I-90 SNOQUALMIE PASS: IMPROVED HIGHWAY SAFETY AND SUTAINABILITY

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ABSTRACT: Interstate 90 (I-90) in Washington State, USA, provides a critical east-west transportation route connecting the ports and people of Western WA with the northern tier of the United States. The highway encounters the Cascade Mountains approximately 55 kilometers east of Seattle, WA, eventually crossing Snoqualmie Pass (921 m) and descending into Central Washington. Average daily traffic (ADT) over Snoqualmie Pass averages 30,000 vehicles per day, reaching peaks of nearly 50,000, with a significant percentage as commercial traffic. The heavy reliance on I-90 for these modes of travel represents a sizeable economic impact when the highway closes, even temporarily.

Approximately 30 avalanche paths affect the highway around the Snoqualmie Pass area and historically resulted in numerous avalanche-related closures each winter, causing hundreds of hours of delays and related economic loss to highway travelers and regional businesses. To reduce these closures, the Washington State Department of Transportation (WSDOT) embarked on a multi-phase project to improve I-90 over the Snoqualmie Pass area starting in 2009.

Two previous papers documented the planning process and operational challenges related to constructing twin avalanche bridges and 1500 meters of snow fencing within active avalanche areas (Stimberis 2012 & 2016). In this final paper related to the highway project and avalanche protection, the author reviews the performance of the avalanche bridges over the seven operational winters following the completion of construction. Most notable is the elimination of over 100 avalanche closures during this period, resulting in improved highway safety, reduced economic impact, and decreased emissions from idling vehicles.

KEYWORDS: avalanche control, highways, avalanche forecasting, avalanche defense, sustainability

1. INTRODUCTION

In the Pacific Northwest region of the United States, the Cascade Mountains present a barrier to travel, with only a few dedicated transportation corridors connecting the urban coastal areas annually. The winter environment defines the characteristics of a maritime snow climate with heavy snowfall and frequent rain-on-snow events. These weather conditions and the steep mountainous topography combine to form nearly 30 avalanche paths affecting the I-90 transportation corridor. The East Shed area is the most active and impactful to the highway.

The Washington State Department of Transportation (WSDOT) maintains and operates I-90 over Snoqualmie Pass, with full winter operations beginning in the 1930s. The WSDOT recognized the significance of the East Shed avalanche paths from the beginning, and winter operations began with a wooden snow shed to protect the highway through the most active of the East Shed paths, East Shed 3 and East Shed 4.

Highway engineers designed an improved snow shed during the 1940s, and the completed concrete shed opened in 1950. A decade later, in the 1960s, the traffic volume on I-90 required more capacity, and the two-lane highway expanded to four lanes, though the two-lane snow shed remained unchanged. From here, the snow shed protected the westbound lanes, while the eastbound lanes became exposed to the avalanche hazard.

Traffic volume and demand shifted during the late 1960s as more vehicles crossed the pass. The traffic volume increased, and use patterns expanded with increased nighttime use and travel during inclement weather. Although specific avalanche records do not exist from that time, Williams (1975) provides accounts of increased accidents and a fatality in 1971.

These factors led to the WSDOT creating an avalanche forecast and control program in 1973 to reduce the avalanche risk on the highway. Over the next 43 years, the WSDOT South Central Region Avalanche Program refined its forecasting skills and avalanche control techniques. Still, as their skills improved to address the avalanche hazard and reduce the overall risk, the traffic volume increased to

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offset these gains. The increased traffic volume also compounded the frequent avalanche control delays, causing further maintenance and operational issues. In the early 2000s, the WSDOT began scoping and design work for an expanded highway that included many environmental improvements and, most significantly, a plan to eliminate the avalanche closures in the East Shed and Slide Curve areas. The original proposal proposed constructing a significantly larger snowshed to cover the new six-lane highway. However, an alternate design proposed by the project's primary contractor eventually gained approval by the WSDOT. The new design called for constructing twin bridges to elevate the highway above the avalanche hazard and avoid some added costs associated with operating a large snowshed.

Construction on the I-90 Hyak East project began in 2009 and moved east through the three-phase, 6-mile project over the following years. The WSDOT limited the active construction season to approximately six months to avoid significant traffic and safety impacts during the winter operation period.

The 2014-2016 period put primary construction activity in the East Shed and zone, including removing the East Snow Shed. Winter weather may show significant variability from year to year, and the two-year construction period around the East Shed was no exception. The 2014-2015 winter produced

the lowest snowfall on record for Snoqualmie Pass, while the 2015-2016 winter started with the most snow recorded for December.

