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Performance Metric for Highway Avalanche Corridors

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16. Abstract

A research project was initiated on behalf of the Colorado Department of Transportation (CDOT) and Transportation Avalanche Research Pool (TARP) to develop a metric for measuring the performance of highway avalanche management programs. The metric is meant to support resource allocation and other management decisions made by avalanche programs while also enabling use in an enterprise transportation asset management program. The performance metric developed is intended to supplement and extend the industry- standard Avalanche Hazard Index (AHI) by incorporating public safety measures, highway worker safety, avalanche worker safety, avalanche control method(s), avalanche control frequency and impacts to the travelling public (Road closure frequency, length, time of day, etc.).

The resulting risk-based metric considers a combination of level of service, public safety, and worker safety with particular emphasis on the exposure of workers to dangerous maintenance and mitigation activities. The performance metric can be applied at the individual avalanche scale or to a group of avalanche paths.

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Executive Summary

This report documents the research and development of a performance metric for highway avalanche corridors developed for the Transportation Avalanche Research Pool (TARP). The report summarizes the development of the performance metric, as well as the implementation tool developed for use of the metric by highway avalanche programs. A research project was initiated on behalf of the Colorado Department of Transportation (CDOT) and the TARP to develop a metric for measuring the performance of highway avalanche management programs. The metric is meant to support resource allocation and other management decisions made by avalanche programs while also enabling use in an enterprise transportation asset management program. The performance metric developed is intended to supplement and extend the industry-standard Avalanche Hazard Index by incorporating public safety measures, highway worker safety, avalanche worker safety, avalanche control method(s), avalanche control frequency and impacts to the travelling public.

The resulting risk-based metric and accompanying software tool considers a combination of level of service, public safety, and worker safety with particular emphasis on the exposure of workers to dangerous maintenance and mitigation activities. The performance metric can be applied at the individual avalanche scale or to a group of avalanche paths.

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I. Introduction

This research was conducted on behalf of the Colorado Department of Transportation (CDOT) and TARP to develop a metric for measuring the performance of highway avalanche management programs. The metric is meant to support resource allocation and other management decisions made by avalanche programs while also enabling use in an enterprise transportation asset management program. The performance metric developed is intended to supplement and extend the industry-standard Avalanche Hazard Index (AHI) (Schaerer, 1989) by incorporating the following:

- Public safety (AHI)
- Highway worker safety
- Avalanche worker safety
- Avalanche control method(s)
- Avalanche control frequency
- Impacts to the travelling public (Road closure frequency, length, time of day, etc.).

The resulting risk-based metric considers a combination of level of service, public safety, and worker safety with particular emphasis on the exposure of workers to dangerous maintenance and mitigation activities. The performance metric can be applied at the individual avalanche scale or to a group of avalanche paths.

II. Avalanche Program Data Gathering

An initial project workshop with BGC and TARP representatives was held in April 2019 to present a draft concept for the performance metric. The draft performance metric concept was presented to TARP member programs, and a 10-question survey was used to gather feedback and data for iteration on the initial design. The survey was completed by ten programs, and follow-up interviews were completed with seven of the programs to gather additional details. The survey and interviews were used to understand the needs of the highway avalanche programs and what existing performance tracking was already being done.

Important information and considerations gathered through the survey and program interviews included:

- The relative safety of various avalanche control types based on program experience
- Control type safety rankings should consider worker safety threats during avalanche control missions but also during maintenance missions (e.g., operating remote avalanche control systems (RACS) versus re-fueling RACS, operating artillery versus recovering unexploded ordinance, helicopter use, etc.)
- Snow clearing operations are a significant safety threat to highway maintenance personnel pre-and-post avalanche control
- Certain control types have short term and long-term reliability concerns (e.g., challenges with RACS re-fueling during winter storms, loss of artillery programs due to incidents or availability of government provided ammunition)
- Level of data collection between agencies is highly variable and metric factors need to be flexible / practical for programs to assess.

