A FRAMEWORK FOR MEASURING THE PERFORMANCE OF HIGHWAY AND RAILWAY AVALANCHE PROGRAMS, AND DEMONSTRATING IMPROVEMENTS WITH INVESTMENT

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ABSTRACT: The availability and applications of remote avalanche control systems (RACS) and other capital-intensive avalanche mitigations are leading to increased scrutiny on avalanche safety programs for highways and railways. Large expenditures on avalanche control systems and other mitigations may need to be justified to transportation authorities or railways companies in the context of improvements in the performance of the program, in order to compete with other priorities across these organizations. But, on what basis should an avalanche safety program be measured, in order to justify investment? Over the past several years a pooled-research fund project supported by many DOTs in the US and Canada, and a private US railroad set out to define a suitable metric, and establish a method to implement it. In this paper we describe the priorities of the metric, which include not just public safety (e.g. AHI) but the sometimes competing objectives of worker safety and mobility of the public; the mechanics of rating the current performance of a program using individual and grouped path ratings based on control type, event frequency, closure time and duration, and exposure of workers; and how the metric can be used to demonstrate improved performance given changes to control strategy or capital investment in RACS or other measures such as snow sheds. We report on extensive testing by several programs, and also describe how the framework for the metric and a simple spreadsheet implementation would form the basis for more sophisticated geospatial web-based implementation and further quantification of performance.

KEYWORDS: Transportation; performance; metric.

1. INTRODUCTION

The availability and applications of remote avalanche control systems (RACS) and other capital-intensive avalanche mitigations are leading to increased scrutiny on avalanche safety programs for highways and railways. Large expenditures on avalanche control systems and other mitigations may need to be justified to transportation authorities or railways companies in the context of improvements in the performance of the program, in order to compete with other priorities across these organizations. But, on what basis should an avalanche safety program be measured, in order to justify investment? Over the past several years a pooled-research fund project supported by many DOTs in the US and Canada, and New Zealand, and a private railroad set out to define a suitable metric, and establish a method to implement it. This paper is intended to report on the framework and implementation of the metric.

2. MEASURING PERFORMANCE

Based on discussions with several members of the Transportation Avalanche Research pooled Fund (TARP; Stimberis et al 2018), from both highway and railway programs, we developed a set of principles to guide the project, as follows:

- Safety of the public, and workers is paramount.
- Most programs are already have an excellent public safety record, although public safety may be achieved at the expense of worker safety and public service.
- Performance is a function of the balance between impacts of the program on the public and the safety of the workers implementing it, i.e. high performance is indicated by both public safety/service, and worker safety. Poor performance occurs where only one, or neither of these, are achieved.

The performance metric presented here is semi-quantitative and hierarchical. It is based on a series of matrices used to estimate sub-parameters, which are then passed forward to a higher level matrix, until ultimately a qualitative rating is estimated. The advantage of this approach is that the overall single performance score can be useful for communicating with decision-makers and managers (outside the avalanche program) while the sub-paramters themselves represent a useful rating for different aspects of the program, mainly for internal use by the program itself to focus on problem areas or guide improvements.

Performance is measured on a path-by-path basis, or for groups of paths where that fits better with a program's operations. As with the sub-parameter approach, this way program managers and decision-makers can estimate overall program performance by aggregating the performance at each path or path group. For use within the program, the path level performance ratings makes 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 a case can be made to transition to a higher performing strategy.

3. PERFORMANCE METRIC FRAMEWORK

Figure 1 shows the overall framework for the performance metric, and the hierarchy of inputs. Each of the main areas (Program safety and Public Impact) are evaluated using the semi-quantitative input parameters (labelled 'P' in Figure 1). The aggregate rating for Program Safety for each path or group is then aligned on the final performance matrix against the aggregate rating for Public Service.

Each parameter P is evaluated on a 5x5 matrix which yields a letter grade between A and E (Figure 2), which is then passed to the next higher matrix. So for the Public Impact side, there is a matrix comparing Closure duration (shorter is better) and closure timing (shorter, scheduled closures are better). In another matrix the reliability of the program (always, permanently available is better) and the importance of the road (higher volume, lifeline roads demand higher performance) are compared to estimate resiliency of the program. The closure and resiliency ratings are then combined to make a public service rating, which is then combined with the public safety rating to ultimately rate public impact.

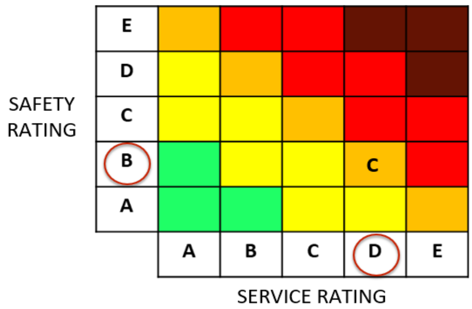

Figure 2. Example of the simple 5x5 matrix used to evaluate each parameter.

