SUMMARIZING TEN WINTERS OF REMOTE AVALANCHE CONTROL SYSTEM (RACS) USE ALONG THE TRANS-CANADA HIGHWAY AT THREE VALLEY GAP, REVELSTOKE, CANADA

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ABSTRACT: Three Valley Gap, located 20 km west of Revelstoke, British Columbia, holds the highest Avalanche Hazard Index (AHI) in the province and ranks among the highest-priority avalanche zones along the Trans-Canada Highway (TCH). With traffic volume growth compounding at 1-2% annually, avalanche risk within this corridor has continued to increase. In 2016, eleven Remote Avalanche Control Systems (RACS) were installed at Three Valley Gap, reducing risk to the travelling public, improving worker safety, and shortening closure durations. This paper summarizes the key operational learnings from the decade since implementation, covering operational improvements and technical advances observed over ten winters of use. Operational benefits were evident from the first winter of operation. Average control mission time decreased from up to 60 minutes to approximately 23 minutes, and average closure duration fell from 3.9 hours (2007/08–2015/16) to 2.4 hours (2016/17–2025/26); average annual closure hours dropped from 45.1 to 25.3, a reduction of 44%. Active, high snowfall winters require careful explosive charge management late in the season, with operational decisions needed on whether to reload the system or reserve charges for night-time control while relying on helicopter support during the day. Winters with high freezing levels (e.g., 2024 and 2025) can result in surplus charges requiring detonation at season's end. The British Columbia Ministry of Transportation and Transit Revelstoke team manages avalanche hazard across a road network extending well beyond the TCH corridor, and RACS-driven efficiency gains – including prioritized treatment of high-risk paths, a shift toward night-time and early-morning control windows, and reduced pre-mission preparation time – free up resources for this broader avalanche management mandate. This additional capacity is particularly valuable given that traffic queuing in the city of Revelstoke and along the highway during closures also draws on team resources. Close coordination with the Parks Canada Glacier National Park (Rogers Pass) avalanche control team further minimizes corridor-wide traffic impacts.

KEYWORDS: TransCanada Highway 1, RACS, traffic volume.

1. INTRODUCTION

Three Valley Gap (3VG) is one of the highest-priority avalanche areas on the Trans-Canada Highway (TCH) Highway 1, with eight high-frequency paths capable of reaching the highway with as little as 20 mm of precipitation. Prior to implementation of additional mitigation measures, avalanche closures averaged 46.5 hours per winter during ~12 closures (2007–2016) using avalanche control performed by helicopter, with many of these closures exceeding two hours (Jones et al., 2018).

In 2016–2018, the manager of the highway corridor, the British Columbia Ministry of Transportation and Transit (MOTT), contracted Wyssen Avalanche Control to install Remote Avalanche Control System (RACS) towers in seven avalanche paths. This was the first installation of Wyssen Towers in North America, which later expanded to eleven towers. Documented results during the first winters demonstrated consistent program improvements by reducing control time (Jones et al., 2018; Steinkogler et al., 2023). This occurred despite steadily increasing winter traffic while the Avalanche Hazard Index remained essentially relatively flat (163→151). Given the high economic cost of a single hour of closure (e.g., estimated on the order of $2M to 3M CAD per hour when considering downstream economic impacts), it can be demonstrated that the $2.3M CAD project cost was recovered in terms of public benefit within the first two winters.

This paper provides a summary of the 3VG program by extending the operational record to ten winters (2016–2026), updating closure, control-time, and traffic-exposure statistics.

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2. TRAFFIC STATISTICS & CLOSURES

Figure 1 shows December to March Winter Average Daily Traffic (WADT) data summarized for the BC MOTT traffic count station at Craigellachie (station P-22-1EW-N), which is located 26 km west of 3VG. Summer (June-August) ADT is also shown for comparison to illustrate a comparable increasing volume trend, but with larger traffic volumes.

WADT volumes along this corridor in 2026 averaged 5286 vehicles per day (vpd). The 5-year compound average growth rate (CAGR) during 2021-2026 was 1.2%, so extrapolating traffic volume (dashed grey line in Figure 1) to future years provides an estimated WADT of 6325 vpd by year 2040 and 7221 vpd by 2050. This represents an approximately 35% increase in traffic volume in the upcoming 24 years. However, should there be major roadway improvements (e.g. increasing from the current 2 lanes to 3 or 4 lanes) or the trend be closer to the long-term (2003-2026) trend, traffic volume could increase substantially above this estimate to approach 8000 vpd or higher by 2050.

