QUANTIFYING THE EFFECTIVENESS OF ACTIVE MITIGATION ON TRANSPORTATION CORRIDORS

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ABSTRACT: Numerous efforts have been made to quantify avalanche risk in transportation corridors (Schaerer 1981, Hendrikx 2006, Margreth 2003, 2016), but little work has been done to quantify the effects of forecasting, closures, and explosives work in terms of actual risk reduction. We collected data on avalanche occurrences, avalanche mitigation techniques, and avalanche accidents from select areas in North America, South America, and Europe. By analyzing avalanche occurrence and closure data from specific transportation corridors, we were able to estimate the effectiveness of avalanche hazard mitigation programs. We use the ratio of artificially triggered and natural avalanches during closure periods to natural avalanches onto an open road to examine the effectiveness of avalanche hazard mitigation programs and techniques. Using the data on avalanche involvements in transportation corridors we get a better understanding of the likelihood of an avalanche accident resulting in injury or death. Comparisons are made between programs with forecasting only approaches versus very active use of explosives. In order to gauge forecasting effectiveness, the ratio of rounds fired to avalanches produced is also examined. These comparisons result in an improved view of the effectiveness of mitigation efforts.

KEYWORDS: Avalanche, mitigation, risk reduction

1. INTRODUCTION

Considerable work has been done in the past to quantify avalanche risk levels to transportation corridors. These efforts have resulted in two different approaches, the Avalanche Hazard Index (AHI) approach (Schaerer, 1989) which is primarily used in North America, and the Probability of Death for Individuals (PDI) approach as used commonly in Switzerland and also in New Zealand (Hendrikx and Owens, 2007; Margreth 2016). What is lacking is an understanding of the actual risk reduction that active avalanche programs generate. Additionally, an emphasis is being placed by decision makers on methods of quantifying program performance. The contributors to this paper have analyzed existing avalanche occurrence records as well as their collective experience to generate a largely statistical but partially empirical view of measurement parameters. The contributors represent a large and geographically diverse statistical basis which should improve our understanding of parameters used for risk calculation as well as addressing means of measuring performance.

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2. METHODS

We contacted forecasters working in avalanche hazard mitigation programs in the Americas and Europe. We posed a set of questions to them (Tbl. 1) and asked them to respond with their comments and data from their programs. We collected comments and values from each program, and then examined the data with typical summary statistics, operational, and regional comparisons. In all we received input from programs in Switzerland, Chile, Utah, Colorado, Wyoming, Washington, Alaska, and British Columbia. Responses were received from 10 programs and data on 14 sections of highway or railway. The data type and amount of data we received varied dramatically between the different programs, with data records ranging from 6 to 70 years. Many of the incidents where vehicles were damaged came from notations in avalanche occurrence data and contained limited details.

Tbl. 1: Data collection questions

What is the ratio of vehicles hit by avalanches to occupants injured and fatalities? Additionally, how many of the vehicles were damaged or swept off the road?
What is the ratio of rounds fired to avalanches produced? What is the ratio of avalanches produced to avalanches reaching the road?
What is the ratio of total avalanches hitting the road to unmitigated avalanches hitting the road?
Is the ratio of mitigated versus unmitigated avalanche reaching the road different for low frequency avalanche paths?
What is the ratio of total avalanches reaching the road to unmitigated avalanches reaching the road for programs that rely solely on forecasting and road closures?

3. RESULTS

A summary of transportation incidents is listed in Tbl. 2. The dataset includes incidents where 357 vehicles were caught in avalanches, 33 of them swept off the road. We documented 83 cases were people were injured with 56 people killed. Eight of these fatalities were transportation workers, all from the North America data set.

The ratio of fatalities to vehicles caught overall is 0.14 (51 people killed and 357 vehicles caught) in the entirety of our dataset. U.S. railways have a lower ratio than North American transportation corridors (0.03 and 0.11 respectively). Swiss highways have the highest regional value of 0.18 (Tbl. 3).