A complete summary of the survey results and interview findings is summarized in the memorandum submitted by BGC (October 8, 2020). This information was used to revise the initial draft performance metric concept and create the framework described in Section IV.

III Performance Metric Framework

The final performance network framework was created based on the initial workshop findings, data gathered from the program survey and interviews, and testing done with program data from CDOT and the British Columbia Ministry and Transportation (MoTI). The performance metric framework is shown in Table III-1. The performance metric can be reported as a single letter grade value of A through E, similar to practices used in transportation asset management.

Performance is measured on a path-by-path basis, or for groups of paths where that fits better with a program's operations. This way program managers and decision-makers can estimate overall program performance by aggregating the performance at each path or path group. More importantly, for use within the program, the path level performance ratings make it possible to identify the particular paths which may be performing the worst, i.e., those with longer, inconvenient closures or those where mitigations may be dangerous to workers, and trade-off analyses can be completed to assess benefit of investment in a transition to a higher performing strategy.

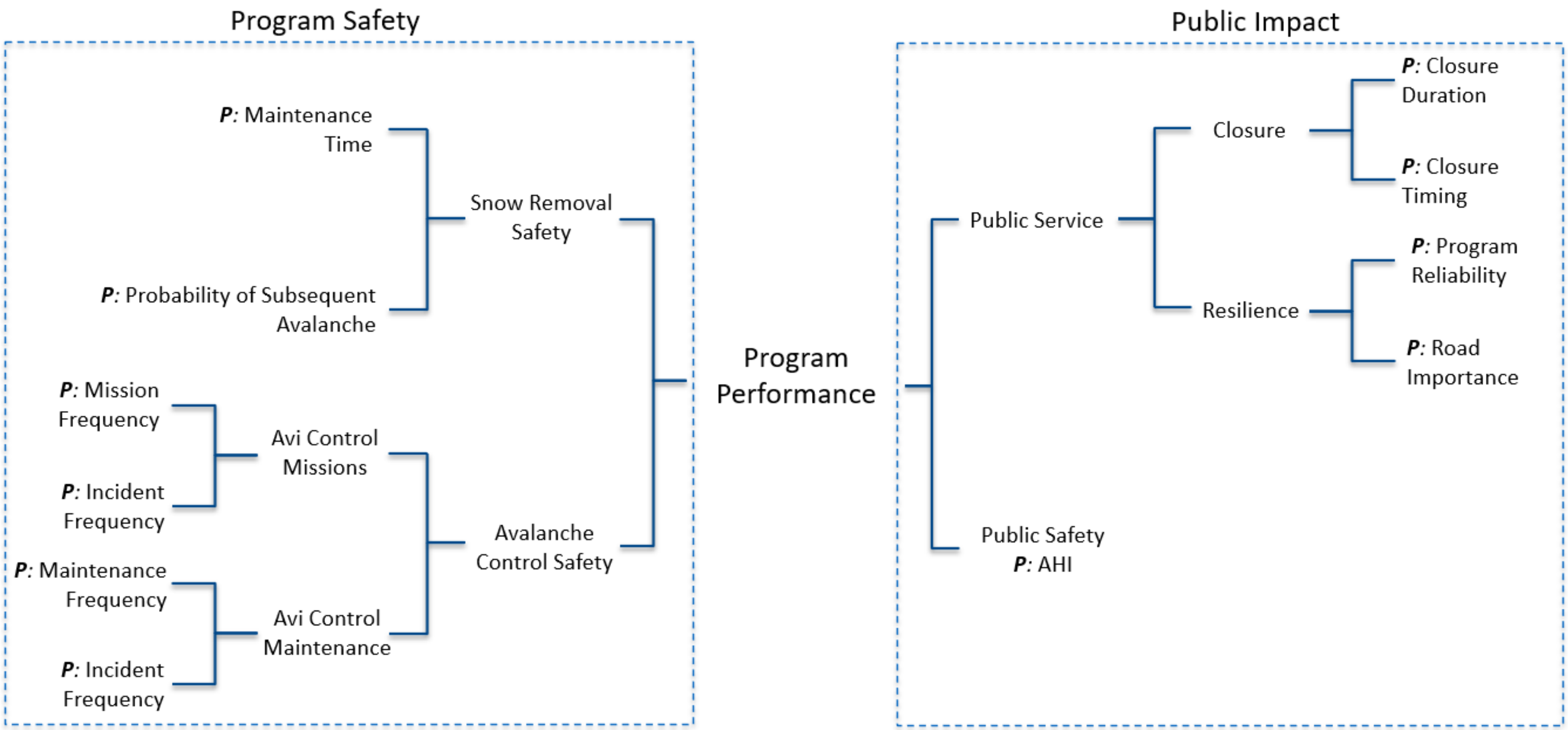

Figure III-1 Performance metric framework, for each path or path group. 'P:' signifies input parameters which are estimated or measured. All others are matrix outputs of combinations of factors. The model flows inward from both sides, through sub-metrics to the ultimate program performance measure.