4. INPUT PARAMETERS

Public Impact:

In the following set of tables we provide the rating criteria for each input parameter used in the development and testing of the metric. These may be customized to suit the needs of a program, although should remain consistent within a program.

As mentioned previously, we assume that other objectives of the transportation avalanche program are secondary to public safety. In developing the performance metric presented here, we acknowledged that a) 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 mobility or public service. As such the performance metric is designed to be sensitive to both public safety and those other sometimes competing objectives, in order to allow for the consideration of tradeoffs between objectives.

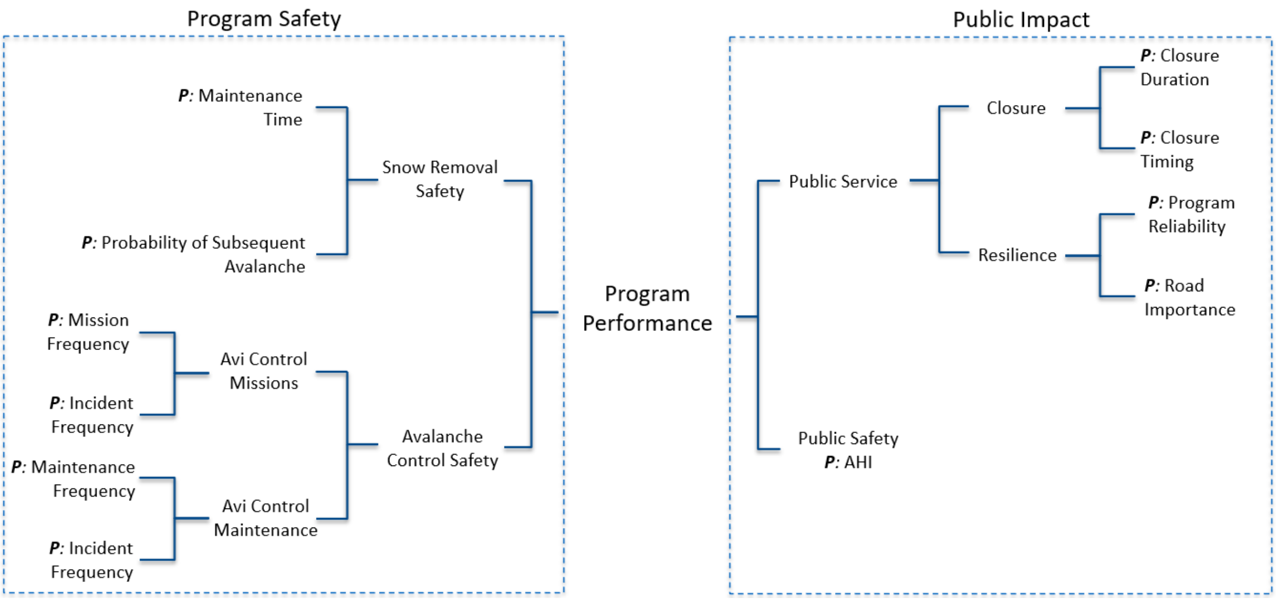

Figure 1. Performance metric framework showing hierarchy of parameters (P) and sub metrics which are combined to ultimately estimate performance for a path or path group.

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 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 (Table 1). Individual path ratings are aggregated to represent performance of the program.

Table 1. Public safety rating parameter reference table.

	Avalanche Hazard Index (AHI)	***Incident History/Experience***
A	AHI is 0	No previous incidents; Not a practical 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

Aside from safety, all other performance objectives on the Public Impact side are contained within the Public Service rating. Public service is a function of road closure duration and timing, and resilience. The resilience rating is a function of the reliability of the program, and the importance of the road.

The closure duration and timing factors are meant to differentiate between short road closures which can be scheduled for low traffic times, and 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.

Tables 2 to 5 show the parameters and rating criteria. Each would be used as broad criteria to allow users to define path or path group ratings.

Table 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 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 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 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

<u>Program Safety:</u>

Many active avalanche mitigation measures are inherently risky 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 risk to the safety of avalanche workers. As such, both the mission and maintenance risks are captured in the metric, and both are considered relative to the frequency at which they occur, so that more frequent and more risky activities would indicate lower performance. Tables 6-11 show the criteria to assess these parameters.

Table 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 7. Avalanche control mission safety incident 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 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 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

Most active control measures will at some point lead to avalanche deposits on roadways or railways. These must of course be removed prior to traffic flow being restored. 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 risky. Further clean-up may be required even if avalanches do not reach the road or rail: during closures, which often coincide with stormy weather, snow may accumulate on the road which would require clean-up prior to opening, or maintenance crews would need to be in the avalanche areas during closures in order to keep the road and rail clean. 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 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 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	-

For the ratings provided in Tables 3-11, it may be helpful 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 Tables 12 and 13 we assigned during testing. However, they should be reviewed and revised as needed prior to use.

