

QUANTIFYING THE RISK TO AVALANCHE PRONE ROADS: CONSIDERATIONS FOR IMPLEMENTING THE AVALANCHE HAZARD INDEX

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ABSTRACT: The Avalanche Hazard Index (AHI) method was pioneered in the early 1980s and published by Schaerer in 1989. Since then, the AHI method has been applied to many North American and other international transportation corridors, including roads and railways. The AHI has been shown to be a useful tool for expressing risk, and for assisting in the planning of hazard mitigation. However, recent work in Alaska at a statewide level has demonstrated the importance of standardizing many of the key input parameters, if the intent is to provide direct comparisons between different avalanche management programs. Simultaneously, when using the AHI to optimally manage risk and prioritize mitigation measures for a single road, site specific calculations have the greatest value. This has been demonstrated to be especially useful for roads where the AHI is calculated over many years or even decades, whereby changes in hazard (or risk) can be tracked that result from either changes in traffic patterns, or in application of mitigation measures that reduce the risk.

This paper provides an overview of the AHI method, and provides examples of where it has been used, and the sensitivity of the results to the selection of input parameters. It also presents solutions for addressing problematic aspects of the Schaerer (1989) formulation, including how to account for multiple lanes of traffic, highly variable traffic flows, variations in traffic composition, waiting traffic considerations, and a wider range of encounter consequences related to different types of avalanche flow. The aim of this work is to share the current state of knowledge in applying the AHI. This will aid our community in understanding the utilization of the AHI, and to promote a more deliberate and explicit application of this method that captures the key processes and decisions that are being addressed.

Ultimately, this work will help provide a greater level of insight and transparency to the quantification of risk on avalanche prone roads, and clarity on how key parameters and assumptions impact the final estimate of risk in both an absolute and relative sense, when compared to prior and future AHI assessments.

KEYWORDS: Avalanche, Risk, Hazard, Management, Road, Railway, AHI

1. INTRODUCTION

The Avalanche Hazard Index (AHI) (Schaerer, 1989) has been a useful tool for expressing avalanche risk to highways and railroads for over 30 years in North America, and elsewhere around the World. During this time the AHI method has been applied to most of the major North American transportation corridors, as well as corridors in New Zealand (e.g., Hendrikx et al., 2006). The method has also been applied to hiking and snowmobile trail corridors.

Over the last decade, many programs have updated AHI estimates to understand the impacts of increasing traffic volumes, changing avalanche mitigation

approaches, and to address public expectations for improving highway safety and reliability. Specific examples include, Hendrikx and Owens (2008), Hamre and Hendrikx (2018), Argue et al., (2018), Hamre et al. (2023), and Thumlert et al (2023).

The AHI is a numerical expression of avalanche risk that is comprised of a series of input parameters that relate to avalanche hazard and vehicle traffic characteristics. Sensitivity analysis of the equations shows that certain parameters can have unintended and sometimes unrealistic outcomes on the resulting AHI values. Therefore, it is important to understand how these inputs affect the AHI estimates, and have a consistent approach to manage the more challenging settings, such as multiple lanes of traffic, variable traffic composition, and highly temporally variable traffic flows. These factors all have a strong effect on the resulting impact on the waiting traffic component

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of risk, which can greatly increase the AHI to potentially unrealistic values.

A standardized approach to addressing these issues ensures that the results are better understood, that they address the question(s) being posed, and allows for greater comparability to prior and future analyses.

Our aim is to share some of our recent experience working with the AHI method to ensure that the community is aware of these approaches. Ultimately, this will improve the rigor of the application of the AHI.

