AVALANCHE ACCIDENTS INVOLVING PEOPLE ALONG TRANSPORTATION CORRIDORS AND THE IMPLICATIONS FOR AVALANCHE OPERATIONS

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ABSTRACT: Here we investigate avalanche accidents involving people along transportation corridors (road or railroad) in the United States, Canada, Switzerland, and Italy. 408 avalanches involving 1257 people have been examined in the period from 1900 to 2014. Of these, 123 avalanches resulted in 382 fatalities. Three quarters of the accidents involved users, generally while travelling on an open road. In contrast, accidents involving workers occurred frequently when the transportation corridor was closed, during maintenance work (as snow or debris clearing). Secondary or delayed avalanches were responsible for more than one quarter of the accidents involving workers. Despite the increase in traffic volume, long-term statistics of the annual number of fatalities and the number of avalanches causing fatalities showed strongly decreasing trends for all four countries. This reduction we attribute to the successful implementation of snow safety programs. It is of note, however, that four of the six avalanches causing fatalities during the last two decades involved workers. Our results strongly emphasize the necessity of implementing and maintaining snow safety programs in avalanche threatened transportation corridors and being particularly aware of the danger of delayed avalanching.

KEYWORDS: road, railroad, avalanche accidents

1. INTRODUCTION

In mountainous areas, avalanches can pose a serious threat to users and workers on roads and railroads. While it is often of economic importance to keep these transportation corridors open during winter, the risk to people and equipment must be minimized. Avalanche safety programs have the responsibility to reduce the avalanche hazard to the traveling public and its workers. This can be incredibly difficult due to the dynamic nature of forecasting snow avalanches. However, as Hendrikx et al. (2006) and Campbell et al. (2007) have shown, the implementation of avalanche programs has reduced the loss of life, despite a strong increase in mountain pass traffic. For instance, in Switzerland the amount of goods transported on Alpine pass roads doubled from 1981 to 2009 (FSO, 2010).

Avalanche forecasters have to make safety decisions to allow workers to clear snow or debris, and the public to travel when avalanche conditions are considered safe. To compound this decision there are political and economic ramifications to a transportation corridor being closed. For example, during the winter of 2000, the Seward Highway in Alaska, USA was closed in places for up to a week. This avalanche event was declared a federal and state disaster leaving thousands stranded with estimated damages at 16 million dollars (D'Oro, R. 2000) and one worker fatality by a secondary/delayed avalanche while clearing avalanche debris (ADOT&PF, 2014).

Here, we describe and investigate patterns in avalanche accidents on roads and railroads with the goal to identify where avalanche programs should focus their safety efforts to reduce fatalities and accidents. In a second step, we investigate long-term trends in fatalities. Finally, we compare accident statistics before and after the implementation of avalanche programs using as examples the programs implemented by the British Columbia Ministry of Transportation (BCMoT) and the Colorado Department of Transportation (CDOT).

2. DEFINING PARAMETERS

We considered avalanche accidents where a descending avalanche hit users or workers on roads and railroads. As far as known, we omitted cases where a train or vehicle ran into an avalanche deposit.

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Several parameters were examined: type of transportation corridor (road, railroad), function (user, worker), corridor status (open, closed), secondary avalanche, worker activity and damage to people.

Type of transportation corridor

- *Road:* Defined as a hard surface for vehicles to travel on, generally maintained, and can be paved or unpaved. A corridor linking settlements, cities, or a place with an economic value (i.e. national park, mine, workplace) that public and private entities can travel on. We excluded roads within a city.
- *Railroad:* Defined as a system of tracks on which trains travel. A railroad is used for industrial, commercial, and public transport. Railroad links settlements, cities, or a place with an economic value (i.e. national park, mine, workplace). A railroad is generally maintained.

Function

- *Worker* has been defined as persons whose responsibility it is to maintain and operate the transportation corridor. This could for instance be a snowplow operator clearing snow or a conductor on a train.
- *User* would be persons who use the transportation corridor. An example would be a driver along a mountain road or a passenger on a train.