Tbl. 2: Ratio of People Killed to Vehicles Caught

North American	0.13
Switzerland	0.18
US Railways	0.03
In areas with only small to medium sized paths	0.02

The percentage of avalanches triggered to shots fired varied from 20% to 86% (Fig. 1). The two roadways with the most recorded avalanches, Little Cottonwood Canyon in Utah, USA and the Seward Highway in Alaska, USA, were on opposite sides of the range with 25% and 86% avalanches to shots respectively. The ratio of avalanches reaching the road to avalanches triggered ranged from 0% to 41%. The two highest values in this data set were Teton Pass and Kootenay Pass at 41% and 33% respectively followed by the Alaska Railroad. The grouping was similar when we examined the number of road hits to shots fired (Fig. 2). Most of the transportation sections we examined had a shots fired to avalanches ratio between 25% and 50%.

The number of avalanches that reached the highway or railway ranged from 8 to 844 in our dataset with a data record between 6 to 43 years (Tbl. 4) With an active avalanche hazard mitigation

Tbl. 3: Summary of Highway Avalanche Accidents

Location	*Vehicles Caught*	*Vehicles Swept Off Road*	*Minor Injuries*	*Injured*	*Number of People Killed*	*Ratio of Deaths to Vehicles Caught*	*Number of Workers Killed*	*Years of Record*
Switzerland- All	167	-	-	51	30	0.18	-	53
Colorado-USA	65	11	15	24	14	0.22	4	70
Little Cottonwood Canyon, UT-USA	34	17	-	8	1	0.03	1	42
Snoqualmie Pass, WA-USA	26	-	-	0	1	0.04	-	45
Stevens Pass, WA-USA	6	-	-	-		0.00	1	10
Kootenay Pass, BC-Canada	20	-	-	-	7	0.35	-	54
Teton Pass, WY-USA	13	-	1	-	1	0.08	-	10
Seward Highway, AK-USA	21	5	-	-	2	0.10	2	44
Pimenton Mine and Road-Chile	10	0	0	0	0	0.00	0	6

Note: Dashes represent missing values, many fatalities were before modern avalanche mitigation programs.

