The Effect of Under-Reporting of Non-Fatal Involvements in Snow Avalanches on Vulnerability

Bruce Jamieson
Professor, Dept. of Civil Engineering, University of Calgary, Calgary, Canada

Alan S.T. Jones
Principal and Senior Engineer, Dynamic Avalanche Consulting Ltd., Revelstoke, Canada

ABSTRACT: For a person caught in a snow avalanche of specified magnitude, vulnerability is probability of death. In North America and most alpine countries, most fatalities due to snow avalanches occur during recreation and are thus a voluntary risk. The previously reported vulnerability of recreationists to snow avalanches is typically in the range of 0.1 to 0.25, which is also applied to workers travelling on skis and snowmobiles in uncontrolled areas (backcountry). This is the base rate (prior probability) for many studies of survival factors such as use of specific rescue devices, burial depth, etc. Most studies of people caught in avalanches assume that all non-fatal involvements are reported. However, in a recent Canadian study, Jamieson and Jones (2012) argued that only 5 to 10% of persons caught but not killed by an avalanche *during recreation* are reported. This results in potential overestimation of vulnerability by a factor of about 10 or greater. Such uncertainty in the base rate can undermine statistical studies of survival factors. We review the assumed reporting rates from international studies and their calculated vulnerability rates from snow avalanches in uncontrolled terrain. We conducted a survey of those who had been caught in an avalanche, which indicated that 11% of non-fatal involvements are reported in Canada. We discuss both positive and negative biases in our survey results. Based on Canadian data, we conclude that the vulnerability for persons travelling on skis or snowmobilers and caught in a potentially fatal avalanche is approximately 0.03. This revised base rate may prove useful in studies of rescue devices, burial depths, public avalanche education programs, and policies concerning risk management and resource allocation.

1. INTRODUCTION

The vulnerability of people caught in snow avalanches is defined as the probability of an individual being killed (e.g. IUGS, 1997). It is the complement of the survival rate. As a component of risk, vulnerability is partitioned by scenario (Kaplan and Garrick, 1981), which are typically defined in terms of event magnitude. For snow avalanches, defining scenarios according to avalanche size (magnitude) (McClung and Schaerer, 1981; Table 1) is effective and has been used to analyze the vulnerability of people caught in avalanches (e.g. Jamieson and Jones, 2012). This classification has been used in Canada since 1981 (Canadian Avalanche Association, 2007) and adopted by some other countries.

For travel on skis or snowmobiles, snow avalanche vulnerability increases with:

- the amount of snow released (more snow implies potentially higher forces and deeper burial),
- the position of the person in relation to the top of the avalanche when it releases (lower position in the avalanche implies potentially higher forces and deeper burial),
- the presence of trees and rocks which increase trauma, and on terrain (e.g. size

Table 1: Classes of avalanche size by destructive potential (McClung and Schaerer, 1981, 2006, p. 322; Canadian Avalanche Association, 2007)

Size[a]	Destructive potential	Typical mass (t)	Typical path length (m)
D1	Relatively harmless to people.	<10	10
D2	Could bury, injure or kill a person.	10^2	100
D3	Could bury a car, destroy a small building, or break a few trees.	10^3	1000
D4	Could destroy a railway car, large truck, several buildings, or a forest with an area up to 4 ha.	10^4	2000
D5	Largest snow avalanches known; could destroy a village or a forest of 40 ha.	10^5	3000

[a] the D prefixing the number is a recent addition to distinguish the classes from other numerical avalanche size classifications not based on destructive potential.

and shape of slope, presence of "terrain traps" that tend to increase burial depth).

Jamieson and Jones (2012) pointed out that recreationists on skis and snowmobiles tend to have lower vulnerability than people on foot low in an avalanche path because:

- most recreationists trigger the avalanches in the start zone where the forces are lower, and opportunities for escaping much of the force and burial mass are greater,
- skis and snowmobiles can help the recreationists escape to the side or out of the avalanche,
- many recreationists on skis or snowmobiles have some awareness or training in how to act once caught in an avalanche, and
- an increasing number of victims are quickly rescued by trained companions equipped with transceivers, probes and shovels.