Corridor status

- *Open* is defined as the road or railroad allowing users and worker to pass unrestricted.
- *Closed* is defined as user or worker travel being restricted. An example of a closed road is workers actively clearing avalanche debris while road closed to public, or a mountain pass road which has been closed for the winter.

Delayed/Secondary Avalanche: For this study, we define a delayed or secondary avalanche as one that released after the first, within a 12hr time frame (but could also have released simultaneously), and disrupts activity along the transportation corridor where the first avalanche came down. For some of the accidents it has been difficult to determine if a delayed/secondary avalanche released from the same starting zone as the first avalanche. This is especially true for historical data that is lacking those specific details. Thus instead of looking at the starting zone we have focused on the run out zone to classify delayed/ secondary avalanches.

Worker Activity: We considered the two activities *clearing snow* or *clearing avalanche debris* based on the comments describing the accident. When there was not enough information we left the parameter blank.

Damage to People: We distinguished between accidents with fatalities and those without fatalities based on database entries or text comments.

3. DATA

Data has been collected from the United States, Canada, Switzerland and Italy. The data used is from 1900-2014. Due to the various data source and recording methods not all parameters were available (Table 1).

The United States data has been compiled from *The Snowy Torrents* publications (Gallagher, 1967; Williams, 1975; Williams and Armstrong, 1984; Logan and Atkins, 1996), Colorado Avalanche Information Center (CAIC, 2014), West Wide Avalanche Network, Avalanche Notes (Williams, 1983-1995), Avalanche.org (avalanche.org 2014) and several periodicals and books (Armstrong and Armstrong, 1977; Jenkins, 2001; Kalitowski, 1988; Martinelli and Leaf, 1999). Data set range is from 1902-2014.

Canadian data has been collected from *Avalanche Accidents in Canada* volumes 1-5 (Stethem and Schaerer, 1979, 1980; Schaerer, 1987; Jamieson and Geldsetzer, 1996; Jamieson et al., 2010), the Canadian Avalanche Center's Incident Report Database (CAC, 2014), snow avalanche atlases and occurrence data from British Columbia (BCMoT,1979, 1980, 1981, 2014 and Schleiss, 1989). The accident data ranges from 1904-2014.

Data from Switzerland was extracted from the destructive avalanche database of the WSL Institute for Snow and Avalanche Research SLF. While the Swiss data ranges from 1909-2012, it is considered complete from 1937 onwards.

The Italian data has been compiled from AINEVA and the Avalanche Centre of Arabba (AINEVA 2014). This data set starts in 1978.

Tbl. 1: Data overview and completeness of data (in %). * - percentage values given for cases with workers

Parameter	*Canada*	*Italy*	*Switzer-land*	*U.S.*
activity*	31%	91%	68%	37%
function	98%	58%	100%	94%
type of transport	100%	100%	100%	100%
corridor status	81%	67%	88%	90%
secondary avalanche	81%	100%	99%	89%
damage to people	100%	100%	100%	100%

4. METHODS

We compared if samples were significantly different using the Mann-Whitney U-test (Boslaugh and Watters, 2008). Long-term trends were investigated using the non-parametric Mann-Kendall trend test (Mann, 1945). Results were considered significant if $p \leq 0.05$.

5. RESULTS

5.1 Descriptive Statistics

Since 1900 at least 408 avalanche accidents occurred in Canada, the United States, Switzerland and Italy. These resulted in 382 fatalities (Table 2).

Tbl. 2: Summary statistics (1900 - 2014).

Country	*Acci-dents*	*Fatal Acci-dents*	*Persons involved*	*Fata-lities*
Canada	91	19	192	87
Italy	69	15	117	28
Switzer-land	142	54	537	115
U.S.	106	35	411	152
all	408	123	1257	382

The two largest accidents occurred in March of 1910. In British Columbia, Canada an accident occurred while railway workers were clearing debris from an avalanche and were subsequently buried by another avalanche; 58 workers died. In Washington, USA a train was stuck in a snow storm and was destroyed by an avalanche resulting in 96 deaths. These two accidents combined, represent approximately 40% of all fatalities (see also Figure 1).

