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Avalanche Signage: Avalanche Warning Signs Along Roadways

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March 2025

CDOT-2025-01

Technical Report Documentation Page

1. Report No. CDOT-2025-01	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Avalanche Signage: Avalanche Warning Signs Along Roadways		5. Report Date March 2025 6. Performing Organization Code 2441-001
7. Author(s) Eirik Sharp, Scott Thumlert, Cam Campbell, Brian Gould (review)		8. Performing Organization Report No.
9. Performing Organization Name and Address Alpine Solutions Avalanche Services 37738 3rd Ave, P.O. Box 7 Squamish, BC, Canada, V8B 0A1		10. Work Unit No. (TRAIS) 11. Contract or Grant No. TPF-5(497)-24-03
12. Sponsoring Agency Name and Address Colorado Department of Transportation Office of Applied Research 2829 W. Howard Place Denver, CO 80204		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the US Department of Transportation, Federal Highway Administration - Transportation Avalanche Research Pool, Tim Glassett (AKDOT) and Kevin Thompson (New Zealand Transport Agency), Champions.

16. Abstract

Avalanche signage is a critical component of risk management for transportation infrastructure in avalanche-prone regions. Effective signage not only reduces the exposure and vulnerability of road users but also demonstrates a proactive duty of care by transportation authorities. A comparative analysis of the current approaches to avalanche signage employed by participating Transportation Avalanche Research Pool agencies reveals a wide range of approaches influenced by local geographic, economic, and traffic conditions. Current guidelines, such as the Manual for Uniform Traffic Control Devices and the Vienna Convention on Road Signs and Signals, do not specifically address snow avalanches and their unique needs, leading to variability across jurisdictions. Specific gaps identified in avalanche signage systems currently used include:

• A lack of consistent approach, a lack of design and placement standardization, inconsistent enforcement of regulatory signs, a lack of clear messaging, a lack of detailed records.

An action plan for addressing these gaps is provided as recommendations for best practice, including:

• Threshold values for avalanche signage, signage placement criteria and considerations, seasonal avalanche signage, sign design criteria and considerations, variable-message signs, maintenance, training and awareness, record keeping, and development of a signage manual.

This report highlights the importance of a consistent approach to signage design and placement through a detailed review of insights from behavioral and ergonomic research. While standardization is desirable, avalanche signage should be guided by accurate risk assessments.

17. Keywords Sign; Signage; Avalanche; Risk; Mitigation; Roads		18. Distribution Statement This document is available on CDOT's website: https://www.codot.gov/programs/research	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 56	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Executive Summary

Avalanche signage is a critical component of risk management for transportation infrastructure in avalanche-prone regions. Effective signage not only reduces the exposure and vulnerability of road users but also demonstrates a proactive duty of care by transportation authorities. A comparative analysis of the current approaches to avalanche signage employed by participating Transportation Avalanche Research Pool agencies reveals a wide range of approaches influenced by local geographic, economic, and traffic conditions. Current guidelines, such as the *Manual for Uniform Traffic Control Devices* and the *Vienna Convention on Road Signs and Signals*, do not specifically address snow avalanches and their unique needs, leading to variability across jurisdictions. Specific gaps identified in avalanche signage systems currently used include:

- A lack of consistent approach
- A lack of design and placement standardization
- Inconsistent enforcement of regulatory signs
- A lack of clear messaging
- A lack of detailed records

An action plan for addressing these gaps is provided as recommendations for best practice, including:

- Threshold values for avalanche signage
- Signage placement criteria and considerations
- Seasonal avalanche signage
- Sign design criteria and considerations
- Variable-message signs
- Maintenance
- Training and awareness
- Record keeping
- Development of a signage manual

This report highlights the importance of a consistent approach to signage design and placement through a detailed review of insights from behavioural and ergonomic research. While standardization is desirable, avalanche signage should be guided by accurate risk assessments. Given the diverse operational contexts and regulatory differences that guide avalanche risk mitigation for transportation infrastructure, Alpine Solutions Avalanche Services (Alpine Solutions) concludes that developing sector-wide policies, design standards, and guidelines for avalanche signage is impractical. Instead, Alpine Solutions advocates adopting a standardized framework for agency-level avalanche signage manuals based on evidence-based best practices. This approach supports transportation authorities in developing signage strategies that are effective and appropriate risk management for their operational context while improving consistency in the application, design, and placement of avalanche signage across jurisdictions.

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1 Introduction

This report was prepared by Alpine Solutions Avalanche Services (Alpine Solutions) for the Transportation Avalanche Research Pool (TARP) according to the scope of work proposed by Alpine Solutions on January 15, 2024 (Proposal #2383-001). The study summarized in this report is in response to the problem statement in the document *Avalanche Signage: avalanche warning signs along transportation infrastructure,* championed by Timothy Glassett of Alaska Department of Transportation and Public Facilities and Kevin Thompson of the Milford Road Alliance[1].

This study addresses the lack of standardization in avalanche hazard signage across different jurisdictions for transportation corridors. The goal is to develop a comprehensive, multidisciplinary understanding of existing practices and propose a unified set of standardized practices for avalanche signage applicable to roadways.

1.1 Background

The International Commission on Illumination (CIE, 1988) defines a sign as:

> A device that provides a visual message by virtue of its situation, shape, colour or pattern, and sometimes by the use of symbols or alpha-numeric characters.

Concise sign messaging is used to communicate important information under a variety of environmental conditions to receivers (i.e., drivers) with varying backgrounds, interpretive and recall skills, and mental and physical states.

Avalanche signage[2] is a widely adopted risk treatment used to manage avalanche danger along transportation infrastructure. In most cases, signage is one component of a comprehensive system of risk mitigations aligning with the principles of Reason's Model of Risk (Reason, 1990). This approach emphasizes the use of multiple overlapping risk mitigations to reduce the likelihood of incidents. Active mitigations, such as conditions monitoring, explosive avalanche control, and traffic management strategies, serve as dynamic safeguards to address immediate risks. Signage complements these measures by enhancing awareness and directing behaviours that reduce the exposure and vulnerability of road users to avalanche hazards, ensuring that no single failure results in catastrophic consequences. Avalanche signage also plays a critical role in managing liability for transportation authorities by fulfilling their duty of care and demonstrating a proactive approach to avalanche risk management.

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[1] Transportation Avalanche Research Pool (TARP) Problem Statement Form submitted on November 2nd, 2023.

[2] In this report, a sign refers to an individual display or marker, while signage encompasses a collection or system of signs designed for broader communication.

Effective avalanche signage engages driver awareness, memory, and decision making by ensuring that its design, placement, and visibility capture the attention of drivers amidst competing stimuli. Consistent symbols, colours, and messaging reinforces drivers' understanding of specific hazards and appropriate responses. Additionally, simplified and intuitive designs reduce cognitive load, which enables drivers to quickly process critical information (Jamson & Mrozek, 2017). Effective signage also benefits from the psychological priming effects of repeated exposure and contextual relevance to enhance driver cognition and compliance (Koyuncu & Amado, 2008).

Road hazard signage generally falls into three broad categories:

1. **Regulatory signs**: The primary purpose of regulatory signs (Figure 1-1a) is to enforce traffic laws and regulations by directing or restricting actions a driver must adhere to. Failure to adhere to these signs may result in traffic violations, fines, or other legal consequences. Regulatory signs are further classified as either prohibitory (those indicating an action a road user must not take) or mandatory (those indicating an action a road user must take).

2. **Warning signs**: In contrast, warning signs (Figure 1-1b) are intended to inform drivers about potential hazards ahead. They do not direct or restrict an action but provide cautionary advice to help prevent accidents. While drivers are encouraged to heed warning signs for their safety, there are no legal penalties for ignoring them.

3. **Indicative signs**: Indicative signs (Figure 1-1c) can be used to direct actions not required by traffic laws, such as identifying safe areas to stop or pool traffic.

Figure 1-1: a) An example of a regulatory avalanche sign employed by the British Columbia Ministry of Transportation and Infrastructure (top left); b) an example of an avalanche warning sign employed by the Colorado Department of Transportation (top right); and c) an indicative sign indicating a safe stopping area employed by the Milford Road Alliance (bottom).

Avalanche-specific signage commonly plays several critical roles when deployed as part of a comprehensive risk-management framework:

- **Avalanche warning signs** inform drivers that they are entering avalanche-exposed road sections. This reduces the vulnerability of drivers to avalanche hazards by priming them to be able to appropriately respond to unanticipated driving conditions, such as debris on the road or sudden visibility loss due to a powder cloud.
- **Variable-message signs** are a common component of intelligent transportation systems that provide real-time updates on road conditions. This allows drivers to manage their exposure to avalanche hazards by alerting them to periods of higher avalanche risks and informs them of temporary delays due to avalanche control or highway closures.
- **Regulatory signs**, such as no stopping or no parking signs, mitigate road-user exposure to avalanche paths by enforcing rules against stopping or parking in avalanche hazard areas.
- **Road-closure signs** eliminate exposure entirely by restricting access to roads seasonally, during periods of elevated hazard, or during times when active hazard reduction measures are being applied (e.g., explosive avalanche control).

The use of avalanche signage should complement other elements of the risk-management framework and address the specific needs of the avalanche-management program's operational environment. Variations in geographic scale, traffic patterns, hazard frequency, road user types, and economic considerations all influence how signage is employed as a risk treatment.

1.2 Problem Statement

Methodologies for identifying and characterizing hazard zones where avalanches affect transportation infrastructure and approaches to actively manage the risks avalanches pose to drivers are well-established. However, best practices for using signage to augment these mitigations remain poorly defined. Depending on the jurisdiction, road signage may follow recommended standards established by either the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA, 2009) or the *Vienna Convention on Road Signs and Signals* (Vienna Convention) (UNECE, 1968). These guidelines, however, do not specifically address avalanche-related signage, leaving national, state, or provincial agencies to develop their own policies, specifications, and standards. This has resulted in gaps in standardization and inconsistencies across jurisdictions.

The lack of standardized avalanche signage presents several challenges, including driver confusion, poor compliance with signage directives, and potential legal liabilities for transportation authorities (Slop, 2005).

1.3 Project Objectives

This project addresses the lack of standardization in avalanche signage along transportation corridors. It seeks to develop a comprehensive understanding of existing practices across jurisdictions and to propose best practices for avalanche signage based on current implementations and insights from relevant literature. Developing and adopting a consistent approach to designing and deploying avalanche signage would address the problem statement and improve safety for drivers in avalanche-prone areas.

Recognizing the competing needs for standardization with the unique operational contexts, priorities, and resources of different transportation avalanche-management programs, this project emphasizes the value of applying a standardized framework for developing signage policy, design, and guidelines. Such an approach prioritizes adaptability and consistency over prescriptive rules, which enables jurisdictions to tailor solutions to their specific needs while enhancing the effectiveness and uniformity of avalanche-hazard signage between regions.

1.4 Scope of Work

This study addresses the need for enhanced guidance on avalanche signage as a risk-mitigation tool along transportation corridors. Recognizing the diverse operational contexts, regulatory frameworks, and risk tolerances across jurisdictions, the project focuses on providing a comprehensive evaluation of current signage practices and developing recommendations for evidence-based best practices. The specific work scope included:

1. **Review of current practices:** Data was collected from TARP-member agencies via surveys and interviews to understand current avalanche-signage practices.
2. **Literature review**: Relevant literature on road-hazard sign design, placement, and effectiveness was reviewed with a focus on behavioural and ergonomic research.
3. **Data analysis:** The design, placement, and deployment strategies for avalanche signage of participating agencies were analyzed in relation to their specific avalanche risk-management program.
4. **Recommendations**: Recommendations were based on existing best practices identified during the analysis and on relevant road-hazard sign literature. An adaptable framework to develop avalanche-signage strategy and policy was also recommended. This agency-specific framework is referred to as a “Signage Manual”.
5. **Future research:** Opportunities for further study as identified throughout the course of this project.

Of note, although the intention was to include railway operations, initial investigations suggested that this study would benefit by focusing solely on public roadway corridors, which consider different criteria for the use and placement of signs. However, certain aspects of the study’s results may still be useful for railway avalanche risk-management programs.

1.5 Uncertainty and Limitations

This study focuses on public roads and does not explicitly consider other types of transportation infrastructure, such as resource or private roads, railways, trails, or pedestrian pathways. Furthermore, the scope is limited to avalanche signage used as a direct risk-mitigation measure, including avalanche closure gates, warning signs, stopping and parking-restriction signs, and variable-message signs. Other types of avalanche signage, such as avalanche-path identification, explosive avalanche control, and magazine and rescue-cache identification, are outside the scope of this study.

The analysis is exclusively based on data collected from TARP-member agencies, which limits the geographic and operational scope of the findings. Consequently, the recommendations should be interpreted with the understanding that the analysis focused on participating jurisdictions. That is, there may be greater uncertainty in applying the results of this study to jurisdictions not directly included in this project.

Data limitations include incomplete or inconsistent avalanche-signage databases and insufficient data correlating sign placement with avalanche hazard. For example, minimum return periods for signage placement were determined subjectively by avalanche forecasters rather than through quantitative analysis. Similarly, the effectiveness of signage is based on the subjective assessments of avalanche forecasters, without supporting objective metrics. Factors such as economic importance and road accessibility were also subjectively assessed.

The recommendations presented in this report have not been field tested or validated to evaluate their effectiveness in improving driver comprehension, compliance, and incident reduction. Ishartomo et al.

(2020) suggest utilizing evaluation methods like comprehension tests, questionnaires, comparative studies, and Human Information Processing (HIP) modeling to assess the effectiveness of traffic signs and guide improvements in design. Berrio et al. (2023) go on to suggest that studies related to traffic-sign comprehension should adhere to rigorous quality standards to enhance the reliability and validity of findings. Therefore, there is uncertainty about the effect of adopting the recommendations as presented.

Furthermore, these recommendations are intended to complement existing regulatory standards, such as those outlined in the MUTCD, Vienna Convention, or local guidelines, and do not replace the critical role of traffic engineers in evaluating and designing roadway signage.