When applied to human life, vulnerability, i.e. the probability of death to an individual (PDI), is calculated as the number of people killed divided by the number of people caught (impacted by) the hazard, $N_{killed.}$ Expanding the denominator, PDI is calculated

$$PDI = \frac{N_{killed}}{N_{killed}+N_{not\ killed}} \qquad (1)$$

This study focuses on the reporting of non-fatal involvements (people caught) during recreation in avalanche prone terrain. We define RR_{NF} as the reporting rate of non-fatal involvements in potentially fatal snow avalanches. If the reporting rate for fatal involvements is greater than RR_{NF}, PDI will be overestimated. We assume avalanche fatalities are consistently reported to the Canadian Avalanche Centre (CAC, recently renamed Avalanche Canada).

If one considers a land slide or snow avalanche hitting a village or mining camp, typically both N_{killed} and $N_{not\ killed}$ would be well reported. Hence, $RR_{NF} \approx 100\%$. In this paper we focus on people recreating (e.g. skiing, snowmobiling, snowboarding) in avalanche-prone terrain. In this study, we included guided and unguided recreationists as well as people working on skis or snowmobiles in avalanche prone terrain, i.e. we assumed RR_{NF} would be similar for the different user groups. We return to this assumption in the discussion.

Most estimates of vulnerability of recreationists caught in avalanches come from survival studies. To assess the influence of a condition C on vulnerability, the PDI becomes the prior or base rate for these calculations. The condition C may be the use of a specific rescue device, buried > 1 m, the size of the avalanche, etc. Writing PDI as P(D), Bayes Law is

$$P(D|C) = \frac{P(C|D)P(D)}{P(C)} \quad (2)$$

in which the denominator is often expanded as P(C|D) P(D) + P(C|~D) P(~D), where ~D is the complement of D.

Using accident data from near Davos, Switzerland from the winters of 1988 to 1997, Schweizer and Lütschg (2001) found the probability of death for a person caught in a human-triggered avalanche was 0.11. They acknowledged that some non-fatal avalanches may not have been reported (selection bias), suggesting PDI < 0.11.

In a study of rescue devices including balloon packs, Brugger et al. (2007) analyzed Swiss data (winters of 1991 to 2004) and Austrian data (1999 to 2005) to find a PDI of 0.19 for persons without balloon packs. They acknowledged that some accidents, presumably more non-fatal ones, may not have been reported, suggesting a PDI < 0.19.

In contrast to the current study, Haegeli et al. (2011) focused on fully buried victims, which results in higher vulnerability. For 301 fully buried recreationists in Canada, Haegeli et al. (2011) reported PDI_{BURIED} = 0.53. They acknowledged that underreporting of non-fatal involvements is common and will decrease PDI.

To reduce reporting biases in their study on the effectiveness of balloon packs for reducing vulnerability, Haegeli et al. (2014) selected only Size D2 and larger avalanches in which at least one person "seriously involved" in the avalanche deployed a balloon pack and at least one person — also seriously involved — did not. In such avalanches, the number of people killed and those not killed would be well reported. While this eliminates the non-reporting bias for non-fatal involvements, the selection of avalanches with at least two people seriously involved excludes some of the smaller potentially fatal avalanches. Also, Haegeli et al.'s (2014) definition of "seriously involved" specifically excludes persons who remained upright or rode out of the avalanche whereas the present study included those cases provided they were carried at least 5 metres in the flow. For caught persons without balloon packs, Haegeli et al. (2014) found PDI = 0.22, which was the base rate in their study.

From recreational avalanche incidents reported to the Canadian Avalanche Centre from 1984 to 2011, Jamieson and Jones (2012) reported that the PDI for avalanches of destructive size D2 and larger could be 0.19 if RR_{NF} was 100%. However, they assumed that RR_{NF} was only 5 to 10%, which lowered the PDI to 0.02 to 0.03. The present study uses survey data to estimate the reporting rate and then PDI.