During the time period from 1978 to 2014, for which all four data-sources were available and data was considered reliable, 72 people died in 40 accidents which occurred on roads and railroads. In another 189 accidents, people were involved. The incidents occurred mostly on open transportation corridors (79%), involving users (75%). 12% of the incidents were due to secondary/delayed avalanches. Road and railway users were mostly caught in accidents when the transportation corridor was open (95% of known cases, see also Table 3), however there have been several accidents where users disregarded closed corridors and where subsequently caught and killed. Operators (workers) were relatively often involved while clearing snow or avalanche debris when the road was closed (59%, Table 4). Secondary/delayed avalanches were responsible for 29% of the accidents with workers and 8% of users.

Tbl. 3: The number (N) and proportional values are shown for all reported avalanche incidents involving *users* during the time period 1978 – 2014. Percent values shown for known cases only. Modes for each factor as described in section 2. Example: Italy corridor status=open 96% the remaining 4% corridor status=closed

Country (N)	*Corridor status = open*	*Transport type = road*	*Secondary avalanche = yes*
Canada (39)	100%	100%	3%
Italy (29)	96%	100%	0%
Switzer-land (46)	87%	93%	9%
U.S. (35)	100%	97%	22%
all (149)	95%	97%	8%

Tbl. 4: The number (N) and proportional values are shown for all reported avalanche incidents involving *workers* during the time period 1978 – 2014. Percent values shown for known cases only. Modes for each factor as described in section 2. Example: US corridor status=open 47% the remaining 53% corridor status=closed

Country (N)	*Corridor status = open*	*Trans-port type = road*	*Activity = snow clearing*	*Secondary avalanche = yes*
Canada (8)	75%	75%	50%	33%
Italy (11)	22%	91%	100%	0%
Switzer-land (14)	25%	79%	92%	36%
U.S. (17)	47%	94%	50%	41%
all (50)	41%	86%	79%	29%

5.2 Temporal trends

When comparing all reported accidents, we note significantly larger numbers of avalanche accidents during the second half of the investigated period (1958-2014), compared to the first 57 years (1901-1957, $p<0.01$) for Canadian, Swiss and U.S. data (no Italian data). However, the number of fatalities showed no significant differences between these two periods (Figure 2). Prior to the 1950s, the database contains almost exclusively fatal accidents. In contrast, during the following years many non-fatal accidents were reported. We attribute this increase in reporting to fledgling avalanche programs with the most stable reporting starting in the mid-1970's with the implementation of current avalanche safety programs.

The reporting frequency of accidents resulting in fatalities is very high and thus statistically robust to investigate temporal trends (McCammon et al., 2008; Techel and Zweifel, 2013). Therefore, we focus in the following analysis on fatal accidents only (Figure 3).

Neither Canadian nor U.S. data showed significant trends when considering the full time period (1900-2014), while Swiss fatalities showed a decreasing trend (1936-2014). Selecting a time period between 1978 and 2014, the number of fatal accidents and avalanche fatalities significantly decreased in all four countries.