2 Methodology

2.1 Literature Review

A focused literature review was conducted to examine best practices in effectiveness of road-hazard sign design and placement. The literature reviewed included international research papers, manuals, guidelines, and books that covered a broad scope of perspectives and concepts, including human behavioural responses, standardization, regulatory frameworks, and technological innovations. This review provided critical context for understanding the operational effectiveness of signage in mitigating avalanche risks.

2.2 Surveys

Information on signage was gathered from stakeholder surveys conducted with TARP-member agencies. These surveys focused on 1) existing signage practices; 2) the influence of avalanche parameters on signage design and placement; and 3) subjective assessments of signage importance and effectiveness as a risk-mitigation measure.

Surveys were distributed to TARP-member agencies during summer 2024 with the objective of collecting data on the governing standards and use of hazard signage in their avalanche risk-management programs. Surveys were expected to take 20 to 40 minutes to complete, and Alpine Solutions received 11 survey responses completed by core personnel from participating TARP members. Generally, survey questions were structured to gain information about:

- **Respondent information**
- **Program context** – This section aimed to establish the operational context of avalanche risk-management programs.
- **Signage standards** – This section explored the standards and policies governing avalanche signage in the programs.

- **Signage design** – This section focused on the design elements of avalanche signs used in the avalanche program.
- **Signage placement** – This section examined the criteria and considerations for placing avalanche signs.
- **Critical review** – This section sought an evaluation of the effectiveness of avalanche signage.
- **Data availability** – This section sought information on the data sets related to signage that the program was able to share.

The survey questions and the detailed responses are provided in Appendix A.

2.3 Interviews with Key Personnel

Key agency personnel were also interviewed during summer 2024 with the intention of gaining deeper insights into the survey results. The interviews followed a generally structured approach that focused on avalanche-risk mitigation but allowed flexibility to delve into avalanche-signage practices that were unique to the specific program. The combination of the survey results and the interviews allowed an analysis that compared current avalanche-signage practices between participating agencies described in the next section.

2.4 Comparative Analysis

We compared sign design specifications, placement criteria, risk-assessment methodologies, and compliance requirements across jurisdictions using a comparative matrix. The analysis incorporated the effects of varying cultural and environmental factors influencing applicability.

3 Literature Review – The Effectiveness of Signage

There are many studies and guidelines that highlight the importance of sign design and placement on effectiveness (Babić et al., 2022; Ben-Bassat & Shinar, 2006; Ben-Bassat et al., 2021; Berrio et al., 2023; Castro & Horberry, 2004; Charlton, 2006; Crundall & Underwood, 2001; Dewar, 1988; Dewer & Pronin, 2023; Ishartomo et al., 2020; Jørgensen & Wentzel-Larsen, 1999; Lay, 1998; Rousseau et al., 2006; Wogalter et al., 2002; and Zhu et al., 2020). However, Castro & Horberry (2004) and Rousseau et al. (2006) also warn that signage effectiveness is largely dependent on driver characteristics, such as the degree of familiarity with the route, the state of urgency, fatigue, and the state of relaxation. In fact, studies have shown that drivers often overlook road signs, with awareness often less than 50 per cent (Darko, et al, 2022).

Ultimately, road hazard signage should be designed to recognize and address the correct importance of its information and prompt appropriate responses. Furthermore, road hazard signage should be based on a systems-approach that considers signage as one element of the operator, environment, and journey system (i.e., a planned and systematic process of managing transportation risks by identifying potential hazards before, during, and after a journey) (Castro & Horberry, 2004). Effective signs not only aid in recognition but may also subconsciously influence driver behaviour (Charlton, 2006).

Sign design directly impacts how drivers perceive, process, and react to hazards, and even small misperceptions in risk may impact safety (Charlton, 2006; Jørgensen & Wentzel-Larsen, 1999). The experiences drivers have at locations where road hazard signs are present influence their overall risk perceptions, not just at those specific spots (Jørgensen & Wentzel-Larsen, 1999). Furthermore, any uncritical use of hazard warning signs may diminish their effectiveness and cause drivers to underestimate risk (Jørgensen & Wentzel-Larsen, 1999; Wogalter et al., 2002). Because of this, Jørgensen & Wentzel-Larsen (1999) emphasize the importance of accurate risk assessments prior to road hazard signage design. They also suggest that considering drivers' risk perceptions and objective values in warning-signage design may not only lead to improvements in road safety but could also lower economic burdens on drivers.

Lay (1998) outlines a framework for evaluating sign effectiveness based on the premise that the driver must successfully pass through the following four stages, with only a single glance:

1. Detect the sign (i.e., conspicuity)
2. Read the sign (i.e., legibility)
3. Understand the sign (i.e., comprehension)
4. Act on the sign (i.e., compliance)

Other evaluation criteria suggested by Castro & Horberry (2004), Rousseau et al. (2006), Wogalter et al. (2002), and Dewar (1988) generally follow Lay’s (1998) framework. These evaluation criteria and associated sign design and placement considerations are discussed separately in the following subsections.

3.1 Conspicuity

Conspicuity, (i.e., the driver’s ability to detect the sign) is vital to the sign’s effectiveness (Babić et al., 2022; Castro & Horberry, 2004; Charlton, 2006; Dewar, 1988; Rousseau et al., 2006; Wogalter et al., 2002; and Zhu et al., 2020). This involves seeing and acknowledging the presence of a warning sign, which is crucial for initiating the appropriate responses (Rousseau et al., 2006). Effective road hazard signs must stand out to grab attention, and high conspicuity helps drivers notice signs even when they are focused on other tasks (Wogalter et al., 2002). Furthermore, Babić et al. (2022) suggest that driver training and awareness on the meaning of different road signs and markings may enhance familiarity and improve recognition speed.

In addition to sign design and placement considerations, well-maintained signs also have higher conspicuity. Regular maintenance of road signs to prevent deterioration (e.g., fading colours or damaged symbols) may help improve their visibility and aid in quicker recognition by drivers. Furthermore, weather and lighting conditions influence conspicuity (Rousseau et al., 2006), and rainfall may reduce sign detection by as much as 32% (Babić et al., 2022).

3.1.1 Sign Design Considerations

Considerations of sign design for conspicuity described in the literature above include:

- **Size** – The eye tends to favor nearby objects that provide a large visual angle (i.e., the angle of a viewed object at the eye); therefore, larger signs are more conspicuous.
- **Luminance** (i.e., the light signal delivered to the driver from the sign) – At night or in low-visibility conditions, retroreflective materials or lights (i.e., illuminated signs or flashing lights) are essential for maintaining adequate conspicuity.
- **Edge contrast** (i.e., contrast and sharpness of the sign edge relative to its background) – Large edge borders are particularly effective at increasing conspicuity.
- **Consistency** – Signs with a uniform appearance and symbolism are more easily recognizable by drivers. Note: this highlights the importance of standardization, which is a common consideration in legibility, comprehension, and compliance.
- **Variable-message signs** – The potential for changing messaging enhances conspicuity.
- **In-vehicle display** – Signage presented using in-vehicle displays echoes external road signs and enables consistent and familiar information presentation.
- **Signal words** (i.e., words that prime the reader for what is about to happen) – Common signal words, including *Danger*, *Warning*, *Caution*, and *Notice*, can grab attention.
- **Width of markings** – Wider markings may be easier to see, especially in high-speed areas.
- **Materials** – The material used for road markings affects their durability and how well they maintain their retroreflective properties over time.
- **Colour** – Charlton (2006) and Wogalter et al. (2002) suggest high-contrast colours improve conspicuity; however, Castro & Horberry (2004) warn that some colours could lead to a loss of luminance; therefore, any colours used in road hazard signs need to have high contrast as well as high luminance.

3.1.2 Sign Placement Considerations

To be conspicuous, a sign needs to be positioned and oriented so that it is geometrically possible to be seen. Furthermore, to be detectable with only a single glance, common practice is that signs must be placed within eight to 10 degrees of the line of sight (Castro & Horberry, 2004). Rousseau et al. (2006) highlight the importance of strategic placement of signs in relevant locations to ensure that they are seen when needed, and placing multiple signs in different locations may increase the likelihood of drivers noticing the sign, especially in busy or distracting environments. Finally, Wogalter et al. (2002) suggest that warning signs are most effective when placed close to the hazard, and reducing visual clutter by minimizing the number of signs at any given location may increase conspicuity. However, Castro & Horberry (2004) remind us that there are often environmental (e.g., terrain), economic, and political constraints to sign placement that must be considered.

3.2 Legibility

Legibility (i.e., the driver's ability to read the words on the sign at a given distance in a given time) is another important factor in signage effectiveness (Babić et al., 2022; Castro & Horberry, 2004; Charlton, 2006; Dewer, 1988; and Dewer & Pronin, 2023).

3.2.1 Sign Design Considerations

Sign design considerations that influence legibility include drivers' ability to detect detail (i.e., the letters and symbols must be discernible) (Castro & Horberry, 2004). This depends on:

- **Lettering size** – Castro & Horberry (2004) provide the following formula for determining optimal lettering size (H):

  $$H = 0.12Nv + 1.7L_p$$

  where:

  H = letter height (mm)

  v = vehicle speed (km/h)

  N = number of words

  L_p = sign placement distance (m) from hazard
- **Font** – According to Castro & Horberry (2004), many countries use the U.S. Bureau of Public Roads (California) letter set (Modified E Series). Bold type may also increase legibility.
- **Spacing of letters** – The amount of space between letters also affects legibility. Words with letters that are too close together are more difficult to read.
- **Contrast and Colour** – Use of high-contrast colours to make the letters stand out against their background is crucial for legibility in different lighting conditions and for people with colour-vision deficiencies.

Drivers' ability to detect whole words is also an important design consideration influencing legibility (Castro & Horberry, 2004). This is a function of shape of the word or symbol and the familiarity of the word or symbol to the reader. Furthermore, the use of lower-case letters (i.e., with varying contours) enhances the driver's ability to detect whole words and should be used whenever possible (Castro & Horberry, 2004).

Finally, Castro & Horberry (2004), Babić et al. (2022), and Dewer & Pronin (2023) highlight the importance of minimizing the number of words to increase glance legibility (i.e., drivers' ability to read the sign during brief periods of exposure). Many sign designs assume that drivers may read four words per second and short-term memory may retain approximately seven words at a time. Furthermore, only one sign of a particular type should be attached on any single post due to limited reading times available to drivers (Castro & Horberry, 2004). Displaying more than three signs at once may reduce effective hazard information conveyance (Kwon et al., 2024).

3.2.2 Sign Placement Considerations

Sign placement also affects drivers' ability to detect detail and overall legibility (i.e., the message must be legible at a given distance over a given time). Castro & Horberry (2004) provide the following guidance for legibility distance (L_d) (i.e., the maximum distance at which detail may be seen and read):

- Many design codes use: L_d (m) = 0.4 x letter height (mm)
- Typical L_d in good light:
  - 60 m for finger-sized detail
  - 80 m for complex signs
  - 125 m for legends
  - 250 m for symbols and fiber-optic signs

3.3 Comprehension

Comprehension (i.e., the driver's ability to understand the sign) is also an important factor in sign effectiveness (Babić et al., 2022; Ben-Bassat & Shinar, 2006; Ben-Bassat et al., 2021; Berrio et al., 2023; Castro & Horberry, 2004; Charlton, 2006; Crundall & Underwood, 2001; Dewer, 1988; Dewer & Pronin, 2023; Rousseau et al., 2006; Wogalter et al., 2002; Ishartomo et al., 2020). This involves understanding the message it conveys and the potential hazards it warns about (Rousseau et al., 2006). The comprehension of signs plays a crucial role in driver reactions in that signs with poor comprehension leads to lower memorability and recognition rates (Charlton, 2006).

3.3.1 Sign Design Considerations

According to Castro & Horberry (2004), signage comprehension depends on whether the perceived message is meaningful, correctly understood, and interpreted unambiguously. The warning should clearly describe the hazard, and it should be detailed but not too long, balancing completeness and brevity (Babić et al., 2022; Darko, et al., 2022; and Wogalter et al., 2002). When designing warning signs, it is important to understand the exact nature of the message that the sign is trying to convey, the context of its use, and the population to whom it is directed (Castro & Horberry, 2004). The warning message must clearly distinguish between mandatory (i.e., what must be done) and prohibitory (i.e., what must not be done) to avoid misinterpretation by drivers (Dewer & Pronin, 2023). Familiarity is also key: road signs that are familiar to drivers (e.g., symbols and messages that people are already accustomed to seeing and understanding) may help with quick and accurate comprehension (Ben-Bassat & Shinar, 2006; and Ben-Bassat et al., 2021).

Berrio et al. (2023), Ishartomo et al. (2020), and Dewer (1988) highlight the importance of incorporating ergonomic principles into road-sign design to enhance comprehension levels among drivers. Ishartomo et al. (2020) and Wogalter et al. (2002) go on to suggest that considering demographic variables and human characteristics, such as age, gender, driving experience, and educational background, in road-sign design may help tailor signs to different user groups, improving overall comprehension. Furthermore, conducting cross-cultural studies on road-sign comprehension may provide insights into how different cultural backgrounds influence understanding, thus guiding the development of more universally comprehensible signs (Ishartomo et al., 2020).

As with conspicuity, comprehension, and compliance, standardization may also improve comprehension (Babić et al., 2022; Ben-Bassat & Shinar, 2006; Ben-Bassat et al., 2021; Berrio et al., 2023; and Wogalter et al., 2002). Consistency in sign design aids in improving comprehension levels among drivers, as individuals from diverse backgrounds and regions may rely on familiar design features to understand the message conveyed by the sign (Berrio et al., 2023). Given the variability in comprehension levels across different countries, there is practical implication for internationally promoting standardized traffic signs to ensure consistent understanding among diverse populations.

When designing warning signs, the choice of sign shape is crucial for effectively conveying the level of hazard (Castro & Horberry, 2004; and Zhu et al., 2020). Common shapes used for warning signs are listed in Table 3-1.

Table 3-1: Common shapes used for warning signs.