Table 12. 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
RACS	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 13. 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
RACS	A	C
Artillery	B	B
Hand / Case	D	B
Ski Cutting	C	A
Preventative Closure	B	A
Blower	B	A
No Control Needed	A	A

5. TESTING AND IMPLEMENTATION

The performance metric is currently implemented in a Microsoft Excel workbook. It includes instructions for use, and a series of tabs that users will work through to enter data for the paths and path groups in their program.

The tabs in the current version of the implementation workbook include the following, intended to provide definitions, context and interaction with the data and calculations.

- Read me - Instructions and implementation details
- Framework - Graphical representation of the framework, with functionally to display any path or path group in the database
- 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.

Figures 3 and 4 show sample results from the summary tab, illustrating how individual path ratings can be viewed or interrogated, and how overall program performance can be visualized in aggregate. Of course, there is an opportunity here to develop a custom or more sophisticated summary.

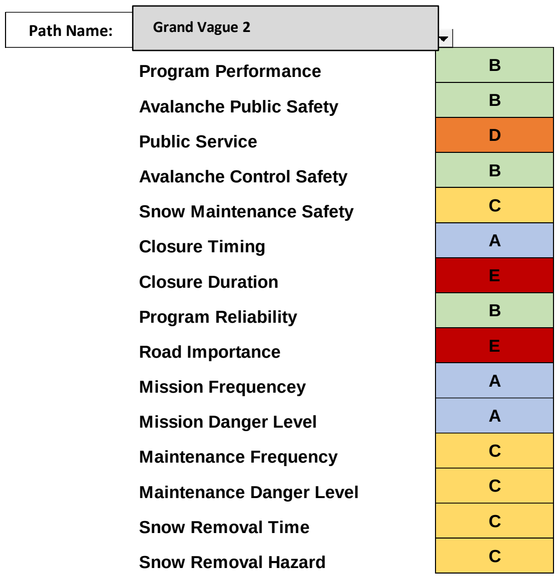

Figure 3. Example performance rating summary for a single (hypothetical) path, computed from path data entered into the implementation tool.

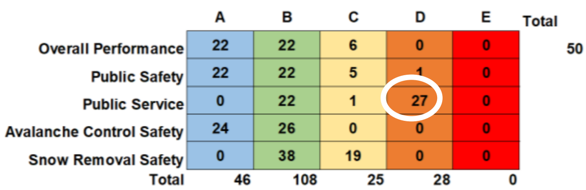

Figure 4. Example program performance summary from testing. Each cell shows the number of paths at each rating level for overall performance. In this example, performance in most categories is good, at the expense of public service for many paths

(e.g. safety is achieved through lengthy, inconvenient road closures).

While consensus on pre-determined values across all avalanche programs may be beneficial, that was not considered practical as part of this scope. 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 programs can be compared.

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 in avalanche management at a given path. To assess how the ratings of a given path change with a new 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 a project lifecycle. Users are also given an estimated cost to road users over the program lifespan when choosing a new control method. Ultimately, the cost benefit tab allows users to assess the changes in costs and letter grades associated with changing control methods for a given path.

The performance metric was tested by several organizations and feedback was used to improve the metric and to calibrate the input parameters and values. Actual path and group data were used to test the metric and implementation. As expected, with disparate data collection and storage methods for different programs, and in some cases widely variable precision in the data, the testing helped us develop a flexible implementation, which could be used for both data-rich and data-sparse areas, even within the same program. This is an important advantage, where precise and quantitative inputs can be used where available, and less precise or judgement based inputs can be used where required.

Feedback from all tests considered in final implementation of performance metric in 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 metric evaluation interface. The expectation is that programs would code the metric into a custom geospatial database or a similar application. Ideally this would be web-based, and shared between programs for widespread analysis and improvements.

6. CONCLUSIONS

The development of this performance metric was informed by input and feedback from several TARP member organisations; nonetheless, it is not a mature product. Rather represents a first step towards a broadly applicable tool. We have developed 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
- Development of a geospatial database to house input data, and reliably coded ratings and calculations
- Further advancement of the cost-benefit tool to suit the needs of programs in decision making around capital investments
- Development of a shared platform for different organizations to post their metrics and benefit from any advancements made by others.

Ultimately, we hope that this proposed metric helps snow avalanche programs estimate their performance on a number of important parameters. Ideally this will promote improvements in currently under-recognized aspects of performance, such as worker safety, and will facilitate discussions with decision-makers who are interested to understand cost-benefit trade-offs for capital or operational investments in snow avalanche programs.

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