 21-27 September 2008*, this issue.

Krüsi, G., P. Weilenmann, and F. Tschirky, 1998: *Lawinenverschütteten-Suchgeräte Vergleichstest "LVS-98"*. Vol. 57, *Mitteilungen des Eidg. Instituts für Schnee- und Lawinenforschung*, 131 pp.

Meier, F., 2001: Determining the width of a search strip for avalanche beacons. *Proceedings International Snow Science Workshop, Big Sky, Montana, U.S.A., 1-6 October 2000*, Montana State University, Bozeman MT, USA, 345-350.

Meister, R., 2002: Avalanches: warning, rescue and prevention. *Avalanche News*, **62**, 37-44.

Schweizer, J., 2000: The European Avalanche Beacon Test "LVS-98". *American Alpine News*, **9**(228), 28-32.

Schweizer, J. and G. Krüsi, 2003: Testing the performance of avalanche transceivers. *Cold Reg. Sci. Technol.*, **37**(3), 427-436.

Semmel, C. and D. Stopper, 2007: LVS Geräte im Test. *DAV Panorama - Mitteilungen des Deutschen Alpenvereins, München, Germany*, **2/2007**, 88-91.

Winkler, K., H.-P. Brehm, and J. Haltmeier, 2005: *Bergsport Winter*. Schweizer Alpen-Club SAC, Berne, Switzerland, 254 pp.