Shape	Description	Hazard Association and Usage
▼	Inverted Triangle	This shape is associated with the highest hazard level. It elicits strong emotional responses and is recognized quickly as a warning of significant danger.
▲	Upright Triangle	Ranked second in terms of hazard level, the upright triangle also signals a high level of danger but is slightly less impactful than the inverted triangle. It is effective in drawing attention and conveying urgency.
◆	Diamond	The diamond shape is the third in the hierarchy of hazard levels. While it still indicates a considerable level of danger, it is perceived as less urgent than triangle shapes.
●	Circle	Circles are associated with a lower level of hazard. They are used to indicate warnings that are important but do not imply immediate or severe danger.
▮	Rectangle	This shape is considered the least hazardous. Rectangles are often used for informational signs rather than for immediate warnings.

Furthermore, sign colour also plays an important role in sign comprehension (Castro & Horberry, 2004; and Zhu et al., 2020). Common colours used for road signs include:

- **Red** – Normally associated with high hazard and may mean stop, give way, wrong way, and reduce speed.
- **Yellow** – Normally used for warning of hazards and used for advisories and temporary signs.
- **Orange** – Normally reserved for warning of roadworks.
- **Black/White** – Normally used for regulatory signs and legends on other signs.
- **Green** – Normally used for permissive, guide, and direction signs.
- **Blue** – Normally used for guide, direction, and service signs.
- **Brown** – Normally used for tourist and recreational information signs.

In most jurisdictions, sign shape and colour need to align with the Vienna Convention and MUTCD. However, Babić et al. (2022) highlight that sign design should also address the unique needs of different end users. This includes cultural considerations such as language barriers, unfamiliar symbols, as well as reliance on environmental context (e.g., due to difficulties in understanding local road signs, tourists often depend on the environmental context or their own driving experience to interpret the message of a sign). This also includes training, experience, and awareness considerations (e.g., road hazard signs designed to be interpreted by maintenance workers might look different than signs for the public).

Zhu et al. (2020) suggest that high-hazard-level words (e.g., *Warning*, *Danger*, *Caution*) play a crucial role in the effectiveness of warning signs. These words convey urgency, improve memory recall, arouse emotional response, and facilitate hazard matching. However, Jørgensen & Wentzel-Larsen (1999) and Wogalter et al. (2002) warn that uncritical use of high-hazard-level words may diminish their effectiveness by causing drivers to underestimate risks.

Dewar (1988), Dewer & Pronin (2023), Rousseau et al. (2006) and Wogalter et al. (2002) suggest pictorials and symbols help people understand warnings, especially those who are unable to read or do not understand the language. Pictorials and symbols work best for simple ideas and should have enough detail to be understood without losing clarity; furthermore, using both text and symbols in warnings may also be effective (Rousseau et al., 2006; Zhu et al., 2020). However, when multiple symbols are used on a single sign, care must be taken to arrange them in a logical and clear manner to avoid confusion and ensure that each symbol's message is easily understood.

Finally, studies that compare existing and alternative traffic-sign designs show that redesigning signs may significantly improve comprehension levels. This implies that transportation agencies could benefit from evaluating and updating current sign designs to ensure better understanding by drivers (Berrio et al., 2023).

3.3.2 Sign Placement Considerations

Crundall & Underwood (2001) and Castro & Horberry (2004) suggest that understanding the primary function of road signs may help optimize their design and placement to maximize their effectiveness in conveying important information to drivers, ultimately contributing to improved outcomes in road safety. Babić et al. (2022) also highlight the importance of standardization and consistency in sign placement. Hazard-warning signs should be consistently placed across the road network in terms of specific hazards that require warning signage, and the position of the sign should be relative to the location of the hazard.

3.4 Compliance

Compliance is the ability and willingness of drivers to act on a sign’s message and is the ultimate measure of sign effectiveness (Castro & Horberry, 2004; Charlton, 2006; Rousseau et al., 2006; and Wogalter et al., 2002). This includes following the instructions or precautions stated on the sign to ensure personal and public safety (Rousseau et al., 2006). While considerations for sign design and placement are listed below, research shows that the behaviour of other drivers plays a significant role in whether individuals obey warnings. When drivers observe other drivers comply with a warning, they are more likely to do the same. Conversely, if drivers observe non-compliance among others, they may also disregard the warning. Furthermore, compliance of regulatory signs depends on whether legal compliance is consistently enforced. Ultimately, Rousseau et al. (2006) suggest creating a system where multiple warning signs along a road complement each other, leading to improved overall compliance behaviour and safety awareness.

3.4.1 Sign Design Considerations

Castro & Horberry (2004) explain that compliance is a cognitive response that requires credible, correct, and appropriate action. This means that the relevance and importance of a sign to a driver is vital and will usually relate to whether: 1) the driver must act on the sign; 2) the message will affect the driver's well-being; and 3) previous signs have been perceived as being useful. Drivers who notice a conspicuous but irrelevant sign will give it little or no cognitive priority, unless it has a degree of novelty. Furthermore, high-cognitive load related to the amount of information on traffic signs may reduce compliance, like how it reduces compliance with medical procedures (Lyu et al., 2017). Under high-cognitive load, drivers tend to focus their gaze on the centerline of the road.

Wogalter et al. (2002) suggest that to improve compliance, a warning sign should explain what could happen if ignored. Specific details about potential injuries help people understand the importance of following the warning. Furthermore, instructions on how to avoid the hazard should be clear and specific (e.g., "No Stopping"; "Max 30 km/h"). Rousseau et al. (2006) found that the use of symbols may enhance compliance by providing visual cues that reinforce the message conveyed through text. Furthermore, signs enhanced with colours and symbols improve compliance by increasing visual appeal and attracting attention.

3.4.2 Sign Placement Considerations

Castro & Horberry (2004) explain that compliance is a physical response that requires timely action. Therefore, if a driver must act on the message provided in a sign, the sign must be sufficiently located in advance to allow the driver to properly detect, read, understand, and respond to the message. Castro & Horberry (2004) provide further details on optimal sign locations relative to the hazard based on legibility distance, driver response time, and braking distance.

To improve compliance, strategies for signage placement need to consider the idea of priming (i.e., an automatic function distinct from the conscious use of information). According to Crundall & Underwood (2001) and Castro & Horberry (2004) there are two types of priming: 1) semantic priming; and 2) repetition priming.

Semantic priming occurs when one sign facilitates the processing of another sign or prepares the driver for upcoming road or environmental conditions (e.g., a warning sign semantically primes drivers to watch for avalanches). Crundall & Underwood (2001) found that semantic priming may facilitate faster recognition and response to environmental cues. Furthermore, experienced drivers may extract information from road scenes faster than novices, which indicates that priming is developed with experience and consistent mapping over time.

Repetition priming is an automatic and unconscious cognitive phenomenon where exposure to a stimulus improves the processing of that same stimulus when it is encountered again. Crundall &

Underwood (2001) and Castro & Horberry (2004) suggest that repetitive use of road signs before hazardous road features may increase comprehension (e.g., a warning sign at the start of a section of highway will help drivers to recognize and respond to a no-stopping sign at the start of an avalanche area). Repetitive priming is more dependent on experience and practice, while semantic priming relies on the meaningful connections between stimuli and memory. While repetitive priming paradigms may facilitate faster reactions to hazards based on prior exposure to warning signs (Charlton, 2006; and Crundall & Underwood, 2001), Jørgensen & Wentzel-Larsen (1999) suggest that overuse of warning signs may diminish their effectiveness.

4 Results

To help identify and understand the existing use of highway signage for avalanche risk management, a qualitative analysis comparing signage use across participating agencies was conducted. The analysis was based on two primary sources of information provided by the participating agencies: 1) survey responses; and 2) interviews with key personnel. Appendix B shows the comparative matrix that was constructed with the intention of providing a quick reference to key similarities and differences across participating TARP programs.

The survey responses and interviews reveal diverse avalanche risk-management challenges and signage practices across the various highway programs globally. TARP programs range from regional to national in scales, covering areas from Norway's coastal roads to North America's mountain highways. Traffic volumes vary significantly, from low-volume mountain passes to major interstate highways carrying tens of thousands of vehicles daily. The economic impact of these corridors can be high with some closures potentially costing the economy several millions of dollars per hour (Wei et al., 2022), whereas some corridors tolerate seasonal closures with limited economic impact. In consideration of these varied contexts, it is apparent that consistent standards do not easily emerge for highway avalanche-signage practices and procedures across programs.

The following sections describe the context of the participating programs, compare similarities and differences across jurisdictions, and discuss patterns in the deployment strategies of the programs.

4.1 Context Descriptions for Each Program

The context (e.g., type of traffic, patterns of traffic flow, economic importance, type of avalanche risk mitigation) of each program appears to strongly influence the strategy for deploying avalanche signage. That is, the participating programs have developed signage deployment practices specifically tailored to their program and operational objectives. The following sections offer brief descriptions of each participating highway program with the intention of providing the link between signage deployment strategy and the context of the highway program.

4.1.1 Norges Vegesen

Norges Vegesen manages the road network for all of Norway with avalanche potential across the country from high mountain roads to coastal areas and deep valleys. Road locations vary from bisecting starting zones of avalanche paths to valley-bottom locations far away from starting zones. Traffic volumes on avalanche-prone roads are mostly low, but often, the road is the only access to communities that may become isolated when the road is closed. Norges Vegesen uses general geohazard warning signs that include avalanches among other hazards (e.g., rockfall).

4.1.2 Milford Road Alliance

The Milford Road Alliance primarily manages 17 km of highway exposed to more than 50 large avalanche paths, some with up to Size D5 potential (American Avalanche Association, 2022; Canadian Avalanche Association, 2024). The road is primarily used for high-value tourism and fishing with approximately 200 to 400 vehicles per day during the avalanche season. The high percentage of tourism and roadside scenery results in frequently interrupted traffic flow, due to the high motivation for road users to stop (often within avalanche zones) to view and take photographs. This situation creates traffic management challenges and influences the avalanche-signage design and placement strategy.

4.1.3 Parks Canada – Mt. Revelstoke and Glacier National Parks

Parks Canada manages a complex highway avalanche program along the TransCanada highway through Rogers Pass in British Columbia. The highway is the principle east-west connector through the Columbia Mountain range, which means it is a critical commercial corridor with high economic value, low tolerance for closures, and high traffic volumes (i.e., 4,220 winter average daily traffic (WADT)). Forty kilometres of the highway corridor through Rogers Pass is exposed to 135 avalanche paths, some of which regularly impact the highway. The Canadian Pacific Kansas City railway line also runs parallel to the highway through Rogers Pass, though it is much less exposed to avalanche hazard due to a significant tunnel and shed system.

4.1.4 Colorado Department of Transportation

The Colorado Department of Transportation (CDOT) manages the Colorado road network with avalanches mainly affecting corridors in the western half of the state. Approximately 272 avalanche paths affect roadways and require regular mitigation efforts. The I-70 is a high-value transportation corridor with critical economic impact if closed. Traffic volumes on the I-70 are approximately 40,000 vehicles per day. Many remote roads and secondary corridors are actively managed. Signage strategy has historically been developed by the local road managers rather than centralized by CDOT.

4.1.5 Washington State Department of Transportation – South Region

The Southern part of the Washington State Department of Transportation (WSDOT) program includes the I-90 Snoqualmie Pass, US-12 White Pass, SR410 Chinook Pass, and SR410/SR123 Cayuse Pass. Only the I-90 and US-12 are open through the winter, while SR410 and SR123 are seasonal highways that close in the fall and reopen in late spring. The I-90 is a high-value critical transportation corridor with little to no tolerance for closures. Traffic is not permitted to stop along the highway corridor outside of designated rest areas, and therefore avalanche signs are not deployed to influence public safety.

4.1.6 Washington State Department of Transportation – North Central Region

The WSDOT North Central Region program manages the northern half of Washington State and covers US 2 and Hwy 20 as well as some secondary roads. US 2 over Stevens Pass has 5,000 to 13,000 vehicles per day and is the second choice for east-west commercial traffic in the state. The program manages 140 avalanche paths with variable return intervals. Economics are primarily tourism to ski areas (Stevens Pass) and eastern Washington towns like Leavenworth, Wenatchee and Chelan. Except for when 1-90 closes, traffic is generally local trucks. When 1-90 closes, interstate commercial traffic passes over Steven's Pass. Steven's Pass generally requires approximately 35 avalanche control missions per season, Highway 20 is a seasonal road that requires only early and late-season mitigation, and the Tumwater Canyon Road requires irregular efforts.

4.1.7 Wyoming Department of Transportation

The Wyoming Department of Transportation program monitors and forecasts avalanche conditions for four different highways that access the town of Jackson. There are two canyon roads, one mountain pass road, and highways adjacent to the town of Jackson. Traffic volumes vary between 5,000 and 12,000 vehicles per day. Jackson is largely a tourist-driven economy with a high volume of daily commuting traffic and traffic accessing the backcountry for recreation. There are approximately 70 avalanche paths that affect the highway corridors, ranging from small road cuts to large Size D5 paths. Teton Pass holds some of the largest of these paths in Wyoming, which the highway crosses.

4.1.8 Utah Department of Transportation

The Utah Department of Transportation has four main avalanche forecast zones spread across the state. Little Cottonwood, Big Cottonwood, and Provo Canyons operate full-time actively managed avalanche programs and see high traffic volumes that mostly access the ski resorts. This results in highly non-uniform traffic flow. The rest of the state falls under the "Statewide Avalanche Program," which includes any road that has a known avalanche hazard during the winter season. These areas usually have a lower frequency of avalanche impacts (greater than a five-year return period) and do not require a full-time level of effort to manage.

4.1.9 Alaska Department of Transportation and Public Facilities

The Alaska Department of Transportation and Public Facilities manages the highway network across Alaska, with active avalanche hazards impacting areas throughout the state. Traffic volumes vary for the remote low-volume roads to more critical highways from 100 to 6,000 vehicles per day. All corridors have high economic value and/or are critical access roads to communities.

4.1.10 British Columbia Ministry of Transportation and Infrastructure

The BC Ministry of Transportation and Infrastructure (BC MoTI) manages most highways across the province, which include highways through all major mountain ranges except for the BC segments of the Klondike Highway near the border of the Yukon Territory. The program manages all types of roadways, from remote gravel forest service roads with less than 50 WADT to high-volume critical corridors with more than 8,400 WADT. The agency includes eight individual avalanche programs that employ 35 total staff during winter months, more than 1400 potential paths, approximately 45 remote avalanche control systems, and radar detection systems in two separate zones. Avalanche paths vary from large alpine features in heavy snow zones to shorter roadside cut slopes that are often smooth with low threshold snow-depth values for avalanches to occur.