2. BACKGROUND

The AHI considers both moving and waiting traffic, and is a function of:

- The size and type of avalanche
- The frequency of avalanche occurrences
- The number of avalanche paths and the distance between them
- The total length of highway exposed
- The traffic volume
- The traffic speed
- The type of vehicle

The following equation (Schaerer, 1989; Hendrikx and Owens, 2008) is used to calculate AHI:

$$AHI = \sum_{i=1}^{i=n} \sum_{j=1}^{j=5} W_j (P_{mij} + P_{wij}) \quad (1)$$

where:

W_j = weighting for avalanche type

P_{mij} = encounter probability for moving vehicles to be hit by an avalanche in path i of weighted size j

P_{wij} = encounter probability for waiting vehicles to be hit by an avalanche in path i of weighted size j

The equations to calculate each of the two encounter probabilities (i.e. P_m for moving and P_w for waiting vehicles) are described in detail in Schaerer (1989).

The following section provides narrative guidance on how we recommend addressing a number of components of the AHI which are not well documented in the current literature. A future paper is proposed that will provide explicit numerical expressions to apply these.

3. RESULTS & DISCUSSION

A key consideration when applying the AHI is whether the intent is to compare directly with prior work to allow for an assessment of a specific traffic corridor over time, or if the intent is to more precisely understand the impact and potential cost-benefit outcomes from mitigation options for a specific section of roadway. This explicit choice will in part, influence the choices of some of the factors listed below:

3.1 Weightings

The weighting values that are applied to each avalanche type (i.e., powder snow, slough, light snow, deep snow, plunging snow) was suggested as 0, 0, 3, 10 and 12 by Schaerer (1989). The weightings were estimated relative to the impact force and expected cost of losses of a powder avalanche (assigned as 1), whereby the “consequences” of powder and slough avalanches were considered low relative to the other classes and therefore neglected in AHI calculations. Realistically, both powder and slough avalanches can be important for some corridors, especially those with high traffic volumes where small, sloughing avalanches (e.g., Copperstein et al., 2023) or destabilizing powder avalanches (e.g., Jones et al, 2014) can result in traffic accidents and potentially fatalities.

A number of AHI analyses used the standard Schaerer (1989) weightings, while acknowledging the short comings of this approach. However, when these analyses are repeated several decades later, using the same weightings allows for a direct comparison on the roadway, and the difference is then solely due to a change in traffic volumes and/or avalanche magnitude and frequency. These standard weightings were applied to the New Zealand Milford Road by Hendrikx and Owens (2008) and Hamre and Hendrikx (2018), and also in Little Cotton Wood Canyon in Utah (Dynamic Avalanche Consulting, 2018a; 2018b).

The alternative approach is to re-calculate the weightings based on current, real-world costs, rather than simply using 1989 costs which are imbedded in these weightings. Hamre et al., (2023) applied this methodology (and termed them “Consultants Best Estimate” or CBE), as well as the “standard” weightings in their statewide assessment of AHI for Alaska. Notably, the cost factor, C was increased from the 1989 estimate of \$500,000 for a single vehicle loss to \$2.6 million for a maximum loss value in Alaska in 2023. These weightings are likely to be at least an order of magnitude higher than the older Schaerer (1989) values, so have the potential to increase the AHI substantially (if all other inputs are held static).

Similarly, the weighting values can be modified based on the type or composition of traffic in a particular corridor. For example, Hamre et al. (2023)

note that some roads in Alaska include a higher proportion of double trailer trucks (e.g. oil tankers), and railways include long trains – both of these situations result in higher impact forces in the weightings due to increased length of the vehicle exposed, compared to a standard vehicle. Calculating weightings independently for passenger vehicles and trucks (or long trains) allows for a more robust analysis of AHI for some corridors.

Another modification of weights was applied by Hamre et al. (2023) to consider slush flow avalanches, which are a hazard unique to the Arctic and sub-Arctic areas of Alaska, and potentially other northern regions (e.g., Arctic Norway; Hestnes and Kristensen, 2010). CBE weightings of 237 (trucks) and 92 (cars) were applied to slush flows in this study, which was significantly higher than the next highest weighting (plunging avalanches) for the Alaska statewide assessment.

Another recent modification of avalanche types was described in Thumlert et al. (2023), whereby powder avalanches in very large paths were classified as either “Heavy Dusting” or “Light Dusting” events, and classified within the Light and Deep avalanche types, respectively. Similar to what’s discussed above, this modification of avalanche types was included to address events in a specific corridor (e.g., Bear Pass in British Columbia) that were not considered in the original (Schaerer, 1989) method, which gave zero weighting to powder avalanche hazards.