Each assessed parameter with the metric framework is represented by a five-tier letter rating (A, B, C, D, E), with A representing the best performance and E the worst for each path (or path group). These letters have no technical meaning and could be replaced by other ordinal descriptors. Four sub-metric performance objective categories exist: public safety, public service, avalanche control safety, and snow removal safety. Eleven input factors at the nodes of the framework are assigned ratings from A to E using rating tables. Where branches in the framework meet the letter grade from one category is crossed with another using a multi-matrix approach illustrated in Figure III-2. Letter grades are crossed throughout the framework to produce the final program performance grade. An example of the performance metric framework filled out with letter grades at each node is shown in Figure III-2.

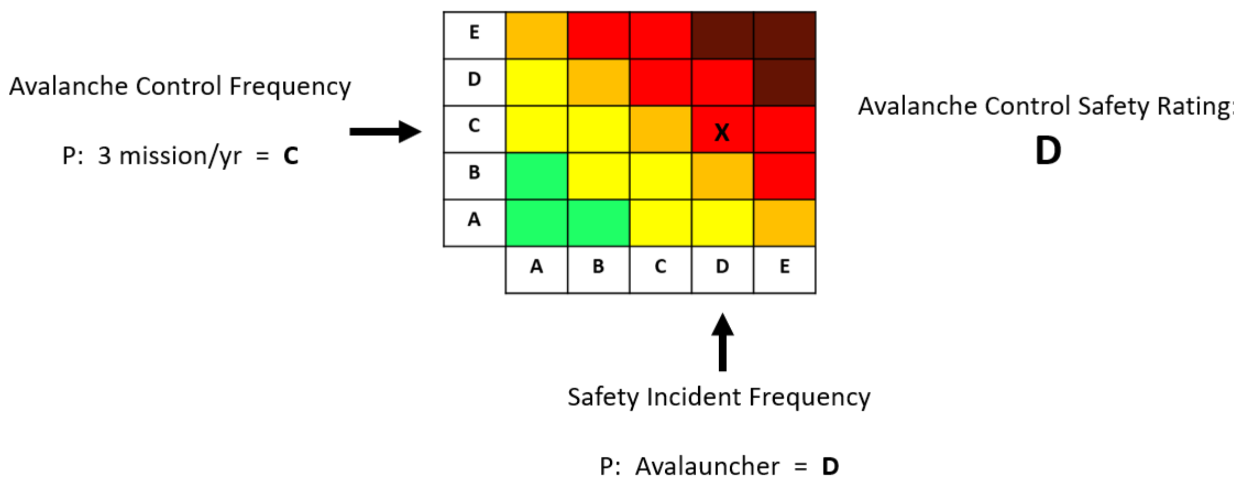

Figure III-2 Schematic example showing how two different factor ratings are crossed using a matrix to get the resulting Avalanche Control Safety rating.

Each of the eleven factors considered in the performance metric are described in the below subsections. An example of the rating table for that factor is provided for reference. Relative values provided in the rating table descriptions are default values assigned by BGC. As described in Section VI, and in the attached implementation tool, the metric is intended to be flexible with adjustment of the rating table bins based on program experience a necessary first step when using the tool.