4.2 Objectives and Intended Audience

The main goal of deploying avalanche signage is managing and mitigating avalanche risk along highway corridors. However, various distinct objectives used by programs to achieve risk reduction have been identified.

A common primary objective is to inform the traveling public about potential avalanche hazards in specific areas along the highway corridor. This objective may be classified as a general “Avalanche Area” warning (Figure 4-1), which alerts or primes drivers to expect potential hazards posed by avalanches. These warning signs are typically deployed before avalanche areas and occasionally at the start of a road that traverses over a high mountain pass (e.g., “Steep Mountain Pass Ahead – Expect Dangerous Driving Conditions in Winter”). Two patterns in deployment strategies for warning signs were identified:

1. A general avalanche-area warning sign accompanied by the approximate distance that the warning is in effect (e.g., Avalanche Area Next 15 km).
2. A general avalanche-area warning sign with an accompanied end-of-avalanche-area sign that indicates when the avalanche area has terminated (e.g., Avalanche Area; End of Avalanche Area).

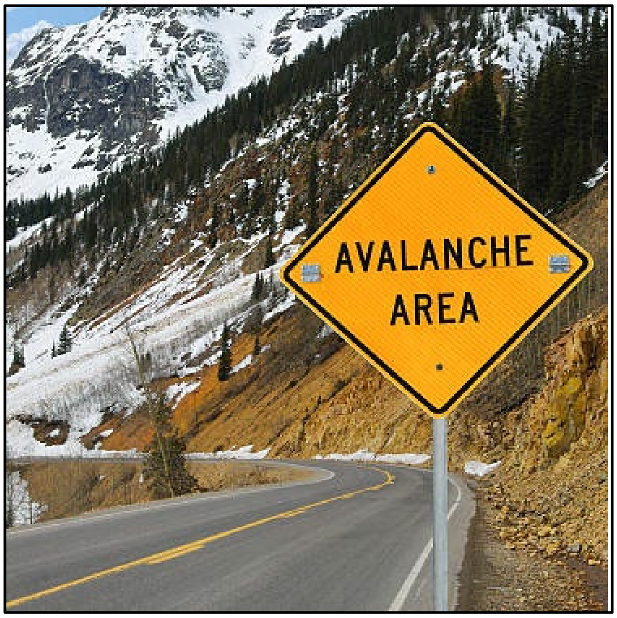

Figure 4-1: Example of a general avalanche-area warning sign intended to prime drivers to be alert for potential avalanche hazards along the roadway ahead.

Another identified common objective is to influence or guide driver behaviour with a more prescriptive regulatory message (e.g., No Stopping – Avalanche Area) (Figure 4-2). Guidance typically is designed to reduce exposure to the avalanche hazard by communicating that vehicles should not stop within the avalanche area. As with the general warning signage strategy, sometimes these signs are deployed with an associated distance (e.g., Avalanche Area Next 10 km – No Stopping), and sometimes they are deployed with an accompanying sign that indicates when the no- stopping recommendation has terminated (e.g., End of Avalanche Area). A key distinction with this type of prescriptive avalanche signage is that the message to drivers is an enforceable directive rather than an alert as with the general avalanche warning signs.

Figure 4-2: Example of a regulatory sign that indicates stopping is not permitted in the avalanche area.

Avalanche signage is often deployed with the objective of helping highway maintenance workers, contractors, and emergency responders identify avalanche areas that influence their safe work procedures. For example, emergency response crews generally must contact avalanche personnel prior to responding when a motor vehicle incident occurs within an avalanche area. Some programs have specific work restrictions (e.g., no working on foot, no stationary work) that apply to avalanche areas and depend on the avalanche-hazard forecast. Therefore, identifying the location of avalanche areas is critical for these risk-mitigation measures. Notably, while public awareness is a key objective, several respondents emphasized that the signs are particularly effective for trained staff and contractors who receive specific orientation on meaning and importance of signage.

Avalanche signage is also often deployed with the objective of communicating closures to traffic. These signs are typically electronic message boards or closure gates that are lowered when a closure is in effect. Closures are normally due to avalanche control operations; however, they may occur because of naturally released avalanches that impact the roadway.

Different approaches to warning versus regulatory (i.e., prohibitory) signage in avalanche areas may vary significantly among programs. Warning signage is mainly intended to inform the public about potential hazards, which primes drivers to anticipate hazards ahead without imposing strict prohibitions. In contrast, regulatory signage explicitly prohibits certain actions, such as stopping in dangerous zones, and aims to guide drivers' behaviour. The enforceability of these signs may be ambiguous. While some signage may carry a regulatory intent, its effectiveness often depends on public awareness, adherence, and the effectiveness of enforcement. That is, it appears rare that traffic enforcement officers enforce no stopping in avalanche areas regulations, and enforcement often falls upon avalanche personnel. This suggests that while some signage may have a regulatory intent, its primary function often tends to be warning and informing the public.

4.3 Design Standards

Survey responses and interviews showed that the regulation of avalanche signage by standards or policies varies considerably across the participating programs. Many general traffic standards, such as MUTCD, have sign design concepts that are applicable to avalanches (e.g., general colouring, shape); however, these types of documents generally do not explicitly address avalanche sign design. This led many of the participating agencies to develop their own avalanche signage design policies through collaboration with avalanche experts and road traffic engineers. Overall, there appears to be a lack of consistent, widespread standards specific to avalanche signage across the surveyed organizations, with many relying on general traffic sign guidelines or internally developed practices.

A few avalanche signage design patterns were identified from the comparative analysis:

- Typically, avalanche signage design is aligned with the primary objective of the avalanche personnel managing the highway avalanche risk. That is, avalanche experts first decide whether general warning (e.g., Avalanche Area) or more regulatory prescriptive signage (e.g., No Stopping) is most appropriate for their program. Then, sign design policies that govern the highway corridors are consulted for the general characteristics (e.g., colouring, shape) specific to the type of signage. Typically, warning signs are yellow diamonds with black writing, whereas regulatory signs are white squares / rectangles with black writing (Figure 1-1).
- Most programs use static signs with reflective materials to enhance visibility, especially during adverse weather conditions or at night.
- Some agencies employ unique colour coding or specific text to distinguish avalanche warnings from other road signs (Figure 4-3).
- The use of electronic message boards is widespread; however, these are mostly used to communicate information about highway closures and changing road conditions.
- Many programs have seasonal elements to the sign design that enable the avalanche messaging to be covered or changed to appropriate messaging for the summer season.
- Some programs recognize the need for signs to be comprehensible in multiple languages.

Figure 4-3: Examples of signs specifically developed by participating agencies to communicate areas of avalanche hazard.

4.4 Placement

Patterns emerged around the placement of avalanche signage relative to avalanche areas and the highway. The following patterns are described:

- Proximity to avalanche areas is the primary consideration. Signage is typically deployed before avalanche paths, with the default being at or just outside of the maximum known extent that avalanches impact the roadway. Signs are also commonly placed after the avalanche paths or avalanche areas, communicating when the hazard area has terminated.
- Visibility by drivers is also a critical factor for signage placement. Road traffic engineers and/or traffic signage policy documents are often consulted to account for driver visibility. Traffic characteristics, including speed and volume, are also considered to ensure drivers have sufficient time to react to the information. Local features, such as road grade, curve, and sight lines, impact placement decisions.
- Traffic management is a key factor influencing sign placement. Breaks in avalanche areas are often specifically signed with the intention that traffic can turn around, pond, or safely park. Programs often consider the likelihood of public stopping in a specific avalanche area when determining sign locations, aiming to discourage behaviour. For example, the Milford Road program intentionally places “No Stopping – Avalanche Area” signs in places that make it difficult to drive around or park. Many programs often specifically plow or do not plow areas to influence where traffic will park.
- Threshold return periods of avalanches that reach highway corridors for when paths are signed are listed in the comparative matrix for each agency and show that generally any path with a return period of 30 years or less is signed. The decision to sign paths with higher return periods may be influenced by past incidents, proximity to other paths, and traffic volume and flow.

4.5 Importance and Effectiveness

The survey responses showed an average rating of 4.0 out of 5.0 for how *important* avalanche signage is to given avalanche risk-management programs (note, 1 being not important; 5 being very important). Whereas the survey showed an average of 2.9 out of 5 for how *effective* program signage is for reducing avalanche risk (note, 1 being not effective; 5 being very effective).

This indicates that while avalanche signage is considered important for avalanche risk-management operations, there is room for improvement in its ability to reduce risk and enhance public safety. This discrepancy between importance and effectiveness might indicate a need for improvements in signage strategies or public education about avalanche risks.

The primary challenges for avalanche signage reported by various organizations include:

- **Public attention and adherence** – Many respondents noted that the public often does not read or pay attention to the signs.
- **Sign fatigue** – Several programs mentioned that the abundance of signs along roadways may lead to "sign fatigue" where drivers become desensitized to warning signs.
- **Visibility issues** – Some organizations reported challenges in maintaining sign visibility during adverse weather conditions such as heavy snowfall or fog.
- **Consistency** – There is a lack of consistency in signage deployment and design across different programs and regions.
- **Language barriers** – Some respondents mentioned the challenge of communicating effectively in areas with multiple languages used by drivers.
- **Budget limitations** – Financial constraints were cited as a challenge in implementing and maintaining effective signage systems.
- **Placement difficulties** – Challenges were mentioned in how to determine optimal sign locations, especially in areas with multiple overlapping hazards or limited safe stopping zones.
- **Balancing the amount of information** – Some respondents struggled with providing enough information without overwhelming drivers.
- **Regulatory issues** – In some cases, there were challenges related to the lack of clear policies or standards governing avalanche signage.
- **Effectiveness in changing behaviour** – Several organizations noted that while signs may inform, they do not always effectively change driver behaviour in avalanche-prone areas.

These challenges highlight the complex nature of using signage as a tool for avalanche-risk communication and management across different geographic and organizational contexts.

4.6 Do the Current Avalanche Signage Systems Work?

The only readily available measure for the effectiveness of avalanche signage as an avalanche-risk reduction measure is the subjective assessment from the key personnel of the participating agencies, which averaged 2.9 out of 5 (5 being most effective). Objective assessment of the effectiveness of an agency's avalanche signage is not currently available within the scope of this study. However, avalanche signage should be deployed as part of the holistic avalanche risk- management strategy developed for the road corridor. That is, the effectiveness of avalanche signage increases when used alongside a formal avalanche risk assessment and incorporated into the active avalanche risk-management program. For example, avalanche signage is more effective for workers and contractors when they have been trained to identify the signs and what the appropriate actions are relative to each sign.

5 Gap Analysis

A gap analysis was performed on the survey and interview data that focused on the considerations for road hazard signage effectiveness uncovered during the literature review. The scope and objectives for the analysis were informed by the problem statement while the current state is summarized in the comparative analysis. The desired future state assumed for the gap analysis is to maximize effectiveness of avalanche hazard signage systems and minimize driver confusion, non-compliance, and potential legal liabilities for transportation authorities. By framing the analysis with these parameters, several gaps were identified in the current signage systems utilized by the participating agencies. These include:

- **Lack of consistent approach** – Although both the MUTCD and Vienna Convention differentiate between warning signs and regulatory signs used for road hazard signage, there was general lack of consistent approach found within an agency as to when to use each of these sign types.
- **Lack of design and placement standardization** – Although sign shape and colour need to align with the MUTCD and Vienna Convention specifications, standards for avalanche-specific wording and symbology were found to differ at a jurisdictional level. Furthermore, design standards at a national level did not always align, and consistent standards for sign placement were found to be lacking even within agencies on a program level.
- **Inconsistent enforcement of regulatory signs** – Although regulatory signs are enforceable, by definition, jurisdictional challenges were found to lead to inconsistent enforcement.
- **Lack of clear messaging** – In some cases, a lack of clear messaging was also found to be a gap. This includes poorly defined or incorrect avalanche area limits, and unclear actions drivers are expected to take (e.g., caused by maintained pullouts within no stopping areas).
- **Lack of detailed records** – Although participating programs kept detailed avalanche path data and occurrence records, there was a general lack of detailed signage data (e.g., sign locations,

installation dates, sign condition, maintenance history, and compliance with applicable standards).

An action plan for addressing these gaps is provided as recommendations for best practice in Section 7 of this report.

6 Innovations and Advancements

There are technological innovations and advancements in road hazard warning signage that are centered around in-vehicle displays and self-driving vehicles. Both rely on a comprehensive and detailed database of road hazard signage as well as signs that may be effectively detected by advanced driver- assistance systems. Advancements in in-vehicle displays include dynamic interactive warning signs where drivers may seek further clarification or instructions, enhancing user engagement and understanding. Particularly for self-driving vehicles, the clarity and condition of signs may directly impact driver safety with poorly maintained road features potentially causing unsafe maneuvers.

There are also innovations and advancements that focus on integration of road hazard warning signage with dynamic messaging on variable-message signs and road-advisory services (e.g., 511, DriveBC). This could include information about upcoming closures and variable speed limits; however, effectiveness of both technologies revolves around timely messaging and automatic updates.

7 Recommendations for Best Practices

Given the variety of operational contexts under which signage is used for avalanche risk mitigation along transportation infrastructure, and the differences in regulations that transportation agencies operate under, it is impractical to propose prescriptive standards for the use of avalanche signage along transportation corridors. However, by adopting a common framework for establishing policies, specifications, standards, and guidelines (henceforth referred to as a signage manual) for avalanche signage at an agency level that are aligned with evidence-based best practices, a measure of consistency and standardization between jurisdictions can be achieved.

Avalanche signage often serves as one layer of a comprehensive system of avalanche risk mitigation. As such, the use of signage should be based on accurate risk assessments that clearly define avalanche path boundaries. To maximize its effective risk reduction, avalanche signage should adhere to ergonomic design principles (i.e., conspicuity, legibility, comprehension, and compliance) and leverage the psychological benefits of repetitive and semantic priming.