This alternative approach, termed the Consultant’s Best Estimate (CBE) is an expert-guided approach, and built on previous work to gain a more comprehensive and accurate outlook on risk values from the AHI.

3.2 Probability of a second avalanche (Ps)

Much like the weightings, the probability of a second avalanche (Ps) is an important input parameter. Schaerer (1989) suggested that “Ps = 0.15 represent average conditions for our studies, although Armstrong (1981) concluded that values in the range $p_s = 0.03\text{--}0.05$ would be appropriate for Red Mountain Pass in Colorado.”

Some prior work has used a fixed value of 0.15 for all Ps values (e.g. Hendriks and Owens, 2008), whereas other studies have developed a matrix to represent Ps between each and every path where an avalanche on one path, could result in a queue below that N+X path (e.g. Hamre and Hendriks, 2018). This secondary approach requires very high quality, long-term occurrence observation data, with precise time stamps that is rarely available for most avalanche programs. Hamre and Hendriks (2018) examining the Milford Road data in detail, found that Ps values in some adjacent paths could be much higher than 0.15. In other applications, a Ps of 0.05 or lower has

been applied and considered suitably representative of the local avalanche paths.

Hamre et al. (2023) reduced the default Ps value for Alaska using the CBE method to 0.03 for most paths but modified to a range of 0.05 to 0.1 for paths with a known history of adjacent activity soon after the initial avalanche event. In a few cases the “standard” Ps value of 0.15 was applied. Similarly, the Ps’ value (probability of a secondary avalanche in the same avalanche path) was reduced to a very low value of 0.01, which reflects the lack of documented repeat avalanche events affecting a vehicle stuck in an avalanche path.

At the high end, Thumlert et al (2023) applied Ps values up to 0.3 for the Fraser Canyon, British Columbia, which has many low elevation short paths that can be subject to rain on snow or warming events that cause widespread avalanching to the road.

Given that the Ps value essentially acts like a multiplier to the sum of the waiting traffic component, the selection of Ps is an important consideration and, like the weightings parameter, should be applied with a specific intent in mind (i.e., direct comparison to prior work, or a more detailed understanding of AHI for specific paths / roadways that is based on long-term historical records).

3.3 Temporal flow variability

A critical input parameter, other than the avalanche related parameters, is the winter-time traffic flow. Often the Winter Average Daily Traffic (WADT) is used as the input into the AHI. While this may be suitable when considering the risk to moving traffic, this average is problematic when we consider the waiting traffic component.

The waiting traffic component is calculated using a standard response time of 1 or 2 hours, based on the proximity of the road crew to move vehicles out avalanche paths, and/or clear the debris from the road. If using 1 hour, and the above approach, then this would simply be the WADT divided by 24 hours, to provide the input for the waiting traffic. However, many avalanche prone roads do not have uniform traffic flow during the day, with many exhibiting a distinct peak, or bimodal flows (e.g. up the road in the morning and down the road in the afternoon would be typical for a road that primarily accesses a ski resort, e.g. Dynamic Avalanche Consulting, 2016).

Our prior work has shown the importance of accounting for both average and peak flow conditions for assessment of the AHI. With increasing WADT, the AHI typically has a linear relationship with the moving traffic component, but not so for the waiting traffic component. The reason is that these longer queues of traffic, from the increased WADT values at peak times, extends more vehicles into adjacent paths.

Given the calculations for waiting traffic, and how these sum for each adjacent path, the result for the waiting traffic component is typically non-linear in nature.

As an example, Dynamic (2016) when assessing the AHI for Little Cottonwood Canyon in 2016 considered average winter traffic volumes of 7000-8500 vehicles per day (VPD), with peak volumes of 9000-12000 on holidays and key winter weekends. Two years later Dynamic (2018b) updated the AHI analysis and included the peak traffic volume of 11,000 VPD in their calculations, which increased the AHI by 27%. This increased yet further, when we combined the traffic volume increase with decreased velocity (5 mph, i.e. “red-snake” conditions), then the AHI increased by 32%. This demonstrates the significant increased risk when peak flows are considered.