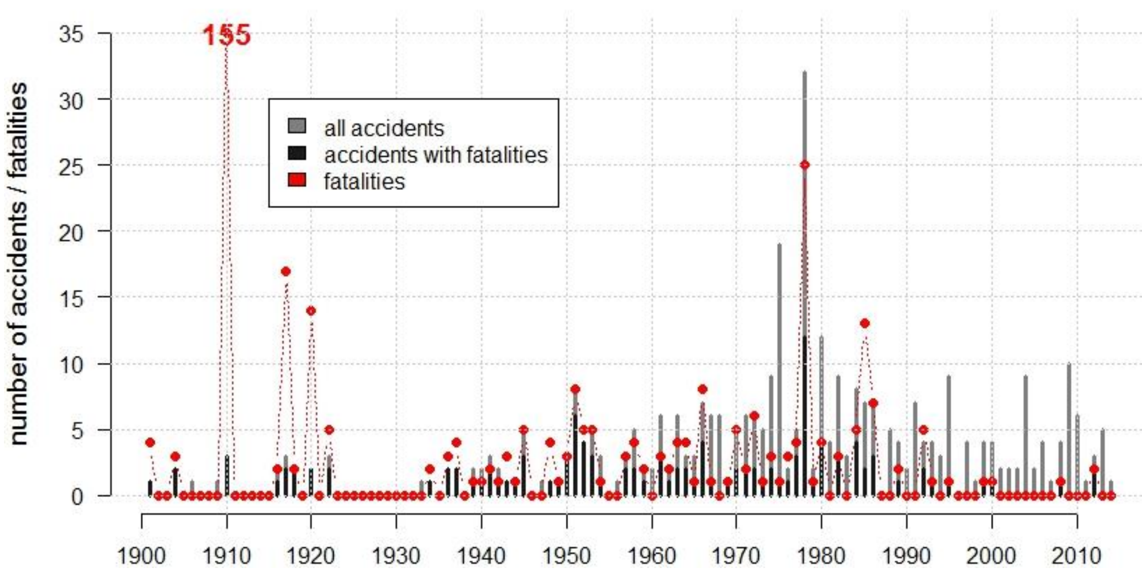


Fig. 1: Number of reported avalanche accidents combined for all four countries (light grey bars), fatal accidents (dark grey bars) and number of fatalities (red dots). In 1910, there were 155 victims.

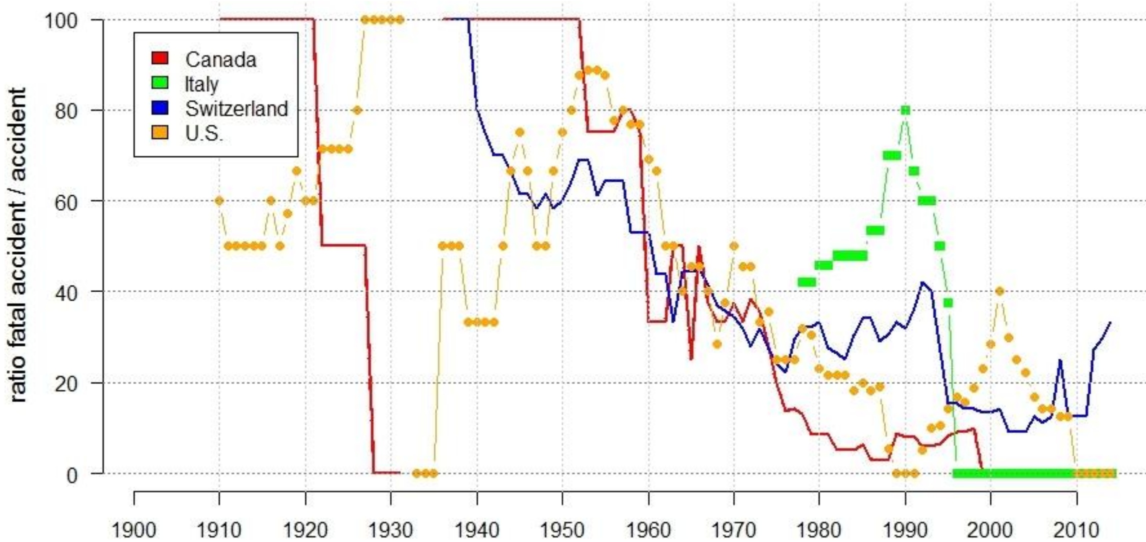


Fig. 2: Ratio of fatal accidents to all reported accidents for each of the four countries. For legibility, a ten-year moving average is shown to highlight the reporting rate, note that the peaks may be offset by several years compared to the annual numbers (for instance a 1990 value incorporates the mean for the ten years 1981-1990).