A. Public Impact: Safety

Public safety is paramount. In developing the performance metric presented here, we acknowledged that generally speaking transportation avalanche programs are operating at a high level of proficiency in this area, i.e., the public is generally safe from serious avalanche threats while travelling on public roads or railways. However, we acknowledge that this has been accomplished often at the expense of the other objectives, such as public service in the context of traffic disruptions or roadway availability. As such the performance metric is designed to be sensitive to both public safety and potentially competing objectives, in order to allow for agency executives and program managers to consider trade-offs between objectives.

Schaerer (1989) defined the Avalanche Hazard Index, which has been used widely across the industry as an index of safety risk to the traveling public. As many, but not all transportation programs have computed AHI for their network, the public safety parameter in the new metric is able to make use of either AHI values directly or a semi-quantitative reference to incident history (calibrated to AHI). In addition, we provide a qualitative descriptor to reference forecaster experience of impression of the path or path group. The framework for translating AHI and incident experience is provided in Table III-1.

Table III-1 Public safety rating parameter reference table.

	Avalanche Hazard Index[1] (AHI)	Incident History	Management Experience
A	AHI is 0	No previous incidents	Practically not a concern for public safety
B	AHI is 1-5	No previous incidents but conditions	Threat to public safety manageable
C	AHI is 6-10	One known incident	Threat to public safety manageable
D	AHI is 10-20	Multiple known incidents	Threat to public safety manageable
E	AHI > 20	Annual to bi-annual incidents	Near constant concern to safety

Note:

1. Schaerer, 1989.

B. Public Impact: Service

Aside from safety, all other performance objectives on the Public Impact portion of the framework are contained within the Public Service rating. Public service is a function of road closure duration and timing, and assessment of operational resilience (Tables III-2 through III-5). The resilience rating is a function of the reliability of the program and the importance of the road, and is adapted from risk-based approaches provided in the CDOT Risk & Resiliency study (CDOT 2020).

The closure duration and timing factors are meant to differentiate between short road closures which can be scheduled for low traffic times, and forced longer closures which happen by necessity with minimal possibility to schedule. This part of the metric is intended to capture the difference between mitigation approaches which offer public safety benefits with less impact to the public, from those which could provide the same benefits but have more impacts to other objectives.

Table III-2 Closure duration rating parameter reference table.

	Closure Duration
A	Path not actively controlled
B	Average closure time < 0.3 hours
C	Average closure time between 0.3-1 hours
D	Average closure time between 1-2 hours
E	Average closure time > 2 Hours

Table III-3 Closure timing rating parameter reference table.

	Closure Timing
A	Majority of closures planned for in advance and carried out at opportune times (night), or closures not required
B	-
C	Mix of planned/unplanned closures occurring at a variety of times
D	-
E	Closures are rarely planned ahead of time and often occur during inopportune times (day)

Table III-4 Program reliability rating parameter reference table.

	Program Reliability
A	Always available and functioning
B	Always available other than short periodic maintenance/disruptions
C	Regular maintenance required for program to function
D	Methods fully time/weather dependent and/or resources limited
E	Sudden loss of mitigation possible due to external/third-party causes

Table III-5 Road importance rating parameter reference table.

	Road Importance
A	Low volume, minimal economic impact, numerous alternative routes
B	-
C	Moderate volume, several businesses, multiple alternative routes
D	-
E	High volume, lifeline corridor, no alternative routes

C. Program Safety: Avalanche Worker

Many active avalanche mitigation measures are inherently hazardous to the avalanche forecasters and technicians that implement them. Some present overt threats during deployment, others may require maintenance and other supporting effort which itself is a safety hazard to avalanche workers. As such, both the mission and maintenance risks are captured in the metric framework, and both are considered relative to the frequency at which they occur, so that more frequent and more risky activities would indicate lower performance. The sub-metric inputs are presented in Tables III-6 through III-11.

Table III-6 Avalanche control mission frequency rating parameter reference table.