Removing the snow shed changed little for avalanche operations; the highway remained exposed to the hazard, though the primary exposure was now in the westbound rather than eastbound lanes. On March 15, 2016, the WSDOT SCR Avalanche Crew performed the final avalanche control mission for the East Shed area. The following winter traffic saw traffic routed onto the first of two bridges and fundamentally removed from any significant avalanche threat. The following sections review the previous efforts to forecast and mitigate the avalanche hazard in this area and examine the behavior of these avalanche paths in the absence of intentional avalanche release using explosives. The review provides a rare opportunity to explore a radical change in an avalanche area.

2. METHODS

Throughout the era of active avalanche forecasting and control in the East Shed Area, the WSDOT SCR Avalanche Program evolved its methodology for predicting and intentionally triggering avalanches. In addition, access to the start zones improved significantly due to improved snowcat technology. Over time, the program installed on-site explosives storage, simple trams to deliver the explosives to the start zones, and various telemetered weather instruments to aid avalanche forecasting.

Eventually, the avalanche program landed on and refined a snow-water equivalency (SWE) methodology as a threshold for avalanche control. These improvements led to better accuracy and fewer naturally occurring avalanches. However, the predictive nature of avalanche forecasting does not guarantee complete accuracy; thus, some small and unexpected avalanches occasionally affect the highway. ADT continued to increase throughout this period, contributing to a gradual risk increase.

2.1 *Avalanche missions and forecasting*

As with any avalanche forecasting and control program, the SCR Avalanche Program evolved and refined its techniques. Rather than provide an extensive programmatic review, this paper looks at the seven years leading up to the construction of the bridges to determine a few key metrics (Review Period A). Applying these metrics to the seven years after the construction of the avalanche bridges provides an estimate of the prevented avalanche closures (Review Period N).

Review Period A encompasses seven winter seasons, beginning in November 2009 and extending through the final avalanche control mission in March 2016. All meteorological data arrives from the WSDOT Snow Study Plot on Snoqualmie Pass (47.425N -121.414, 919m). Snow and weather observations contain both manual and automated data.

During Review Period A, 105 avalanche control missions occurred on the East Shed 3 & 4 paths, with a mean of 15 control missions per year. Avalanche control missions ranged from a minimum of 0 in 2014-2015 to a maximum of 38 over the 2011-2012 winter. In addition, nine natural avalanches reached the highway or edge of the road during this period. The median number of natural avalanches for East Shed 3 and East Shed 4 were 0 and 1, respectively, over Review Period A.

The first avalanche control mission for the season ranged from November 19 to as late as February 10, with an average first date of December 14, while the average last date from avalanche control averaged March 10. During this review period, April 6 was the latest date for avalanche control on the East Shed paths. The average length of the avalanche season from start to finish came in at just over 85 days. The snow height for the first avalanche control mission of the season averaged 112cm. Snowfall (HN24) and height of snow (HS) at the East Shed start zones closely follow the WSDOT Snow Study plot; the elevation difference is offset by the proximity to the Cascade Crest, with a general decrease east of the summit area.

During the 1990s, the SCR Avalanche Forecasting program adopted a metric of 19mm SWE as an avalanche control target. The consensus was that this threshold marked the critical mass of snow that might reach the highway. The threshold did not present as a forecasting tool specifically, as individual events vary greatly based on various snow and weather factors. However, an analysis of control missions during the review period shows the threshold to have value.

For the seven-year avalanche control period, the median precipitation received in the critical pre-avalanche control period came in at

18.5mm, with the mean at 22.9mm (n=94). The critical pre-control period is usually from the onset of the most recent storm, though there may be little overall break between individual events in a maritime environment. Nonetheless, a noticeable decrease in precipitation intensity or wind shift usually marks the end of one system and the beginning of the next. Here, the review revealed a median lead-in period of 18.5 hours. However, as little as a six-hour gap occurred between control events on the low side. Extended gaps also exist between events, and a maximum of 1345 hours between events on the more extreme, likely following a significant rain-on-snow event. As approximated by HN24 values, snowfall for these events falls in line with expected snow- to-water ratios typical of maritime environments with a median of 25.4cm (n=105). Again, the range of values for HN24 maintains a significant spread with 0cm on the low end and 71cm on the upper.