2. SURVEY METHODS

We conducted a survey of people who had been caught in avalanches and who were familiar with the size classification of snow avalanches based on destructive potential (Table 1). The surveys were distributed by email to members of the Canadian Avalanche Association and handed out at two advanced courses for avalanche workers offered by the Canadian Avalanche Association in the fall of 2014. The preamble to the survey and the email invitation allowed the survey to be forwarded to experienced recreationists. To promote quality responses, the completed forms were either handed to an instructor on either of the two courses or emailed to the first author.

There were two questions in the survey (italicized below). The first dealt with the number of times a respondent was caught (involved), and the number of times he or she reported being caught. The responses were partitioned by the avalanche size (Table 1). The Canadian Avalanche Association recording standards allows half sizes such as D2.5 and D3.5. Avalanches smaller than size D2 were excluded since they are defined as "relatively harmless to people."

1a. How many times have you been caught, i.e. carried more than 5 m, in a size 2 or larger snow avalanche? Enter your responses — by size — in the table below. Avalanche size is defined by destructive potential in the Canadian Avalanche Association's 2007 Observation Guidelines and Recording Standards.

1b. Of the involvements in Question 1a, estimate how many were reported to the Canadian Avalanche Association (CAA) or Canadian Avalanche Centre (CAC) for inclusion in their incident/accident database? (Note that involvements reported to the CAA InfoEx are ***not*** *shared with the CAA/CAC incident/accident database.) Enter your responses — by size — in the table below. Since your estimate will be combined with estimates by others, your responses will be useful even if you have low confidence in your responses.*

Size (destructive potential; CAA, 2007)	*Times caught*	*Times reported*
D2		
D2.5		
D3		
≥ D3.5		

The second question asked respondents to estimate the reporting rate of non-fatal avalanches in Canada. The question referred specifically to reporting to the incident database previously managed by the Canadian Avalanche Association (CAA) and more recently by the Canadian Avalanche Centre.

2. For backcountry recreationists and avalanche professionals in Canada, estimate the percentage of people caught in size 2 and larger avalanches that are reported to the CAA/CAC for inclusion in their incident/accident database? (Do not include involvements that were only reported to the CAA InfoEx.) Your estimate should be based on the years for which you are familiar with people travelling in avalanche terrain and reporting to the CAA/CAC. Since your estimate will be combined with estimates by others, your responses will be useful even if you have low confidence in your estimates.
_____%

3. RESULTS

Based on the survey methods described in Section 2, we are confident that most respondents had at least 10 years of experience travelling on skis or snowmobile in avalanche terrain. The majority of respondents were employees of avalanche safety programs in western Canada.

3.1 Question 1 – number of respondents who reported being caught

Forty-three people answered the first question. The number of respondents caught decreased from 37 in a Size D2 avalanche to 3 in a Size D3.5 or larger avalanche. Respondents could report more than one involvement for a given size of avalanche. Eighty-one percent of the 155 reported involvements were Size D2. The number of involvements decreased from 122 in a Size D2 avalanche to 3 in a Size D3.5 or larger avalanche. As shown in Table 2, 9% of involvements in Size D2 avalanches and 11% of involvements in size D2 or larger avalanches (rightmost column) were reported to the Canadian Avalanche Centre.

3.2 Question 2: Estimated reporting rate of non-fatal recreational involvements

Forty-four respondents answered Question 2 in which they estimated the reporting rate of non-fatal involvements to the Canadian Avalanche Centre. Table 3 shows the quartiles and mean of the reporting rate estimated by the respondents. The estimates ranged widely, with an interquartile range from 5 to 30%. The median was 15% and the mean was 19%.

Table 2: Results of Question 1 regarding personal involvements and reporting

	Avalanche size (Canadian Avalanche Association, 2007)				
	D2	D2.5	D3	> D3.5	≥ D2
No. of respondents caught at least once	37	8	7	3	43[a]
Number of avalanches with respondent caught (involved)	122	14	12	3	151
Number of involve-ments reported	11	2	0	3	16
Reporting rate	9%	14 %	0%	100%	11%

[a] Not a sum of columns 2 to 5 since individual respondents may have been caught in avalanches of different sizes.