	Control Frequency
A	Active control not required
B	Every few years
C	A few missions per year (1-3)
D	Many mission per year (3 < Frequency < every winter storm)
E	Every winter storm (storm as defined by regional threshold)

Table III-7 Avalanche control mission safety incident rating parameter reference table.

	Safety Incident Frequency
A	No known incidents or obvious hazard
B	Obvious hazard but no known incidents
C	At least one known incident
D	Several known incidents
E	Yearly incidents

Table III-8 Avalanche control maintenance frequency rating parameter reference table.

	Maintenance Frequency
A	No maintenance required
B	Every few years
C	A few missions per year (1-3)
D	Many mission per year (3 < Frequency < every winter storm)
E	Every winter storm

Table III-9 Avalanche control maintenance safety rating parameter reference table.

	Safety Incident Frequency
A	No known incidents or obvious hazard
B	Obvious hazard but no known incidents
C	At least one known incident
D	Several known incidents
E	Yearly incidents

D. Program Safety: Snow Removal

Most active control measures will at some point lead to avalanche deposits on roadways or railways. The deposits must be removed prior to traffic flow being restored and in consideration of worker safety in the path deposition zone. That clean-up operation would normally be conducted by employee or contractor maintenance staff in heavy equipment. Any work like this, conducted in avalanche areas during avalanche season, particularly just after avalanche control missions, is inherently hazardous. Further, snow removal may be required even if avalanches do not reach the road or rail. This can occur during closures that often coincide with prolonged storm cycles when snow accumulates on the road or rail, or during maintenance operations seeking to maintain a clear road below avalanche areas. The performance rating for this is dependent on the length of time a snow removal worker would be exposed to the avalanche area, and the likelihood of additional avalanches in the path.

Table III-10 Snow removal time rating parameter reference table.

	Snow Removal Time
A	-
B	Low (<30 minutes)
C	Moderate (30mins to 1 hr)
D	High (1-8 hours)
E	-

Table III-11 Probability of subsequent avalanches rating parameter reference table.

	Probability of Subsequent Avalanches
A	-
B	Low (Unlikely; Less than half the time)
C	Moderate (Possible; Half the time)
D	High (Likely; Most of the time)
E	-

IV. Pre-selected Values

For the ratings provided in Table III-7 to Table III-10, it may be helpful for each program to pre-select a range of ratings for different control methods, so that each would be assigned a consistent and calibrated relative rating compared to other measures. This also streamlines the workflow in data entry and calculation of the metric. The values presented in Table IV-1 and Table IV-2 were assigned in consultation with CDOT and MoTI during testing. However, they should be reviewed and revised as needed prior to use.

Table IV-1 Suggested reliability and closure timing ratings for select mitigation measures.

Primary Control Method	Reliability	Closure Timing
Passive - in runout zone	A	A
Passive - in start zone	A	A
Helicopter	D	E
Avalauncher	B	C
O'Bellx	B	A
Wyssen	B	A
Gazex	B	A
Avalanche Guard	B	A
Artillery	E	C
Hand / Case	B	C
Ski Cutting	B	C
Blower	A	C
Preventative Closure	A	A
No Control Needed	A	A

Table IV-2 Suggested safety ratings for select mitigation measures.

Primary Control Method	Mission Safety	Maintenance Safety
Passive - in runout zone	A	A
Passive - in start zone	A	B
Helicopter	D	B
Avalauncher	D	B
O'Bellx	A	C
Wyssen	A	C
Gazex	A	C
Avalanche Guard	A	C

Primary Control Method	Mission Safety	Maintenance Safety
Artillery	B	B
Hand / Case	D	B
Ski Cutting	C	A
Preventative Closure	B	A
Blower	B	A
No Control Needed	A	A

V. Performance Metric Implementation Tool

The performance metric is currently implemented in a Microsoft Excel workbook with input and calculation steps. It includes a 'read me' tab with instructions, and a series of tabs that users will work through to enter data for the paths and path groups in their program. This tool was developed to provide users with a means to explore the metric and its inputs and outputs. It is not intended to be a functional database or long-term implementation solution.