2.2 <u>Bridges</u>

The WSDOT diverted highway traffic onto the first of two bridges in the East Shed area starting with the 2016-2017 season, marking the first time the primary avalanche hazard did not affect highway traffic. Using the bridges also meant the end of avalanche control in the East Shed area and the unique opportunity to observe and document natural avalanche activity on these paths. The WSDOT SCR Avalanche Forecasting and Control program tried to predict avalanche control needs and results through the season, but the results are speculative. Forecasting the initial avalanche control effort for the season is achievable, but predicting additional needs based on subsequent imagined results is quite another task. The author attempted this exercise for a few seasons, and the results tended to mirror previous avalanche control efforts. Over three years, the imagined avalanche control results had a mean average of 22.5mm SWE and 24cm snowfall before the expected event (n=69). These figures also displayed a range of variations based on local weather and snowpack development.

Natural activity in the East Shed area displayed some variation from the previously controlled environment. Notably, the average first date for avalanche occurrence advanced to January 10, while the average last observed natural activity regressed to February 15.

Here, we see the avalanche season reduced from a mean of 85.3 days during the 2009-2016 period to a mean of 36 days during the 2016-2023 period, a reduction of 49 days.

Forty-three natural avalanches occurred during this period, with a median of 5 per season, or approximately one-third of the average avalanche control mission count per season from the previous review period.

3. DISCUSSION

Avalanche forecasting and control programs show considerable variation in the demand to reduce avalanche risk to transportation routes. High-demand transportation routes with active avalanche paths face a significant challenge: maintaining a reliable transportation network while providing a safe travel route. When faced with these situations, the operational risk band narrows, with more frequent avalanche control resulting in a reduced likelihood and destructive size of natural avalanches. In some transportation settings, even the smallest avalanche onto the travel lanes can significantly impact those with high ADTs and critical functions.

Avalanche control events disrupt traffic, with the more frequent events resulting in shorter delays, while those associated with extreme snowfalls or significant avalanche results produce the most prolonged closures. This study did not explore the overall effects of avalanche control on traffic delays, though Ivanov (2009) provides a more in-depth exploration of an extended closure during the 2008-2009 winter. Additionally, an unpublished paper examines the impacts of weather- related traffic delays on Snoqualmie Pass (Stimberis, 2022). Here, the author found that the mean 90-minute traffic delay affected up to 900 vehicles and resulted in a traffic queue of 2km. The WSDOT assigned a delay range of 30 minutes to 2 hours for the typical avalanche control closure at the East Shed. However, many factors contribute to longer delays due to weather, traffic volumes, and vehicle collisions.

Avalanche activity from the East Shed paths significantly impacted the interstate, resulting in thousands of hours of delays to traffic, accidents, and at least one fatality over the life of the snow sheds. The economic and environmental impacts are immeasurable, though quite significant. The long-term benefits from this project serve both highway users and the professional avalanche community. It is a rare opportunity to observe the behavior of a once high-demand avalanche control location.

4. CONCLUSION

Avalanche control at the East Shed area averaged 15 missions per year. In contrast, natural avalanche activity in the post- avalanche control years averaged around five events per season from the two primary paths, East Shed 3 and 4. Attempts to theorize the number of possible avalanche control events during these years resulted in significant discrepancies between possible scheduled events and actual natural events. During the 2022-2023 season, approximately 25 or more control events may have occurred versus the single observed natural event.

Removing traffic from the primary avalanche hazard by replacing the snow shed with two bridges marked a significant milestone in improved transportation network reliability on I-90 Snoqualmie Pass. The primary impetus for this project was to improve safety and economic reliability in the project area.

Additional benefits from the overall highway project included environmental improvements for waterways and wildlife. A somewhat overlooked but significant environmental benefit arises from eliminating the numerous traffic delays from avalanche control missions. Avalanche control delays and closures, particularly on the order of several hours, result in thousands of idling vehicles emitting noxious emissions. Eliminating these closures reduces the likelihood of this source of emissions. These two benefits, economic and environmental, support the ideals of sustainable transportation. The third leg of sustainability, equity, is also realized due to the reduced need for a detour to bypass the Snoqualmie Pass closure.

The standard detour for a Snoqualmie Pass closure involves a 605km reroute, increasing time and fuel costs, plus additional environmental emissions. The added costs incur equity-based impacts as many hourly employees and short-haul drivers experience a disproportionate impact from more prolonged closures, with an increasingly racially diverse workforce filling these roles, as reported by the US Census (2019). Again, the concept of transportation network reliability feeds into the need for more sustainable approaches to resolving avalanche problems along critical transportation routes. To date, most long-term benefit studies focus on meteorological impacts on travel. However, additional efforts should focus on the long- term sustainability of eliminating avalanche closures on high-demand transportation routes. The overall benefits should exceed the initial investment.

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