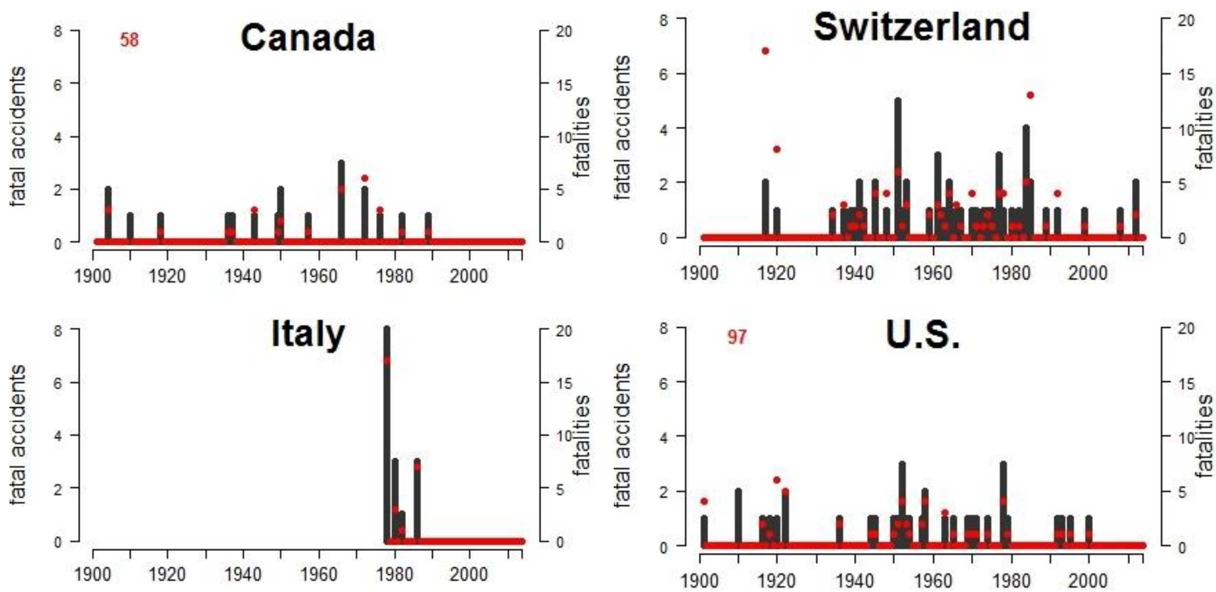


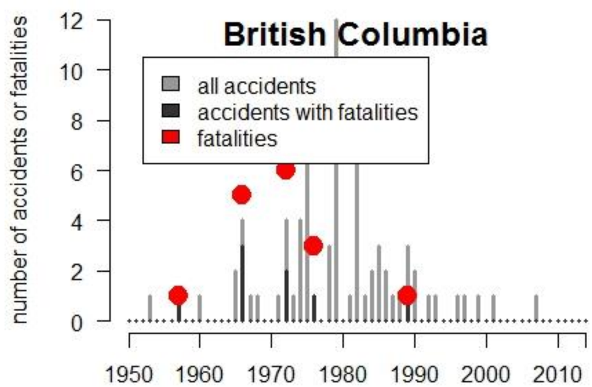
Fig. 3: Number of fatal accidents (black bars) and number of fatalities (red dots). For 1910, the years with very large avalanche catastrophes, the total number of fatalities is given.

During the most recent twenty years (1995-2014), the number of avalanche accidents resulting in fatalities on roads or railways was low (N=6), and significantly lower than the twenty years prior (1975-1994, p<0.01, see also Figure 2). Since 1995, in four of the 6 fatal accidents, workers were involved on closed roads while clearing snow or debris. One user was caught while walking on a closed road, while the other accident involving users, occurred on an open highway.

5.3 Case Studies

Two notable case studies from avalanche programs in British Columbia, Canada and Colorado, USA:

From 1950 until 2014, 80 accidents were reported on roads and railroads in British Columbia. Eight of those resulted in 16 fatalities, with the last fatal avalanche in 1988/1989 who was a railroad worker (Fig. 4 top). In 1976, the British Columbia Ministry of Transportation (BCMoT) implemented an avalanche program responsible for a very large proportion of the highways in the province (BCMoT, 2011). Since the implementation of the program, which included avalanche forecasting, active mitigation and construction measures, there were no fatalities on BCMoT highways (Campbell et al., 2007). Since 1976, the annual number of fatalities and fatal accidents involving people has decreased, although this is only marginally significant (p=0.06, note that these statistics include all roads and railroads in B.C., not just BCMoT, Fig. 3 top).