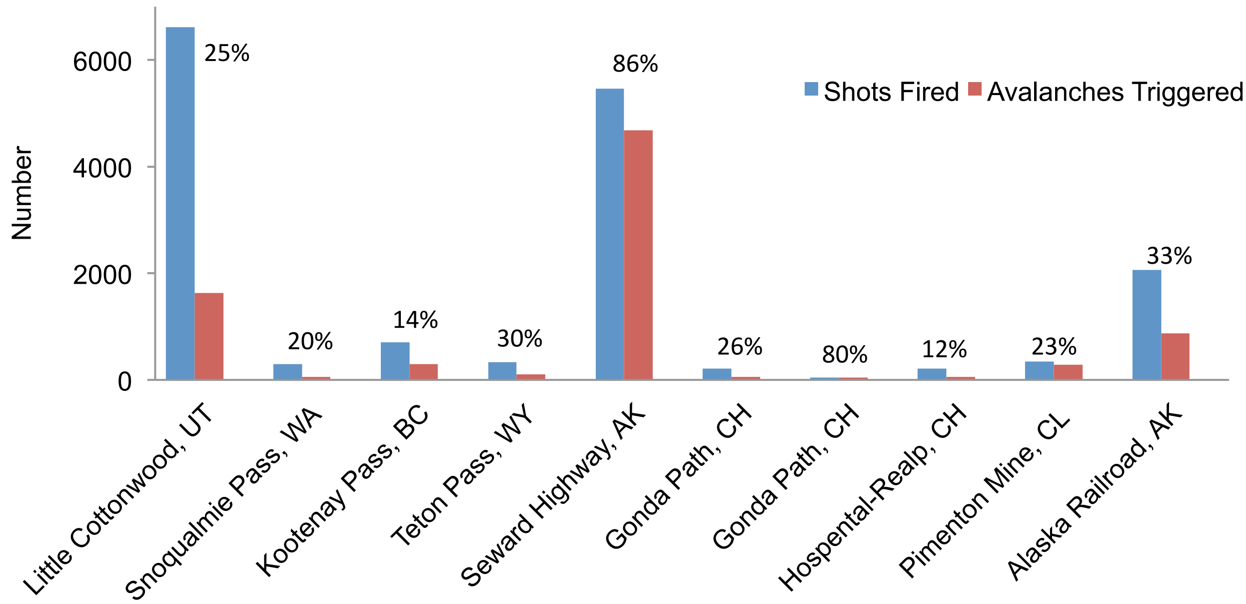

Fig. 1: The number of shots fired and avalanches triggered for each highway section. The years of records range from 3 to 44. Data labels are the percent avalanches triggered verses shots fired.

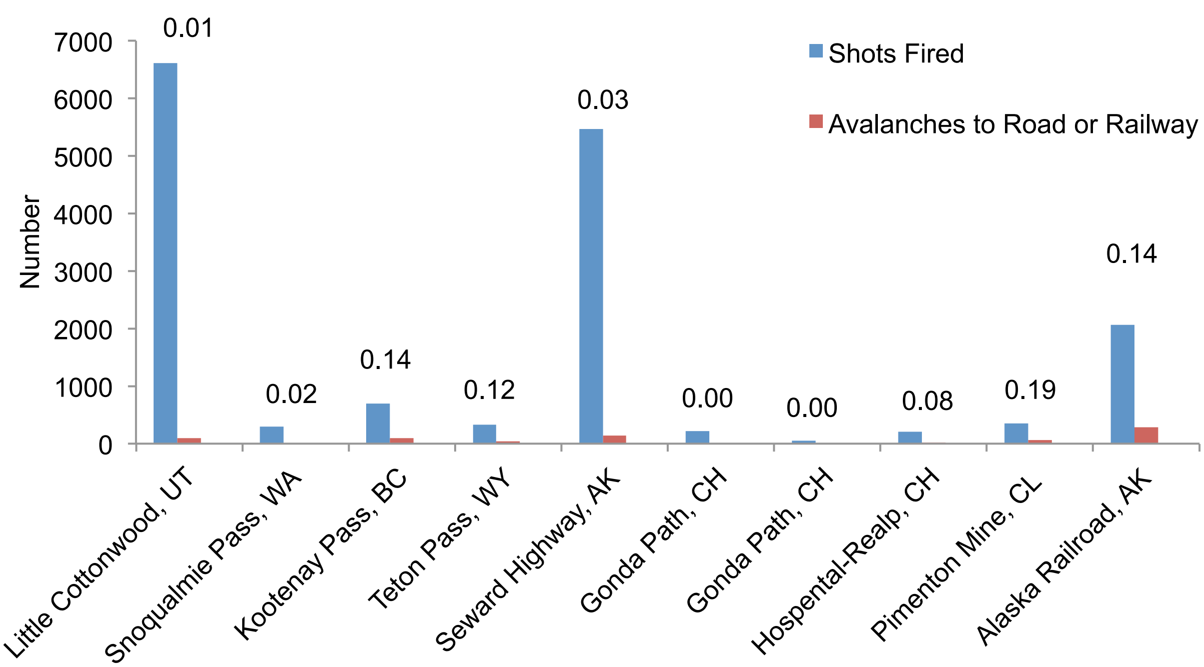

Fig. 2: The number of shots fired and triggered avalanches that reached the road or railway. The years of records range from 3 to 44. The value at the top of each bar group is the ratio of avalanches that reached the road or railway to the number of shots fired.