Table 3: Reporting rate of non-fatal involvements estimated by survey respondents (Question 2)

	Rate (%)
Minimum	0.1
First quartile	5
Median	15
Third quartile	30
Maximum	70
Mean	19

In unsolicited comments, two respondents asked whether the period before, or after, the CAC started online reporting should be considered. The period was not stated in the question, and the ambiguity may have influenced the results. To assess the effect of online reporting, we retrieved the number of reported involvements and the number of fatalities before and after online reporting was introduced in 2009. Prior to 2009 in Canada, avalanche incident reports were submitted by fax, email or postal mail. The number of fatalities reported annually from 2009 to 2014 averaged 13, similar to the 12 fatalities per year reported in the preceding 10 years. In contrast, the number of involvements reported annually from 2009 to 2014 averaged 56 compared to 25 per year in the preceding 10 years. Prior to 2009 the ratio of reported involvements to reported fatalities averaged 2.1, and from 2009 to 2014 the ratio averaged 5.8. Hence, the reporting rate of non-fatal involvements more than doubled with online reporting.

4. DISCUSSION

Since most of the respondents had at least 10 years of experience with travel in avalanche terrain and with avalanche reporting in Canada, we expect that most respondents weighted the period prior to online reporting. Based on the reporting rate estimated by respondents in Table 3, this suggests that 15 to 20% of non-fatal involvements were reported to the Canadian Avalanche Centre.

Eighty-one percent of the reported involvements (Table 2) were in Size D2 avalanches, which is the smallest size that is potentially fatal (Table 1). This could be because recreationists and workers are careful not to expose themselves to larger avalanches, or due to underestimation of avalanche size (Jamieson et al., 2014).

Since people caught in avalanches tend to remember such events, the reporting rate in Table 2 carries more weight than the estimated rates in Table 3, suggesting a report of non-fatal involvements of about 11%. The results of Question 1 summarized in Table 2 are not affected by the advent of online reporting. There is, however, another potential reporting bias that may have affected both questions.

The majority of the respondents were employees of avalanche safety programs in western Canada, who travel on skis and by snowmobiles as a part of their work and for recreation. Almost all these operations including ski guiding operations report observed weather, snowpack and avalanche information daily to the Canadian Avalanche Association's Information Exchange (InfoEx) program. When a person is caught in an avalanche at any of these operations, the event is routinely included in the operation's daily report to the InfoEx. However, involvements reported to the InfoEx are not shared with the CAC incident database and this fact was mentioned in both questions. However, some of respondents expressed surprise that involvements should be reported separately to the CAA InfoEx and to the CAC incident database. Other respondents stated that there was an error in the wording of the questions because they were sure that involvements reported to the CAA InfoEx were entered the CAC incident database either automatically or by CAC avalanche forecasters (who read the InfoEx). However, Karl Klassen, the manager of the CAC's Public Warning Services has definitively stated "InfoEx data is considered private and proprietary and we have never pursued permission to take incident/accident reports from InfoEx and transcribe them into the Avalanche Canada incident database." The misconception about the handling of involvements by avalanche workers — many of whom completed the survey — means that the estimated reporting rates of non-fatal involvements from Questions 1 and 2 in Tables 2 and 3 are overestimated. This will tend to positively bias the vulnerability (PDI).

There is also a potential negative bias in the results of our survey. Our survey method selected those who had extensive experience travelling in avalanche terrain, many of whom were avalanche practitioners. Specifically, the survey was distributed at two courses for avalanche practitioners. The preponderance of Size 2 avalanches in Table 2 suggests either that many respondents were skilled at not exposing themselves to terrain and snow conditions favorable to larger avalanches, and/or that avalanche size was sometimes underestimated (Jamieson et al., 2014).