7.1 Threshold Values for Avalanche Signage

Consistent signage practices are critical to comprehension and compliance. The decision regarding which avalanche areas and paths should be indicated with signage depends on the context of operational risk management, including geographic scale, traffic patterns, road user types, and economic considerations. However, consistency at the jurisdictional level is crucial for managing liability for transportation authorities by fulfilling their duty of care and demonstrating a proactive approach to avalanche risk management. Transportation agencies should establish minimum thresholds in terms of return frequency, magnitude, or Avalanche Hazard Index (AHI) values to determine which avalanche areas or paths are signed, ensuring consistency across the jurisdiction. Different thresholds may be assigned to different types of signage. These thresholds should serve as a minimum requirement for signage to allow for a more conservative approach in areas of higher exposure or vulnerability (e.g., a scenic lookout where people commonly stop and exit their vehicles). These thresholds should balance the potential risk reduction against the installation and maintenance cost of signage.

7.2 Signage Placement Criteria and Considerations

Avalanche areas that meet threshold guidelines should always be indicated with an avalanche warning sign. Warning signs reduce the vulnerability of drivers to avalanche hazards by alerting them to the potential of encountering unexpected driving conditions, such as debris on the road or sudden visibility loss due to a powder cloud. Warning signs also serve a semantic priming function by preparing drivers to recognize, interpret, and comply with any regulatory signage that may follow.

Regulatory signs (e.g., No Stopping) may be implemented within an avalanche area to limit the potential exposure of drivers to avalanche paths. Regulatory signs should always be mirrored by a corresponding sign that indicates the end of the restriction (e.g., “No Stopping – Avalanche Area” signs should be followed by an "End of Avalanche Area" sign) to clearly communicate where the restriction concludes. Regulatory signs may bracket individual avalanche paths or a group of paths in close proximity. In determining where to place regulatory signs, it is important to balance the benefit that repeated signs support repetitive priming against the cognitive workload; too many signs may tune out drivers and reduce compliance. Road closure signs are a subcategory of regulatory signs; however, their placement should also consider traffic management factors.

Sign placement should be determined in consultation with traffic engineers to ensure effectiveness and compliance with regulatory standards. Several critical factors must be systematically evaluated to optimize safety and functionality. Visibility is paramount; signs must remain unobstructed and conspicuous under various weather, lighting, and road conditions. Placement should allow sufficient distance for drivers to react, ensuring safe decision-making and compliance with the sign’s directive. Road geometry is a key consideration, requiring signs to be positioned at points with clear sightlines and away from curves or blind spots. Traffic speed and volume also influence placement strategies, with high-speed corridors necessitating earlier warnings. Proximity to hazard zones, such as avalanche-prone areas or intersections, demands precise alignment to maximize effectiveness. Environmental factors, including snow accumulation and vegetation growth, must be addressed to maintain visibility across all seasons. Adherence to regulatory standards, such as those outlined in the MUTCD or Vienna Convention, ensures consistency and reinforces driver expectations.

7.3 Sign Design Criteria and Considerations

Avalanche sign design should follow ergonomic principles to enhance driver cognition and compliance. Signs should be consistent, easy to understand, and incorporate universal symbols to overcome language barriers, ensuring messages are effectively conveyed to drivers. Signs must be highly noticeable across various driving conditions and comply with standards like MUTCD or Vienna Convention. Sign dimensions should be related to traffic speed, and appropriate symbols, line widths, and contrasts should be used to make the signs clear and legible from a distance. Sign size is specified in the MUTCD; however, there are instances when larger than standard sizes should be used, including sight restriction and sign visibility. Signs should be reflective, and possibly lit, for visibility in low light. Additional measures, such as flashing beacons or flags, can further enhance sign effectiveness.

Nearly all MUTCD-influenced warning signs are diamond-shaped and yellow (Figure 7-1); some warning signs may be fluorescent yellow-green to draw extra attention. Warning signs influenced by the Vienna Convention are usually triangular (Figure 7-1) and often include an exclamation mark. Warning signs should include auxiliary text specifying the hazard (e.g., Avalanche Area Next 15 km) but avoid directing behaviour, which is reserved for regulatory signs.

Figure 7-1: Examples of avalanche/rockfall warning signs conforming to MUTCD (left) and Vienna Convention (right) standards.

Almost all prohibitory regulatory signs (e.g., No Stopping – Avalanche Area) use a red circle with a slash or cross as per the MUTCD and Vienna Convention (Figure 7-2). Some have a white background with black or red elements. Regulatory signs should feature auxiliary text and be paired with end-of-prohibition signs instead of distance indicators (e.g., "End of No Stopping Area" sign instead of "No Stopping Next 15 km"). Indicative sign designs should be used for these end-of-prohibition signs (Figure 7-3) and for signs that guide drivers to safe stopping or parking areas (Figure 7-4).

Figure 7-2: Examples of regulatory no parking (left) and no stopping (right) signs that conform to MUTCD (top) and Vienna Convention (bottom) standards.

Figure 7-3: Examples of “End of No Stopping” indicative signs that conform to Vienna Convention (left) and MUTCD (right) standards.

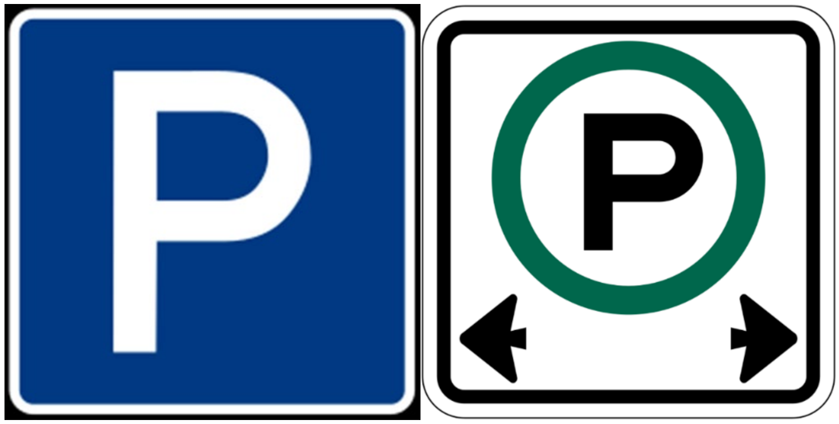

Figure 7-4: Examples of parking permitted indicative signs that conform to Vienna Convention (left) and MUTCD (right) standards.

7.4 Seasonal Avalanche Signage

Avalanche signage should be removed or covered outside of avalanche season to ensure warnings remain contextually appropriate, accurate, and credible. Seasonal use of avalanche signage highlights their importance during periods of actual avalanche hazard. Removing unnecessary signage also reduces visual clutter and cognitive load for drivers, helping critical signs stand out. Failure to remove or cover avalanche signage outside of the season may lead to conflicting messaging and confusion for drivers.

7.5 Variable-Message Signs

Variable-message sign systems are a crucial component of intelligent highway systems, providing real-time information to enhance public safety and traffic management. Multi-message illuminated signs, placed at the start of roads with avalanche-prone areas, enable the prompt dissemination of messages regarding avalanche control delays or highway closures. Since these systems are often managed by communication personnel without technical avalanche expertise, it is essential to develop clearly defined and standardized messaging. This ensures accurate and effective communication, reducing confusion and improving compliance among drivers.

7.6 Maintenance

Regular maintenance of avalanche signage is essential to ensure visibility and functionality throughout avalanche season. Annual inspections should be conducted to identify and address any damage, fading, or obstructions caused by snow, vegetation, or debris. Before winter, signs should undergo preparation to resolve issues like fading reflective surfaces or structural wear, ensuring they remain effective under harsh conditions. Snow accumulation around signs must be promptly cleared after storms to maintain visibility. Additionally, using durable, weather-resistant materials and reflective coatings ensures signage may withstand extreme winter weather and remain visible in low-light situations. Proactive management of environmental factors, such as trimming vegetation, further enhances the long-term effectiveness of avalanche signage.

7.7 Training and Awareness

Training and public education on avalanche hazard signage are essential for fostering awareness, understanding, and compliance. Transportation maintenance personnel should receive thorough training to ensure they are familiar with the placement, maintenance, and interpretation of signage. Public messaging should include clear and accessible materials and may take the form of brochures, videos, and online resources that explain the purpose and significance of avalanche hazard signage. Outreach efforts should focus on at-risk groups, including outdoor enthusiasts, snowmobilers, and backcountry skiers, leveraging community events, social media, and partnerships with local organizations to amplify the message. While enforcing regulatory signage is outside the purview of transportation authorities, engaging with and educating drivers who violate posted restrictions may improve compliance and enhance safety.

7.8 Record keeping

Transportation authorities should maintain records of each sign, including location, installation date, condition, maintenance history, and compliance with applicable standards, such as MUTCD guidelines. GIS-based systems add value by integrating geospatial data, enabling visual analysis of signage in relation to avalanche hazard paths and related datasets. Additionally, maintaining comprehensive records may streamline audits, inspections, and reporting processes while serving as a historical reference to evaluate signage performance and guide future improvements.

7.9 Signage Manual

Transportation authorities should develop an avalanche signage manual that outlines policies, specifications, standards, and guidelines for using signage as a risk treatment tool along transportation infrastructure. The manual should adopt a systems approach that integrates signage into a broader avalanche risk-management context and should include the following sections:

- **Operational context** – Provides an overview of traffic patterns, hazard frequencies, drivers, operational risk tolerance, and expectations for enforcing regulatory signs, establishing the context for avalanche signage use.
- **Sign inventory** – Describes the types of signs (e.g., warning, directive, prohibitive, informational) and their intended risk treatment, supported by a graphical sign index, size specifications, and standardized messaging for variable signage.
- **Placement criteria** – Details thresholds for determining sign locations based on avalanche risk assessments (e.g., AHI or magnitude-frequency estimates), visibility standards, and road features like curves, grades, sightlines, speeds, and traffic volumes.

- **Maintenance and inspection requirements** – Schedules and procedures for inspecting, maintaining, replacing, and decommissioning signage to ensure year-round visibility and functionality, with special considerations for non-avalanche seasons.
- **Record-keeping requirements** – Establishes protocols for documenting sign locations, types, conditions, and a system to track installations, replacements, and removals for operational transparency and planning.
- **Training** – Includes programs to train staff and contractors on signage use and maintenance and public awareness initiatives to educate drivers on the purpose and importance of avalanche signage.
- **Legal framework and enforcement** – Details on the regulations, policies, and legal jurisdictions pertaining to avalanche signage.

Many sections of the manual may cross-reference avalanche program or agency documents, such as an avalanche safety plan or MUTCD, to ensure consistency and integration within the overall risk-management framework.

8 Future Research Directions

Based on the findings from this study, the following directions for future research were identified:

- **Sign placement thresholds** – This report recommends setting standards for sign placement thresholds. Research at a jurisdictional level could focus on determining avalanche hazard or risk thresholds (e.g., AHI or frequency-magnitude) for identifying avalanche areas or paths where signage should be used and areas or paths where signage is not needed.
- **Statistical correlation** – Analysis of statistical correlations between signage characteristics (e.g., size, design, and placement) and the frequency of accidents in avalanche zones could help refine avalanche sign design and placement criteria.
- **Behavioural research** – Sign evaluation methods (e.g., comprehension tests, questionnaires, and comparative studies) could be used to assess the effectiveness of avalanche signs and guide improvements in design.
- **Performance validation** – Testing signage system effectiveness at the conspicuity, legibility, comprehension, and compliance stages to validate performance standards.
- **Driver education** – Development and delivery of driver awareness initiatives aimed at road avalanche hazards and associated messaging.
- **Intelligent transportation systems** – Research and development of avalanche signage integration systems for in-vehicle displays, self-driving cars, and dynamic messaging systems.

9 Closure

This document was prepared by Alpine Solutions Avalanche Services for the Transportation Research Avalanche Pool and the Colorado Department of Transportation. The material in it reflects Alpine Solutions' best judgment considering the information available to Alpine Solutions at the time of preparation. Any use that a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Alpine Solutions accepts no responsibility for damages, if any, suffered by any third party due to decisions made or actions based on this report.

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Alpine Solutions trusts the above currently satisfies your requirements. Should you have any questions or comments, please do not hesitate to contact us.

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Appendix A – Survey Responses

Respondent Information

Organization	Name	Position
Norges Vegvesen (NVV)	Jens Tveit	Geologist
Milford Road Alliance (MRA)	Graham Clarke	Asset Manager
Parks Canada (PC), Mt Revelstoke and Glacier National Parks	Andrew Jones	Avalanche Operations Officer (Avalanche Forecaster)
Colorado Department of Transportation (CDOT)	Brian Gorsage	Avalanche program manager
Washington State Department of Transportation (WSDOT) South	John Stimberis	Avalanche Program Supervisor
Alaska Department of Transportation and Public Facilities (AKDOT&PF)	Timothy Glassett	Program Manager
British Columbia Ministry of Transportation and Infrastructure (BC MoTI)	Paul Harwood	Senior Avalanche Officer
WSDOT North Central Region	Harlan Sheppard	Avalanche Supervisor
Wyoming Department of Transportation (WYDOT)	Don Lawless	Avalanche Supervisor
Utah Department of Transportation (UDOT)	Steven Clark	Avalanche Program Manager
California Department of Transportation (CalTrans)	Robert D. Bickor	Avalanche Control Superintendent

Program Context** – **This section aims to establish the operational context of your avalanche risk-management program.

- *Describe the nature and variation of avalanche risk across your program in terms of geographic scale, traffic volumes, program size, economic value of the corridor(s), and number or nature of key avalanche paths*:

  NVV – Various avalanche sites around the country. From high mountain roads to coastal areas and deep valleys. In some places the road is near the starting zone for avalanches, and in other places the starting zones are high in the mountain while the road is located at a lower elevation. Traffic volumes on avalanche-prone roads are mostly low (compared to highways in the U.S.), but often the road is the only road in the area, and communities may be isolated when the road is closed.