The tabs in the current version of the implementation workbook are:

- Read me: Instructions and implementation details
- Framework: Graphical representation of the framework, with functionally to display any path or path group in the database to follow in a subsequent update
- Ranking Tables: The base ranking tables used to compute the metric, with functionality to modify some parameters to suit
- Group Data Entry: Basic data entry for groups of paths
- Individual Data Entry: Path by path data entry, with reference to path groups
- Path Rankings: Computed metric score for each path or path group in the database
- Performance Summary: Tabular and graphical summary of program performance
- Cost Benefit (Short): Functionality to adjust parameters at the path or path grouping level to test impact of investment decisions on performance.

While consensus on pre-determined values across all avalanche programs may be beneficial, that was not considered practical as part of this scope and based on feedback from TARP members. Instead, the implementation tool is meant to be flexible and can be tailed to specific program needs. With an understanding of the tool setup users should be able to modify specific fields to better align with their program. For agencies with multiple regional programs, values should be kept consistent within an agency, so program performance can be compared.

A. Cost Benefit Tool

A preliminary cost-benefit tool is provided in the implementation workbook. The purpose of the cost benefit tool is for programs to compare potential changes future performance in response to different levels of investment and mitigation types for avalanche management at a given path. To assess how the total and sub-metric performance grades of a given path change with a different avalanche control method, users can choose a new method and input assumptions related to the change in method, including avalanche control mission frequency and maintenance frequency, expected average closure duration using the new method, expected snow removal time per avalanche and assumed AHI. Users can also input cost information of the new and current method to estimate the cost differences over an inputted project lifecycle. Users are also given an estimated cost to road users over the program lifespan when choosing a new control method.

The cost benefit tab allows users to assess the changes in costs and performance grades associated with changing control methods for a given path and across an entire program. Where favorable investment alternatives exist, program managers are encouraged to seek project funding and support from transportation asset management programs, resiliency initiatives, and safety, operation and maintenance programs. The performance metric and cost-benefit tool are developed with the objective of demonstrating the value of an avalanche management program in the context of broader transportation agency performance objectives.

When applied in conjunction with other potential department considerations and objectives, they can be used to make better-informed decisions.

B. Testing and Calibration

Initial concepts for the metric were presented to TARP members, and several program managers were interviewed to provided input into the design of the system. BGC (2020) documented that process in a report.

The performance metric was tested by several programs and end user feedback was used to improve the metric framework and to calibrate the input parameters and values, as follows:

CDOT: Data provided by CDOT was used for development of the implementation tool and testing of the framework and resulting avalanche performance grades. Once the implementation tool was useable, it was tested by CDOT staff using real data entry and by working through the functions in the implementation.

BC MoTI: Data provided by MoTI for Kootenay Pass avalanche program. Those data were used to populate the metric and test its functions, as well as to evaluate the results. Subsequently the output was reviewed with MoTI staff, and each step of the data entry process was presented. Furthermore, one of MoTI's engineering consultants was provided with the implementation tool for testing.

Feedback from user testing considered in final implementation of performance metric in Microsoft Excel. While the implementation tool has been tested extensively, it is not intended to be the ultimate deployment solution. Rather it is intended to provide a simple data entry and performance metric evaluation tool. The expectation is that programs would code the metric framework into an asset or risk management geospatial database or a similar application.

VI Future Work

The development of this performance metric was informed by input and feedback from several TARP member organizations. It represents a first step towards a broadly applicable tool that can communicate investment needs to executives and asset managers. Through this research, the TARP has a logical framework, rating tables, and a simple testing and implementation tool. We suggest future work on this project include:

- Additional testing and refinement of the logic and rating tables based on implementation use cases
- Development of a geospatial database to house input data, and reliably coded ratings and calculations for individual TARP members and potentially across TARP programs
- Further advancement of the cost-benefit tool to suit the needs of programs in decision making around capital investments

Development of a formal shared platform for different organizations to post their metrics and benefit from any advancements made by others

VII References

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