Further, it is possible that as a result of their training and experience, the practitioners and experienced recreationists might be better at escaping avalanches and at creating an air pocket around their face — and thereby extending survival time — than a typical winter recreationist. Also, the respondents might have more often traveled with others skilled at rescuing companions, which is certainly true for guided recreation. Specifically, the response to an avalanche involvement at work (included guided recreation) may be faster and more effective than during typical backcountry recreation. Such factors would tend to reduce the vulnerability, i.e. create a negative bias for the vulnerability of recreationists.

Hence, we have identified a positive bias on PDI due to overestimation of reporting to the CAC incident database by practitioners, and a negative bias due to the skills of practitioners at escaping avalanches and rescuing companions. The positive bias is substantial, and the negative bias due to the escape and rescue skills may also be substantial. Lacking data to compare the weight of these opposing biases and noting that these biases are weak compared to the under-reporting of non-fatal involvements, we propose that the net effect on PDI is negligible. This suggests that RR_{NF} is approximately 9% for Size D2 avalanches and somewhat greater for larger avalanches. Using RR_{NF} = 10%, the data summarized by Jamieson and Jones (2012) indicate PDI for recreationists is approximately 0.01 for size D2 avalanches and 0.03 for the reported distribution of avalanches involving recreationists.

This estimate of PDI for recreationists contrasts sharply with the PDI of nonrecreationists low in an avalanche path. For people on foot outside buildings, Barbolini et al. (2004) estimate PDI of 0.17 and 0.65 for people partly buried and fully buried, respectively. This is for large avalanches that reach buildings in or near the valley bottom. This estimate of PDI = 0.65 for fully buried people is close to Haegeli et al.'s (2011) estimate of 0.53 for fully buried recreationists. For people inside unreinforced buildings struck by size D2.5 and D3 avalanches (similar in magnitude to those that involve recreationists), Keylock et al. (1999) estimate PDIs of 0.03 and 0.07, respectively.

Keylock et al.'s (1999) values are slightly higher than the values for recreationists in this study (assuming 10% reporting of non-fatal involvements). These comparisons to people caught on foot inside and outside buildings located in the valley bottom implies that the following recreational factors (e.g. Jamieson et al., 2010) substantially reduce the PDI:

- typically being caught near the top of the avalanche,
- having some skill to escape on skis or snowmobiles,
- prompt rescue by companions with transceivers, shovels and probes.

An analysis of these risk reduction factors would be worthwhile.

We also recommend a study of the difference in vulnerability between avalanche practitioners compared to recreationists since we were unable to separate these groups in our study.

We are unaware of studies that assess the reporting rate of non-fatal human involvements for avalanches and other slope hazards that have affected settlements, work camps, etc. However, we expect better reporting of non-fatal involvements for non-recreational activities. While avalanche involvements at work should be reported to regulators, such incidents are currently not systematically entered into Avalanche Canada's incident database. For property damage including damage to snowmobiles from snow avalanches, reporting is likely poor in Canada because of Avalanche Canada's focus on human involvements.

5. CONCLUSIONS

In situations in which backcountry recreationists and avalanche practitioners travelling by ski or snowmobile voluntarily report their involvement in avalanches in Canada, there is currently extensive under-reporting of non-fatal involvements. Without adjusting for under-reporting, vulnerability will be overestimated. For the Canadian recreational incident data in the last 20 years, we estimate that only about 10% of non-fatal involvements were reported. However, this rate is increasing with online reporting, which started in Canada in 2009.

Using the Canadian data summarized by Jamieson and Jones (2012) and a reporting rate of non-fatal involvements of 10%, the vulnerability of recreationists caught in Size D2 avalanches is approximately 0.01, and approximately 0.03 for the full distribution of sizes in Canadian avalanche incidents involving recreationists and workers who travel by ski and snowmobile in avalanche terrain. This low vulnerability applies only to recreationists and to workers who travel in the same way as recreationists. It reflects factors in the Canadian Avalanche Centre's incident database from 1984 to 2011. During this time, many of those caught had an avalanche transceiver and were caught high in an avalanche path while travelling on skis or by snowmobile (Jamieson et al., 2010). Those caught were often accompanied by companions who had avalanche transceivers, probes and shovels and at least basic skill in avalanche rescue.

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