  Milford Road Alliance (MRA) – Primarily 17 km of highway at risk with approximately 50 paths, average daily traffic about 850 vpd but generally 200-400 during season with high per-cent buses. Up to size 5 avalanches. High value tourism and fishing industry route, up to 800,000 visitors per annum

PC – Ours is a complex program of 135 avalanche paths across a ~40-km section of transportation corridor. Avalanche paths very from low to extremely high hazard indices. The transportation corridor includes the TransCanada Highway and the CPKC rail line and is the principal corridor for travel and commerce in Canada. Our risk-management program is complicated by high traffic volumes, few safe stopping zones/ponding areas, and frequent avalanche cycles.

CDOT – The western half of Colorado's avalanches intersect interstate and state highways. 40,000 cars a day on I-70; 2,000 cars a day on Red Mountain Pass. Everything in between on all other routes. At least $1 million/hour in economic loss if the interstate is closed. 272 avalanche paths statewide receive regular mitigation l.

WSDOT South – Program covers the southern half of WA State, including I-90 Snoqualmie Pass, US-12 White Pass, SR410 Chinook Pass, and SR410/SR123 Cayuse Pass. I-90 and US-12 are open through the winter, while SR410 and SR123 are seasonal highways that close in the fall and reopen in late spring. I-90 has the highest traffic volume in the state, with an average daily traffic (ADT) of around 35,000 vehicles, including 10-12,000 trucks. About 35 avalanche paths potentially affect the highway, but around 12 affect the road yearly and require avalanche control or other methods of hazard and risk mitigation. Recent highway projects included adding snow nets and bridges to reduce the number of avalanche paths regularly affecting the highway. The economic value of I-90 runs into the millions of dollars as the highway provides the primary east-west transportation corridor connecting Puget Sound to the northern U.S. The highway also provides access to significant recreation centers, including the Summit at Snoqualmie Ski Areas. US-12 is a secondary highway with an ADT of around 3-5,000. It includes freight and recreation, including the White Pass Ski Area. Approximately 12 avalanche paths regularly affect the highway, though most are small and usually affect one travel lane. Numerous cut banks affect the road during particular weather events. In both instances, short-term closures are the preferred hazard mitigation technique. SR410 and SR123 present unique challenges due to elevation, weather, terrain, and regulatory issues. Both highways are recreational roads with a prohibition on commercial traffic. SR410 runs mid-track through over 100 avalanche paths, and the area receives more than 700 inches of snow annually. Thus, it is unreasonable to consider keeping the highway open through the winter. SR123 has 30-40 avalanche paths, significant snowfall, and, due to its location in Mt Rainier National Park, a variety of administratively restrictive policies that prevent operations through the winter. Both highways have avalanche safety programs to protect workers during spring clearing.

AKDOT&PF – Arctic to subarctic conditions. The spanned area of active avalanches areas is 1,110 miles apart. Traffic volumes from 100-6,000 vehicles per day, understaffed program size when compared to other programs accounting for AHI values. Every corridor has high economic value. This is due to there being only one roadway to access areas. There is no bypass road in most locations. The main oil pipeline from the north slope of Alaska runs parallel to two of the top three roadways for AHI risk.

BC MoTI – Scale is provincial and includes almost all major mountain ranges and significant snowpacks. All types of roads and highways from dirt roads with less than 50 WADT to a freeway with peak volumes of 13,000 vpd. Eight individual avalanche programs with 35 total staff during winter months. Economic value is hard to estimate, certainly on a provincial scale; however, closed roads can affect the economy throughout BC and isolated communities. 1,400 potential paths in 62 avalanche areas. 45 RACS by this winter and two radar detection systems. Key paths vary from large alpine in heavy snow zones to valley bottom short slopes with low threshold values. Total residual AHI is 880.

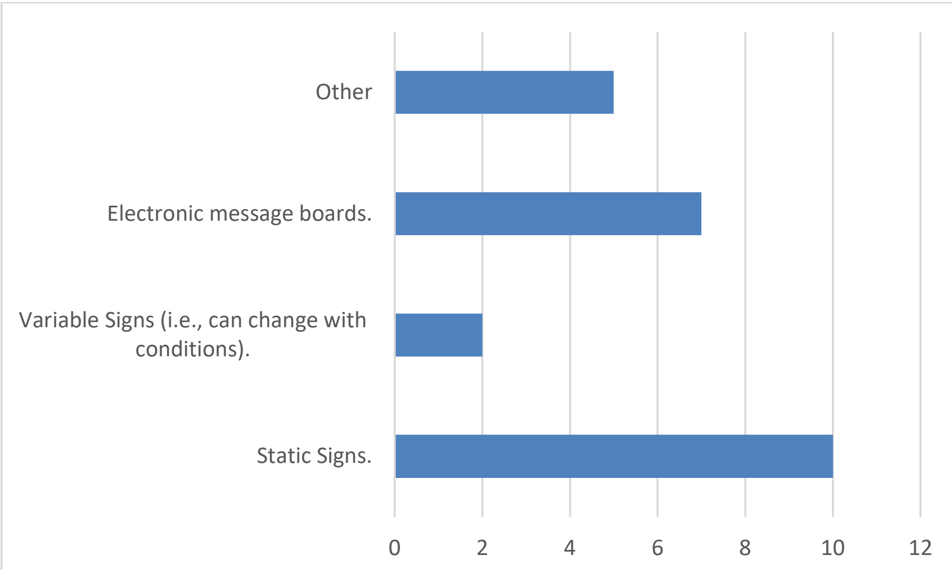
WSDOT North – NCR is basically the northern half of Washington State and covers US 2 and Hwy 20 as well as some secondary roads. US 2 over Stevens Pass has 5,000-13,000 vehicles per day and is the second choice for east-west commercial traffic in the state. In the region, we manage 140 avalanche paths with variable return intervals. Economics are primarily tourism to ski area (Stevens Pass) and eastern WA towns like Leavenworth, Wenatchee, and Chelan. Except for when 1-90 closes, we generally have local truck traffic. When 1-90 closes, we see interstate commercial traffic. During winter operations we average 35 risk treatments per season on Stevens Pass with an active control program. Tumwater Canyon to the east of the pass is a separate zone both in climate and mitigation which is primarily closures. It raises its head on a 1-3-year return interval and generally lasts for a couple of days to weeks. Hwy 20 is a seasonal road with early winter hazard and spring mitigation and risk. There is a hydro plant with limited traffic on the west side that is open all year.

WYDOT – The WYDOT program monitors and forecasts avalanche conditions for four different highways that access the town of Jackson, WY. There are two canyon roads, one mountain pass road, and highways adjacent to the town of Jackson, which have avalanche paths that terminate at the highway. The area is generally encompassed within a circle with a 15-mile radius. Traffic volumes will vary between these roads but are between 5,000 and 12,000 vehicles per day. WYDOT has two full-time avalanche staff with two additional temporary workers that are hired for the winter forecasting season. Jackson, WY, is largely a tourist-driven economy, and all four roadways in and out of Jackson can be affected by avalanche activity. Jackson depends on workers being able to travel from outside of Teton County to get to their jobs daily. There are approximately 70 avalanche paths that affect the highway corridors ranging from small road cuts to large D5 capable paths. Teton Pass holds some of the largest paths where the highway crosses those paths within their tracks.

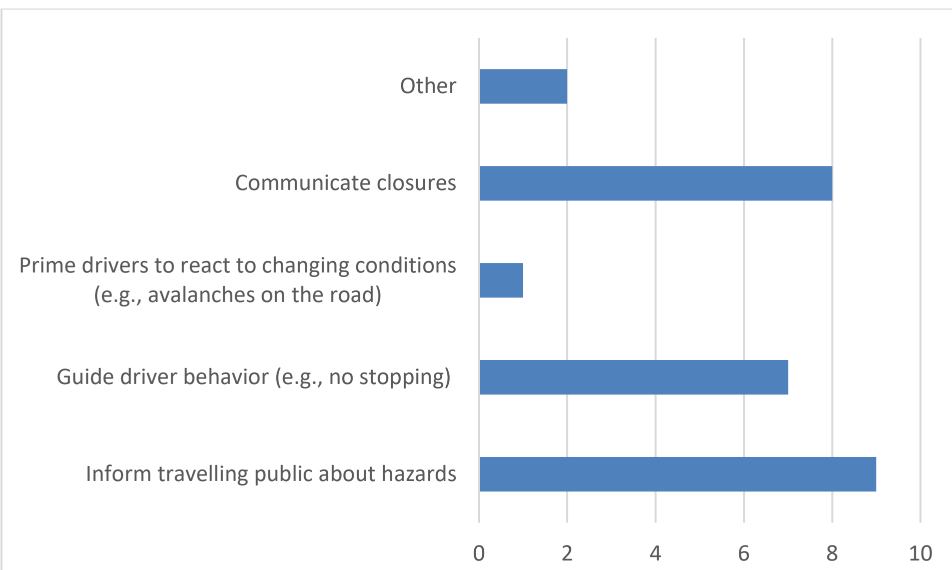
Utah Department of Transportation (UDOT) – The Utah Department of Transportation (UDOT) has four main avalanche forecast zones spread across the state. Little Cottonwood, Big Cottonwood, and Provo Canyons have forecast offices with regularly scheduled avalanche forecast teams. The rest of the state falls under the "Statewide Avalanche Program"; these include any road that has a known avalanche hazard during the winter season. These areas usually have a lower frequency of avalanche impacts (>5yrs).

California Department of Transportation (CALTRANS) – California has three active control programs on SR88, SR89, SR158, US50 and US395 and several other lower-frequency zones without active programs.

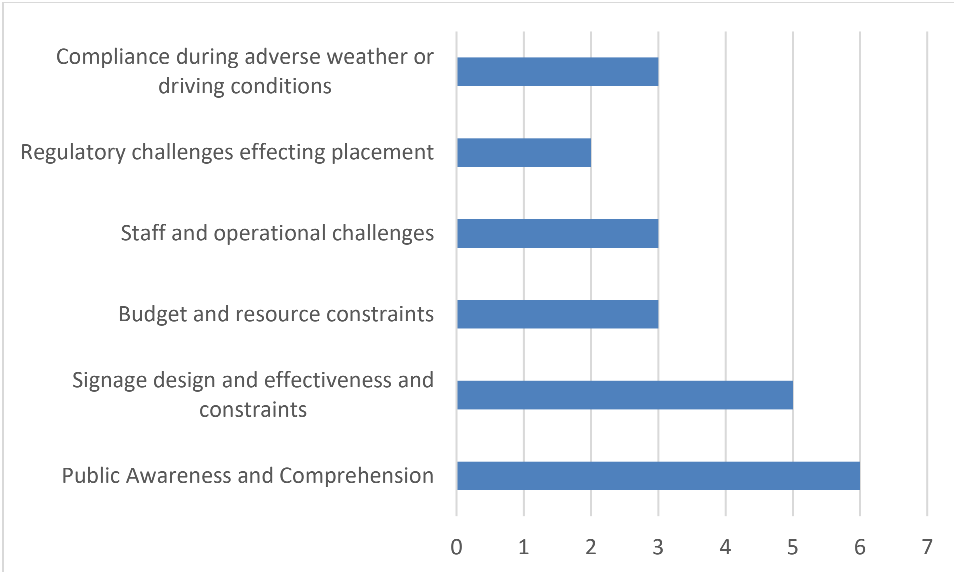
- *How are avalanche hazard areas communicated to the travelling public in your program? Multiple-choice (select all that apply):*



- *What are the primary goals of avalanche signage in your program?*



- *What challenges does your program face in using signage to reduce avalanche risk (e.g., public risk awareness, signage comprehension, budget limitations, etc.)?*



Signage Standards** – **This section explores the standards and policies governing avalanche signage in your program.

- *Is avalanche signage governed by any internal policy or standards documents (e.g. avalanche safety plan, supplementary guidance to Manual Uniform Traffic Control Devices (MUTCD), design specification, etc?*

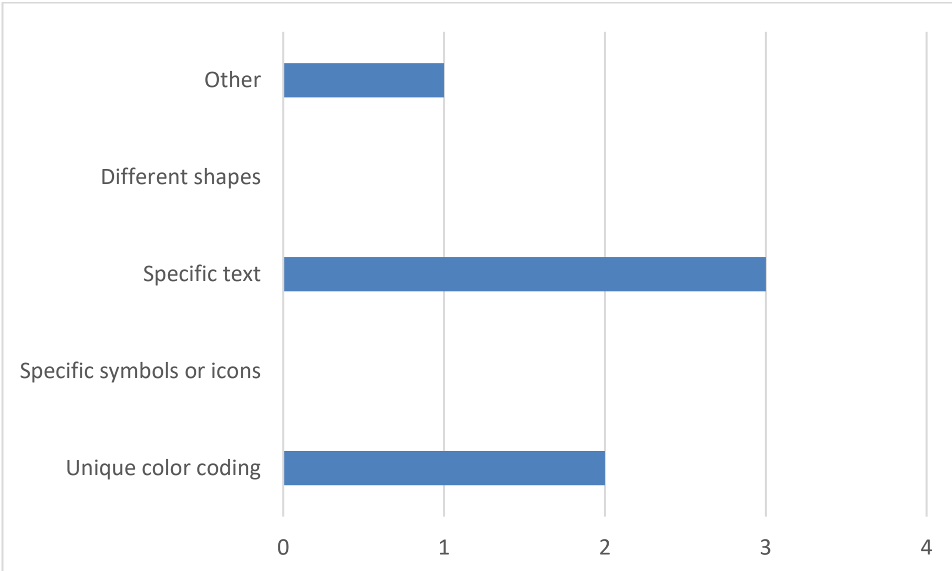
  Yes (3)
  No (3)
  Unknown (2)
  Other (3)

Signage Design** – **This section focuses on the design elements of avalanche signs used in your program.