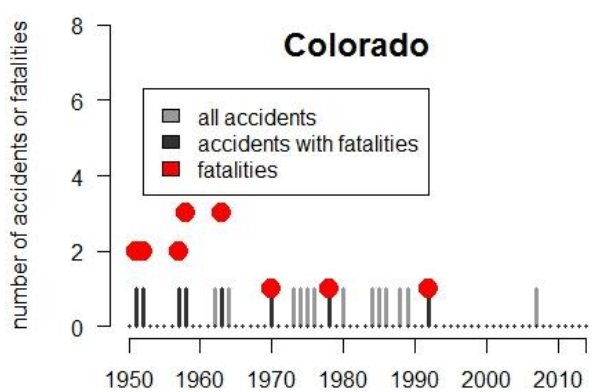


Fig. 4: Number of reported avalanche accidents (light grey shaded area) and fatal accidents (dark grey shaded area) and the number of fatalities (red dots) for transportation corridors in British Columbia (above) and roads in Colorado (below).

In 1992, the Colorado Department of Transportation (CDOT) and the Colorado Avalanche Information Center (CAIC) began avalanche mitigation. This program implemented a partnership with forecasting and active control (CDOT, 2014). Since the program initiated, there were no fatalities on roads in Colorado (CDOT, 2014). During the period between 1950 and 2014, 22 accidents were recorded, of those 8 there were 15 fatalities with the last fatal avalanche 1991/1992 (Fig. 4 bottom). As for B.C. the annual number of fatalities, fatal accidents, and accidents involving people has decreased since the implementation of the program in 1992 ($p<0.05$).

6. DISCUSSION AND CONCLUSIONS

6.1 Limitations

We have investigated a multi-annual data-set from a large variety of sources including historic data, statistics and summaries from avalanche centers and extracts from databases in different countries with slightly different recording standards.

While avalanches causing fatalities have a high level of reporting (McCammon et al., 2008; Techel and Zweifel, 2013), many non-fatal avalanche accidents are likely unreported, particularly in the early part of the investigated period. Therefore, this study provides a representative, but not complete overview about avalanche accidents along transportation corridors in North America and the Alps. However, we doubt that trends and patterns can be projected onto developing countries where several large avalanche accidents occurred in recent decades (e.g. large avalanche catastrophes with many fatalities occurred on roads in Tibet/China, March 1996, Tajikistan, Dec 2007 or Afghanistan, Feb. 2010).

6.2 Conclusions and implications for practitioners

Despite increasing traffic numbers on roads, the number of fatalities has decreased significantly during recent decades on roads and railroads in Canada, Italy, Switzerland and the USA. We attribute this significant reduction to the successful implementation of mitigation measures including snow safety programs, active and passive control measures (e.g. Hendrix et al., 2006; Campbell et al., 2007; CDOT, 2014) as well as protective building measures, the winter closure of some of the most threatened mountain passes (e.g. Margreth et al., 2003), but also to an industry-standardized training of snow safety personnel (e.g. BCMoT, 2011). Despite all these measures, avalanches remain difficult to predict and some fatalities do occur.

- Since 1995 the majority of fatalities have been workers clearing snow or debris. Worker-related avalanche fatalities can be further reduced by establishing stringent standards and providing continuous quality training through an avalanche safety program.
- Secondary or delayed avalanches pose a serious threat to both workers and users especially during times of continuing critical avalanche conditions. These avalanche events were responsible for 29% of worker fatalities and 8% of user fatalities.
- There is a significant decrease in avalanche accidents and fatalities since avalanche programs were implemented, despite the strong increase in traffic numbers on alpine mountain passes.
- We strongly suggest that avalanche threatened transportation corridors that do not have an avalanche safety program, implement one to minimize the risk and enhance safety to workers and users alike.

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