We recommend examining both the average and peak flow to gain an improved understanding of the relationship between traffic flow and risk. Does it increase in a steady, predictable way, or are there critical traffic flow volumes, where the risk increases significantly due to the sum number of adjacent paths that queues now extend into? When comparing roadways to prior historical analysis, or other roads, it is typically best to use WADT only.

3.4 Variable traffic composition

Schaerer (1989) did not explicitly consider the difference in vehicle type. All vehicles were treated equally, where observational experience and differences in length, height and weight would all indicate that the risk posed to a passenger vehicle is different than it is for a bus, given the same avalanche forces are applied. Furthermore, a bus may have 30-40 people onboard, and a passenger vehicle typically has an average count below 2. Therefore, to capture the impact of this on the AHI, the composition of the traffic should be accounted for explicitly. This is particularly important where other vehicle types, such as busses or long double trailer trucks are common.

Hendrikx and Owens (2008) provided an example of this for the Milford Road, where busses represent a substantial portion of the total traffic volume. Accounting for these increases, the AHI more accurately represents the real risk and consequence should an avalanche strike a bus, or busses.

Fehr & Peers Associates (2006) also accounted for busses in their work on Little Cottonwood Canyon by reducing vehicle traffic from 7,000 to 800 vpd with a shift to bus traffic (and a corresponding 83% reduction in the residual AHI), which was later also reflected by Dynamic (2016; 2018b).

Recently Hamre et al., (2023) extended this concept further, with explicit recognition of the high volume of double trailer oil trucks moving over Atigun Pass in

Alaska. This inclusion in the AHI increased the AHI substantially, and resulted in a higher AHI than the traffic volume would suggest, if all traffic was simply considered to be a passenger vehicle. This also captures the potential significant impact of an encounter of a truck carrying fuel with an avalanche, which presents a higher risk that is not normally explicitly considered with the AHI method.

3.5 Multiple lanes

Multiple lanes of exposed traffic poses a challenge for the standard AHI calculations. The moving and waiting traffic components both need to be adjusted.

For moving traffic, explicit consideration needs to be given for the runout of each path, and an assessment needs to be made if each path, at each avalanche type, would run over all, or only some of the lanes of the road. A four-lane road for example might be impacted by a “light snow” avalanche on two lanes, but untouched on the other two lanes. This directly impacts the moving component, but also the resultant waiting traffic component. If the road is divided with a hard traffic barrier, or physically separated, as are many modern highways, then the traffic flow should be treated as separate one-way roads.

As noted above, these adjustments also impact the waiting traffic calculations. The simple 1 or 2-hour waiting time cannot be automatically assumed for all corridors. Furthermore, the length of the queue is halved (if there are two lanes versus one), but the number of elements (cars, trucks, busses) at risk doubles. Depending on the spacing between paths and the return period of larger events on adjacent paths, the impact of these shorter queues with more elements at risk can have strongly non-linear increases. Therefore, it is critical that these situations are factored explicitly into the calculations.

4 CONCLUSIONS

This paper presents an overview of the AHI and a narrative discussion of the more challenging aspects of applying the AHI to modern road settings.

The purpose is to share the current state of knowledge in applying the AHI. We hope that this will aid our community in understanding the utilization of the AHI, and support future implementations of the AHI in a more deliberate and explicit method, to capture the key processes and decisions that are being addressed.

Ultimately, we hope that this work has provided a greater level of insight and transparency to the quantification of risk on avalanche prone roads, and clarity on how key parameters and assumptions impact the final estimate of risk in both an absolute and relative

sense, when compared to prior and future AHI assessments.

Future work will provide more explicit guidance on how these considerations, and others can be implemented numerically, with specific examples to illustrate the impact of these choices on AHI estimates.

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