- *Does your program use unique static signage designs to differentiate avalanche areas from other hazards (e.g., rockfall, winter driving conditions, etc.)?*

  Yes (6)
  No (5)

- *If yes: What are the specific design features that help distinguish avalanche hazard signs from other hazard signs?*



- *Does your program incorporate any reflective or illuminated elements in its avalanche signage to enhance visibility at night or during poor weather conditions?*

  Yes (8)
  No (3)

- *If yes, please describe these elements.*

  Reflective elements (8)

- *Does your program incorporate any dynamic elements (e.g., flip signs, flashing lights) in its avalanche signage?*

  Yes (6)
  No (5)

- *If yes, please describe these elements.*

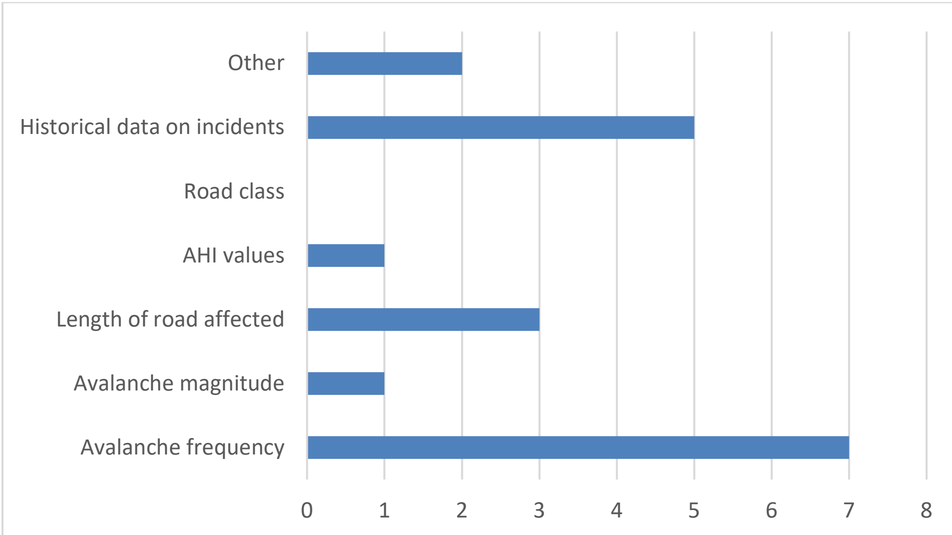
  Flip signs (3)
  Flashing lights (1)

Signage Placement** – **This section examines the criteria and considerations for placing avalanche signs.

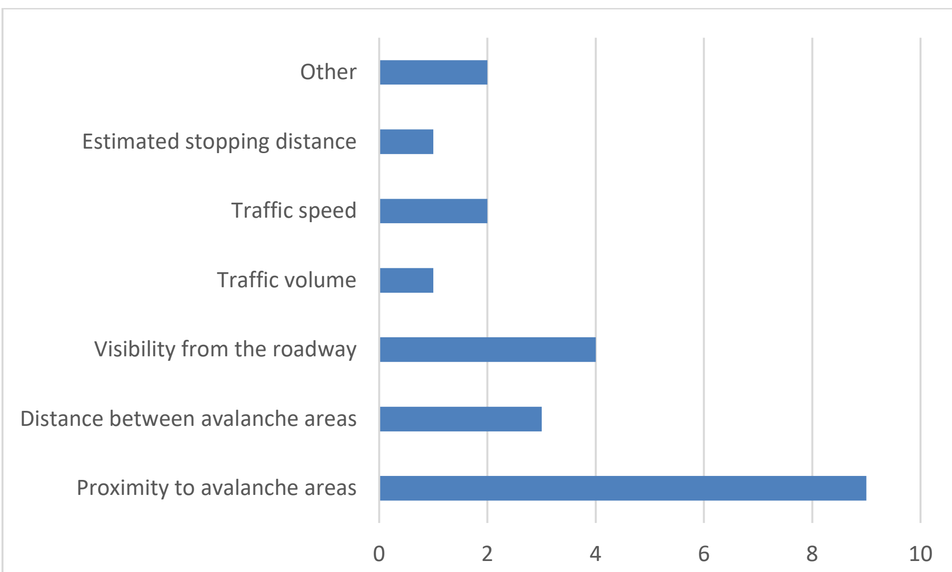
- *Are all avalanche hazard areas managed by your program marked with signage?*

  Yes (4)
  No (7)

- *If not, what criteria are used to identify avalanche areas that require signage?*



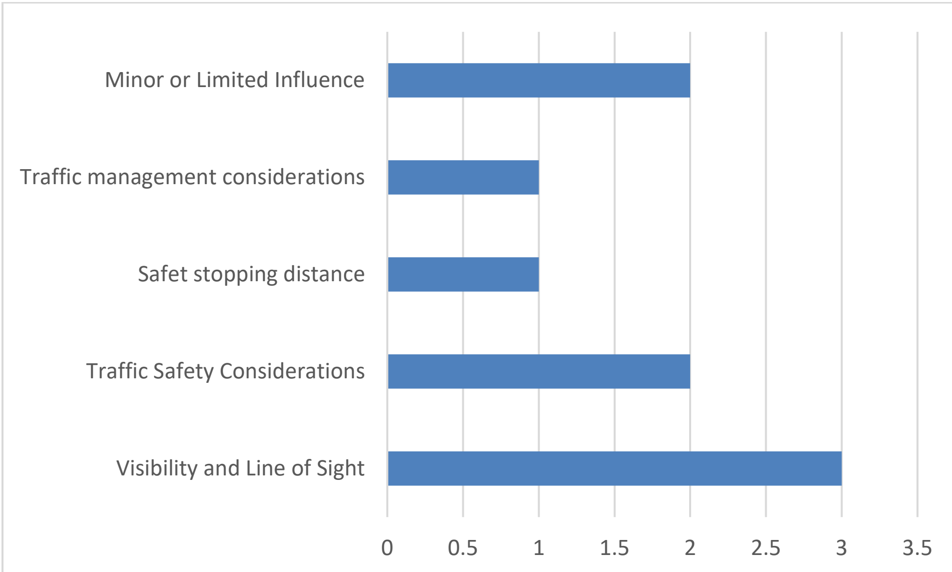
- *For areas where signage is required, what criteria are used to determine the location of signs in relation to an avalanche hazard area?*



- *Is avalanche signage placed before, within, or after avalanche hazard areas?*

Before (11)
Within (7)
After (7)
Other (0)

- *What role do local features (e.g., road grade, curves in the road that may limit the line of sight) play in determining the placement of avalanche signage?*



- *What role does ensuring signage visibility during adverse weather conditions (e.g., heavy snowfall, fog) play in determining the placement of avalanche signage?*

  None (11)

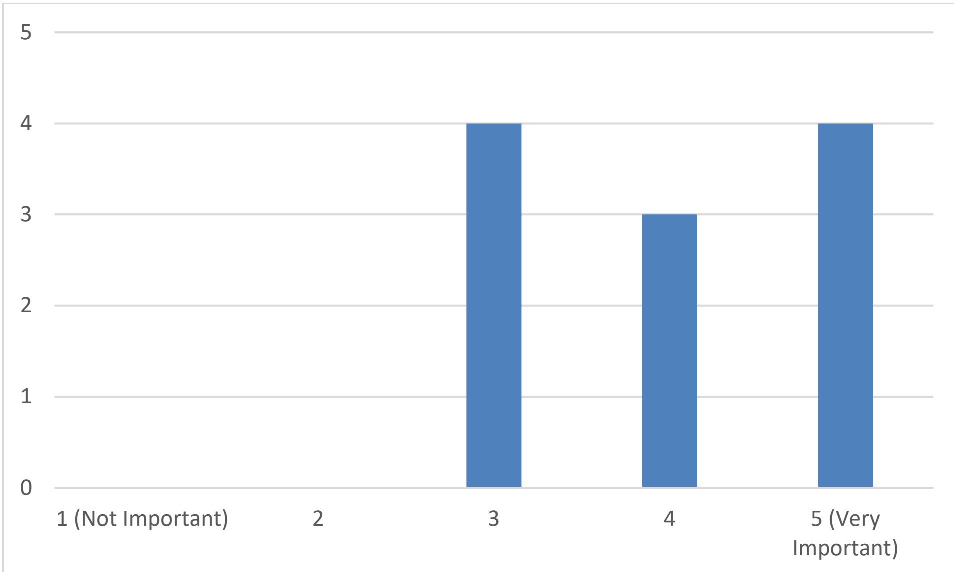
- *How does your program prioritize signage placement in areas with multiple overlapping hazards (e.g., avalanche, rockfall, winter driving conditions)?*

  Yes (4)
  No (7)

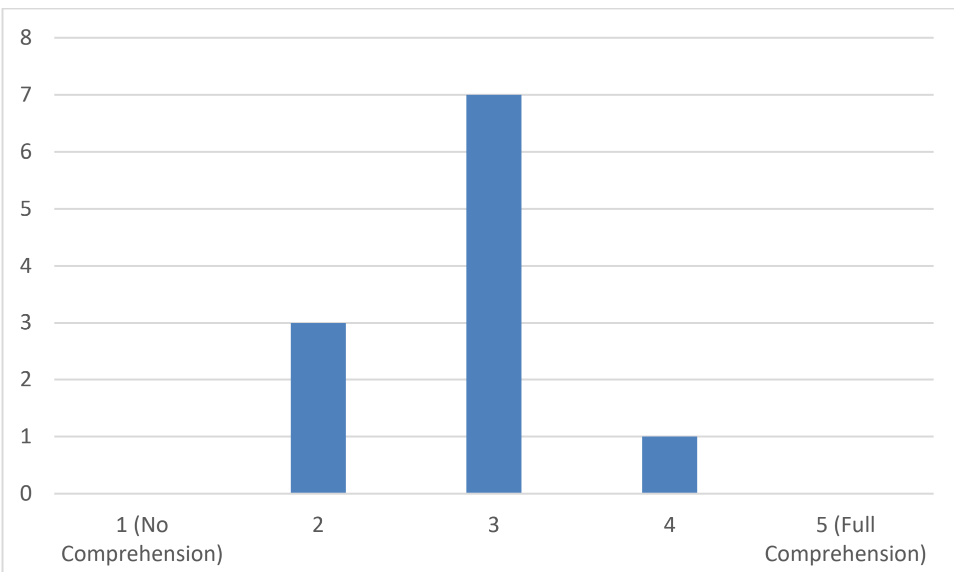
- *If yes, please describe the circumstances and process of relocation.*

Critical Review** – **This section seeks your evaluation of the effectiveness of avalanche signage.

- *How important would you rate avalanche signage to your avalanche risk-management program (1 = Not important, 5 = Very important)?*



- *Given the cultural and linguistic diversity of your road users, how well do you think the road users comprehend the signage (1 = No comprehension, 5 = Full Comprehension)?*



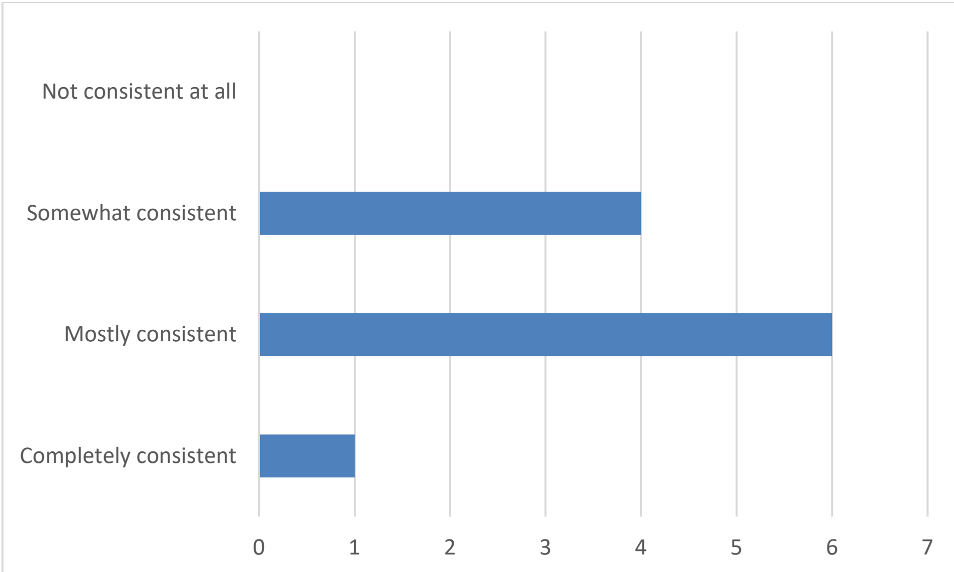
- *Have you conducted any studies or surveys to assess the effectiveness of your signage design in influencing driver behavior?*

Yes (1)
No (10)

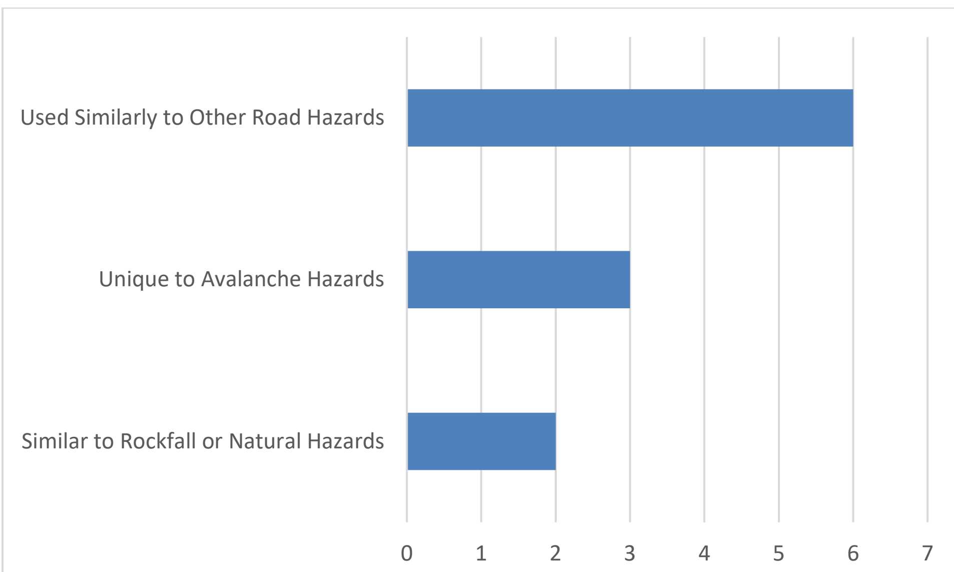
- *If yes, what were the key findings from these studies or surveys?*