Tbl. 4: Summary of Avalanches that Reach the Highway or Railway

Location	*Avalanches to Road*	*Triggered and Natural Avalanches that Reach a Closed Roadway*	*Natural Avalanches that Reach an Open Roadway*	*Residual Risk*	*Years of Data*
Red Mountain Pass, CO-USA	844	785	59	0.07	13
Wolf Creek Pass, CO-USA	109	99	10	0.09	15
Loveland Pass, CO-USA	34	33	1	0.03	15
Little Cottonwood Canyon, UT-USA	204	180	24	0.12	17
Snoqualmie Pass, WA-USA	82	66	16	0.20	10
Stevens Pass, WA-USA	8	6	2	0.25	10
Kootenay Pass, BC-Canada	100	94	6	0.06	12
Teton Pass, WY-USA	86	73	13	0.15	8
Seward Highway, AK-USA	144	126	18	0.13	17
Lukmanier Pass-Switzerland	338	331	7	0.02	10
Hospental-Realp-Switzerland*	182	150	32	0.18	43
Fluela Pass-Switzerland	65	57	8	0.12	27
Pimenton Mine and Road-Chile	347	282	65	0.19	6
Alaska Railroad, AK-USA	288	244	44	0.15	30

*Most of these events were small avalanches

program, the residual risk (the ratio of natural avalanches reaching the road to all avalanches that reached the road) ranged from 0.03 to 0.19. We were only able to collect data from two programs that solely used passive mitigation methods (preventative closure) in one location each. These programs had a residual risk of 0.25 and 0.88. Programs that use this approach often have avalanche paths that produce small avalanches, have low traffic volumes, or have a long return interval.

4. DISCUSSION

4.1 Highway avalanche accidents and lethality

The Avalanche Hazard Index (AHI) contains a rating system for the nature of the avalanche (Schaerer, 1989). This value reflects how strongly an avalanche impacts the roadway, and each avalanche or path is rated as a slough, light snow, deep snow, or plunging snow. An important variable in these calculations is the probability of realizing the anticipated damages from an event. This probability is typically higher for events with a deep or plunging rating. Many of the documented fatalities occurred in large avalanche paths and are likely more representative of avalanches described as deep snow or plunging snow in this rating system and thus the new ratios identified in this work may be useful for these risk calculations.

Previous work has identified a ratio of people killed to vehicles struck in the range of 0.09 to 0.60 (Margreth pers com 2016) and estimated the yearly death risk is between 0.012 and 0.02 (Kristensen, 2003). In the data we collected, the ratio of people killed to vehicles caught in avalanches is 0.13 for all areas, with a range from 0.02 to 0.18 for different regions (Tbl. 3). Of the people killed, 1/3rd are highway workers. The low end of the range (0.02) comes from data collected in areas with only small to medium sized avalanche paths (Snoqualmie, Stevens Pass, areas in Pimenton with only small paths). These locations would produce avalanches primarily classified according to the AHI scale as sloughs or light avalanches.

Information from the Colorado database shows a marked decrease in highway avalanche deaths, 1940 to 2015 (Fig. 3). The most significant change corresponds with the implementation of a modern forecasting and mitigation program in 1993.

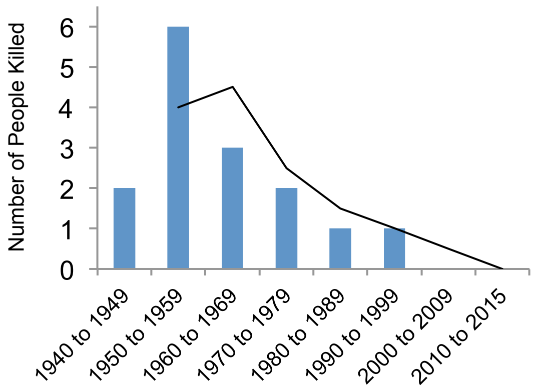

Fig. 3: The number of people killed in Colorado in highway avalanche accidents. The black line is a two-period moving average.

Most of the data identifies whether there were injuries from the avalanche that struck their vehicle. In some cases notations of minor injuries were provided, but in both cases insufficient detail exists to categorize the extent of injuries. Given the lack of detail little reliance was placed on these statistics.

4.2 Effectiveness of explosive mitigation

The cost of operating artillery, as well as fixed and mobile explosives systems, has increased substantially in recent years. This puts pressure on forecasters to be judicious in their use of explosives. Analyzing the range of baseline values from the different programs may yield insights into how effective the use of explosives is in generating avalanches. Given the programmatic and regional differences in the operations we surveyed, it makes intuitive sense that we would see differences in the summary statistics.

In general, practitioners believe that a very active explosives program will decrease the number of avalanches reaching a given point in the runout such as a road. The records from a program should tell us if this assumption is correct. If the ratio of shots fired to avalanches reaching the road is small, then the program is applying many shots to produce a few avalanches. Figure 2 shows the total shots fired and the total number of avalanches triggered for ten areas. Figure 3 shows the total shots fired and the number of triggered avalanches that reached the element at risk. The period of the data for each program varies dramatically, from 3 to 44 years. The ratio of avalanches that reached the road or railway to shots fired ranges from 0 at the Gonda Path is Switzerland, to 0.14 on Kootenay Pass and the Alaska Railroad. One of the locations where the application of intensive mitigation efforts was most obvious is in Little Cottonwood Canyon, UT. With a very high AHI value, their standard mitigation protocols include preventative closures on the basis of forecasts, and intensive explosives mitigation efforts. The result is 6,613 rounds fired to 96 avalanches reaching the road for a rate of 0.01. Not all programs can achieve this high a ratio as pointed out by data from Kootenay Pass and Teton Pass. In both these locations, the roadway crosses avalanche paths in the avalanche track, not the runout zone. The location of the roadway in relation to the avalanche path likely has a large impact on their shots to road-hits ratios, of 0.14 and 0.12 respectively. Differences in operating parameters and terrain characteristics play a large role in the value of this parameter. A program that is intensive and operates in a compact location would be expected to produce a lower ratio than a program that covers a large geographical area with limited resources and this is borne out by results from the data analyzed.

4.3 Residual risk

The ratio of triggered avalanches to natural avalanches that reach the roadway is an important metric for an active hazard mitigation program. Avalanches falling short of the roadway do not represent a significant risk to motorists whether they are mitigated events or natural, with the exception of powder clouds that might obscure a driver's vision. Only those avalanches that run far enough to reach the road would be considered a threat. Using this logic, events could then be divided into mitigated events versus unmitigated events. Mitigated events would consist of events that were triggered artificially plus those events that occurred naturally during a period of time the road was closed. Unmitigated events would be those events that reach a road that has no closure or traffic controls in place.

We define residual risk as the ratio of unmitigated avalanches reaching an open road to the total number of avalanches reaching the roadway.

There are many factors that affect residual risk. This is reflected in the fact that all of the surveyed avalanche programs have similar resources and approaches, but the residual risk factors vary from a low of 0.02 to a high of 0.25 (Tbl. 5).

4.4 *Residual risk for low frequency paths*

Almost every active program has a number of locations that avalanche infrequently. As a result, active mitigation missions for these locations may be less frequent than locations that produce more consistent avalanche activity. This operational factor may affect this residual risk value. Intuitively it makes sense that paths that avalanche infrequently pose a small risk to the transportation corridor. However, they may have a higher residual risk than paths that regularly avalanche. This is due to the small total number of events and the relatively high number of events that reach the road when it is still open.

While we tried to address this topic in the survey, there was no definitive information on a path by path basis that would help clarify this issue. Paths that threaten the Alaska Railroad and receive infrequent explosives treatment typically run later in an avalanche cycle and are thus more likely to avalanche during periods of closure and thus qualify to be included in the mitigated category.