  None

- *How consistent is the deployment of avalanche signage across your program?*



- *Is avalanche signage used in a similar way to other hazards (e.g., winter driving conditions, rockfall, wildlife)?*



- *Have you received any feedback from the travelling public regarding avalanche signage?*

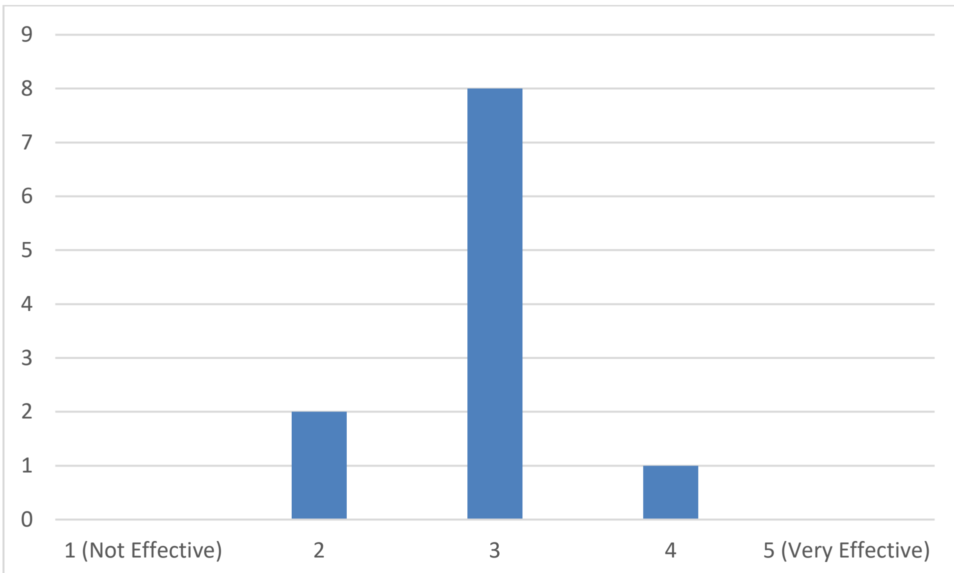
  Yes (3)
  No (6)

- *If yes, please summarize the feedback.*

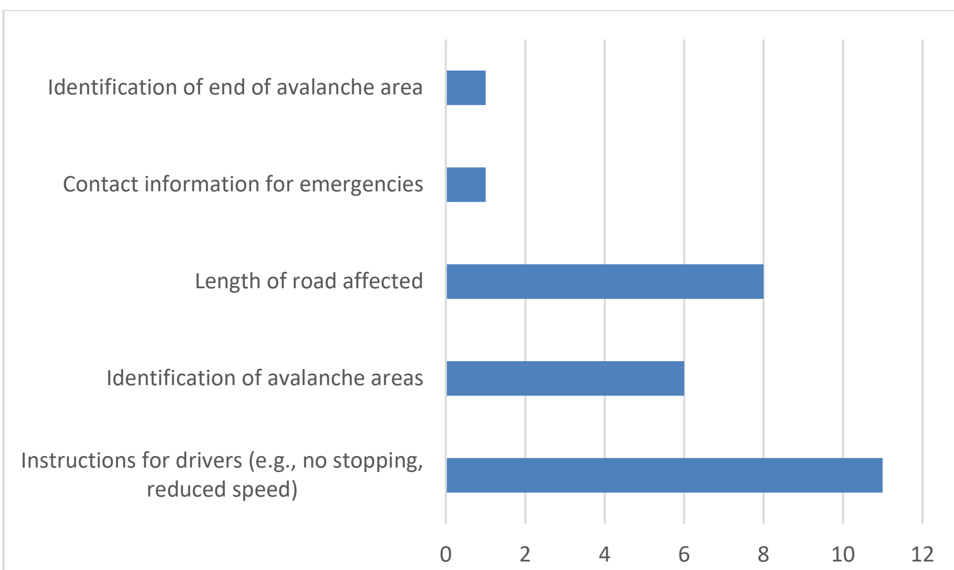
  MRA – Signs are perceived as routine and often ignored by users.

  BC MoTI – Signage is more effective for workers trained to interpret them, less so for general travelers.

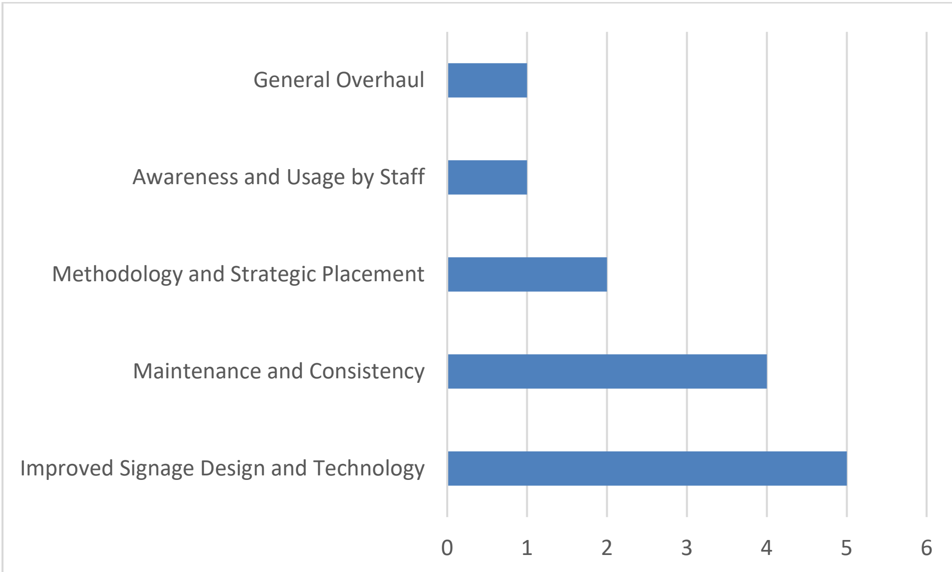
- *How effective is signage in terms of reducing risk and enhancing public safety (1 = Not effective, 5 = Very effective)?*



- *What specific information should be included on avalanche hazard signs?*



- *What improvements would you suggest for the current avalanche signage system in your program?*



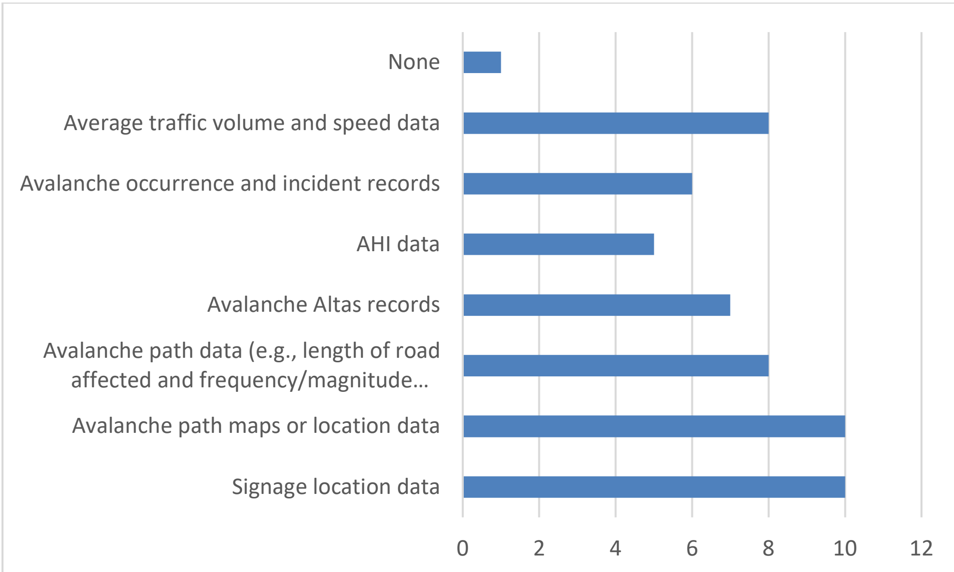
- *Please provide any other comments or information relevant to this study that may not have been captured in the previous questions.*

  BC MoTI – Signs are critical for passive mitigation, helping workers assess traffic in avalanche zones; however, the public generally pays little attention to highway signs, reducing their effectiveness.

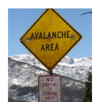
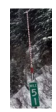
  AKDOT&PF – Suggestion to forward the information to traffic safety engineers for additional insights.

Data availability** – **This section seeks information on the data sets related to signage that your program is able to share.

- *Which of the following signage-related data sets would you be willing to share? Alpine Solutions will follow up later to coordinate the transfer of available datasets.*



Appendix B – Comparative Matrix

	Criteria	Vegesen	Milford Road Alliance	Parks Canada - Rogers Pass	CDOT	WSDOT - South	WSDOT - North	AKDOT	BCMoTI	WYDOT	UTDOT
Geographic Scale	Description	National Network	Single Corridor	Single Corridor	State / Province / Regional Network	State / Province / Regional Network	State / Province / Regional Network	State / Province / Regional Network	State / Province / Regional Network	State / Province / Regional Network	State / Province / Regional Network
	Number of Corridors	266	1	1	28	11	11	23	54	11	4
	Number of signs	1362	Unknown	62	Unknown	Unknown	Unknown	79	535	21	30
	Number of Avalanche Paths	1582	45	135	586	236	201	306	1545	80	96
Corridor Description	WADT (range)	40 to 10300	230	4220	50 to 13000	50 to 27000	50 to 4000	100 to 840	25 to 8450	3800 to 7000	50 to 5300
	WADT Descriptor	High	Low	High	High	High	High	Moderate	High	High	High
	Primary Road Users	Mixture	Tourist	Mixture	Mix	Mix	Mix	Mix	Mix	Mix	Mix
	Economic Importance	High	Moderate	Critical	High	Critical	High	High	High	Moderate	High
	Access Importance	All	Primary	Secondary	All	All	All	All	All	All	All
	Tolerance for corridor closures	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted	Multiple consequtive day closures accepted
Sign Description	Signange intent: Warning or Prohibitive	Warning	Both	Directive	Both	Warning	Warning	Directive	Directive	Both	Both
	Are the avalanche signs specific to snow avalanches or are they applicable to other hazards?	Other Geohazards	Avalanches Only	Avalanches Only	Avalanches Only	Avalanches Only	Avalanches Only	Avalanches Only	Avalanches Only	Avalanches Only	Avalanches Only
	Design standard?	Yes	Yes	Yes	Unknown	No	Yes	Yes	Yes	Yes	Yes
	Example image of signs - start of area / example 1						NA				
	Example image of signs - end of area / example 2	NA				NA	NA				
	Condition Dependent signs?	Message boards	Closure gates and message boards	Closure gates and message boards	Closure gates and message boards	Closure gates and message boards	None	Closure gates	Closure gates and message boards	Closure gates and message boards	Closure gates and message boards
	Do avalanche signs change for summer?	No	Message changes	Yes	Yes	No	NA	Yes	Yes	No	No

	Criteria	Vegesen	Milford Road Alliance	Parks Canada - Rogers Pass	CDOT	WSDOT - South	WSDOT - North	AKDOT	BCMoTI	WYDOT	UTDOT
Sign Placement	Are all avalanche paths signed?	No	No	Yes	Yes	No	No	No	Yes	No	No
	Are avalanche areas deliniated with start and finish signs?	No	Yes	Yes	No	No	No	Most	Yes	No	No
	Signs more important for worker or public risk mitigation?	Public	Public	Mixture	Mixture	Workforce	NA	Public	Mixture	Commutors	Public
	What criteria are used to determine the location of signs in relation to an avalanche hazard area?	Proximity to avalanche areas	Proximity to avalanche areas, Likelihood of public stopping for scenery	Visibility from the roadway, Proximity to avalanche areas	Ditance between avalanche areas, Visibility from roadway, Traffic volume, Traffic speed	Proximity to avalanche areas, Visibility from the roadway	Proximity to avalanche areas	Proximity to avalanche areas, Visibility from the roadway, Estimated stopping distance, Traffic speed	Proximity to avalanche areas, Distance between avalanche areas	Not Sure	Proximity to avalanche areas, Distance between avalanche areas
	Minimum return period for paths not to be signed (years)?	20	30 to 100	30 to 100	30 is the norm with exceptions for higher risk (exposure or vulnerability) roads	30 to 100	NA	Approximately 30 year	Approximately 30 year	Annual or more frequent are signed specifically, otherwise covered by warning signs next # miles.	Approximately 100 year
	How important is traffic flow, ponding, safe stopping areas, turn around areas for signage placement?	Moderate	Critical	High	Moderate	Moderate	NA	High	High	High	Critical
	How are safe stopping areas communicated?	Break	Specifically Signed	Break	Break	Other	Break	Break	Break	Break	Break
	Does or has AHI data (or other metric) influenced signage placement?	Yes	No	No	No	No	NA	No	No	No	No
	Where are signs placed in relation to avalanhce paths?	Before hazard area	40 years of data to show good spots for the signs, likely max extents	Outside maximum path extent	Usually at maximum path extents, no standard rule	Outside maximum path extent	Before hazard area	Signs placed at places with turnarounds, mostly for traffic flow and turning. Generally out of max path extent.	Close to path boundary. Operations and traffic management are very important.	Before the path ~100m. Sight lines important. No sign at end of path.	Mostly determined by safe parking and max extents.
	Multiple signs within an avalanche area?	Rare	Yes	No	Yes	No	NA	No	No	Yes	No

	Criteria	Vegesen	Milford Road Alliance	Parks Canada - Rogers Pass	CDOT	WSDOT - South	WSDOT - North	AKDOT	BCMoTI	WYDOT	UTDOT
Effectiveness	Effectiveness of signage for public avalanche risk mitigation?	2	4	3	2	4	2	3	3	3	3
	How important is avalanche signage to the avalanche risk management program?	3	3	5	3	3	4	5	5	4	4
	Are the signs enforeable?	No	Yes	Yes	Yes	No	NA	Yes	Yes	No	Yes
	Are the signs enforced?	No	Sometimes	Rarely	Yes	No	NA	Sometimes	Sometimes	No	Sometimes