4.5 *Residual Risk for programs that rely solely on forecasting*

It is general accepted within the avalanche safety industry that programs that rely solely on forecasting and closures cannot achieve the same level of risk reduction as those using these techniques plus explosives. The only way comparable risk reduction levels are possible is with long closure periods (Margreth pers com 2016, Gubler pers com 2012). Examples of this approach are represented on secondary roads in Switzerland where a combination of modest explosives mitigation combined with long road closures produces residual risks below .10.

Very few operations rely solely on the use of forecasting and closures to mitigate avalanche risks to highways. Risk is managed in this way primarily due to very low frequency and/or traffic volumes, or the inability to provide effective mitigation with explosives. The two examples generated from our inquiry are the Tumwater section of U.S. 2 near Leavenworth, WA and the Snake River Canyon in Wyoming. Both locations are managed by experienced avalanche forecasters and are part of a broader regional highway avalanche mitigation program. In both cases, there is reluctance by transportation officials to close the roads on the basis of a forecast due to the critical nature of access that is provided, as well as difficult locations and logistics for explosives work. Without the ability to close the road, every avalanche that hits the road is thus an unmitigated event except that the first avalanche closes the road so subsequent events do not affect traffic. In the case of Snake River Canyon where there are two main paths, the ratio of unmitigated avalanches is very high at 0.88 An O'Bell system was recently installed in this location. Avalanche activity after the initial event is somewhat rare. With Tumwater Canyon, it is more likely that small sluffs indicate the onset of a cycle and are thus used as an indicator the road should be closed. There are many avalanche paths in this section so subsequent avalanches are frequent after the road is closed, thus arriving at a residual unmitigated risk of 0.25. On some secondary roads and Little Cottonwood Canyon, Utah there is a higher tolerance for preventative road closures. When combined with active mitigation measures some of the largest risk reduction levels are achieved.

4.6 *Variability of the survey resutlts*

There is some risk in pointing out individual risk reduction ratios and coming to the conclusion that all programs can achieve the same levels. All of these surveyed programs have adequate resources and are staffed by very experienced avalanche professionals. In analyzing the data and having familiarity with all of these locations, it appears there are three factors that combine to result in the lowest residual risk levels. The first is a willingness on the part of transportation officials to preventatively close roads or railroads. The second is the introduction of more efficient explosives mitigation methods. There is a hierarchy of proven methods, but experiences noted by most of the forecasters in the survey show that the progression from helicopter bombing to avalauncher use to artillery to fixed delivery systems in selected locations continually contributes to further risk reduction. Lastly, programs that have numerous very active avalanche paths spread over long distances are at an inherent disadvantage for higher risk reduction levels.

4.7. *Other Issues of Interest*

One issue that came up broadly in our work was the incomplete data. Many participants mentioned the need to get their data set into a more usable form. Another issue was that the data in many cases did not have avalanche size classifications, so it was difficult to determine lethality by size of avalanche. We can see a decrease in fatal avalanche accidents in the Colorado data, which coincides with a change in the avalanche risk management approach. This is in spite of an increase in vehicle traffic and thus unmitigated risk levels. For all of the programs we surveyed, better data records and records in a format where they can be queried will help answer the questions we examined during this project and other important operational questions that will arise in the future. Tracking of close calls would assist in managing operational risk.

5. CONCLUSIONS

This new data set shows modest differences in fatality rates from previous work. A clearer picture of the effectiveness of explosives mitigation is provided. It also offers a new approach to creating a metric on which to record program effectiveness. There are likely a number of other ways to express this effectiveness, but this method is easy to quantify and track for forecasters.

6. ADDITIONAL INFORMATION

6.1 Conflict of Interest

The creation of this document was not supported financially or materially by ISSW. None of the authors benefit financially from the production or sale of ISSW proceedings nor have they received any related grants or patents. None of the authors are promoting any goods for sale through this publication.

6.2 Acknowledgements

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