Around 63% of traffic is associated with vehicles under 6 m in length, with the remainder associated with commercial vehicles. This highlights the economic importance of this highway corridor.

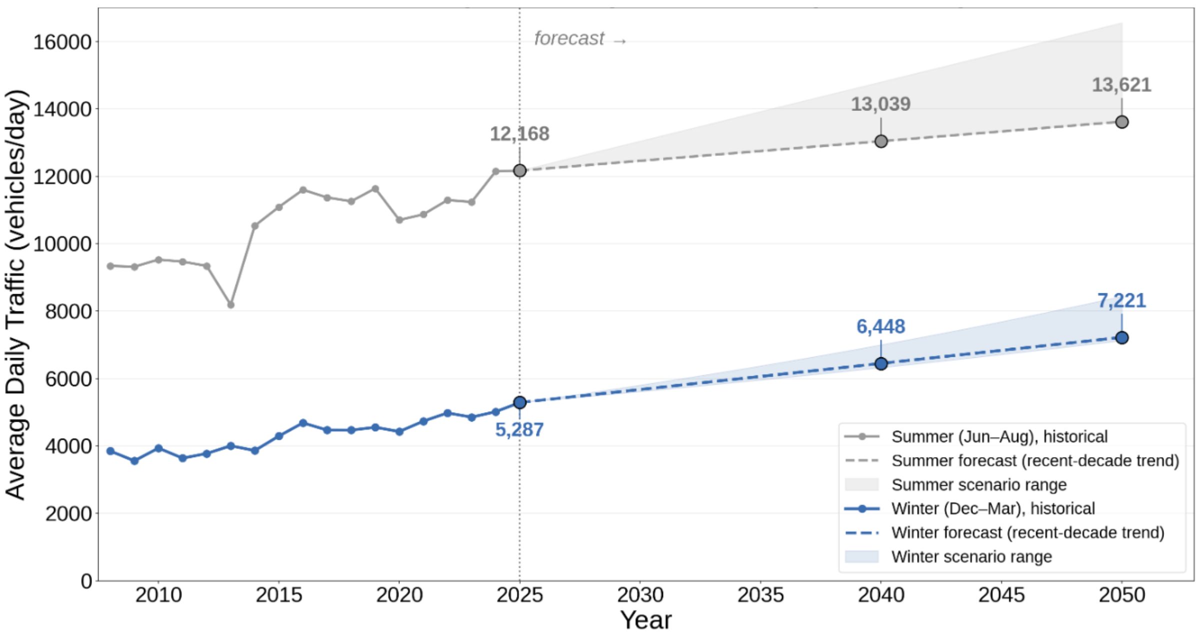

Figure 1: Winter average daily traffic (WADT) for the BC MOTT traffic count station at Craigellachie (site P-22-1EW) close to Three Valley Gap and possible future WADT scenarios until 2050. Winter forecast range spans three scenarios: full-history CAGR (2008–2025, 1.89%/yr, upper), recent-decade linear trend (2016–2025, central), and a 1.2%/yr 5-year CAGR (lower). Summer forecast range spans full-history linear trend, recent-decade linear trend, and recent-decade CAGR (2016–2025). Central dashed line = recent-decade linear trend. Winter (blue) = Dec–Mar monthly average; Summer (gray) = Jun–Aug monthly average.

2.1 *Closure times*

Closure duration exhibits a clear long-term declining trend since RACS implementation, both in total seasonal closure time and in the average duration of individual closures (Table 1). Average control mission time decreased significantly. Comparing the periods before and after the installation of the first RACS in 2016 the average number of closures per year decreased only slightly; yet this has to be expected to be heavily dependent on the winter as new snow events with approximately 20 cm or more (or the water equivalent of 20 mm) typically results in control missions being needed at 3VG.

Table 1: Avalanche closure metrics on TCH West (area 38100) before and after RACS commissioning, by winter season (Oct–Apr). Pre-RACS: 2007/08–2015/16 (9 seasons). Post-RACS: 2016/17–2025/26. Excludes April/May demobilization events. Control mission time available only from December 2018 onward; no pre-RACS value exists for comparison. [1]As noted in Jones et al. (2023).

	2007–2015	**2016–2026**	**Change**
Average closures per year	11.6	10.6	↓ 8%
Average control mission time	Approximately 60 min[1]	23.0 min (n=83, Dec 2018–2026)	—
Average closure duration	3.9 hrs	2.4 hrs	↓ 39%
Average annual (seasonal) closure hours	45.1 hrs/year	25.3 hrs/year	↓ 44%

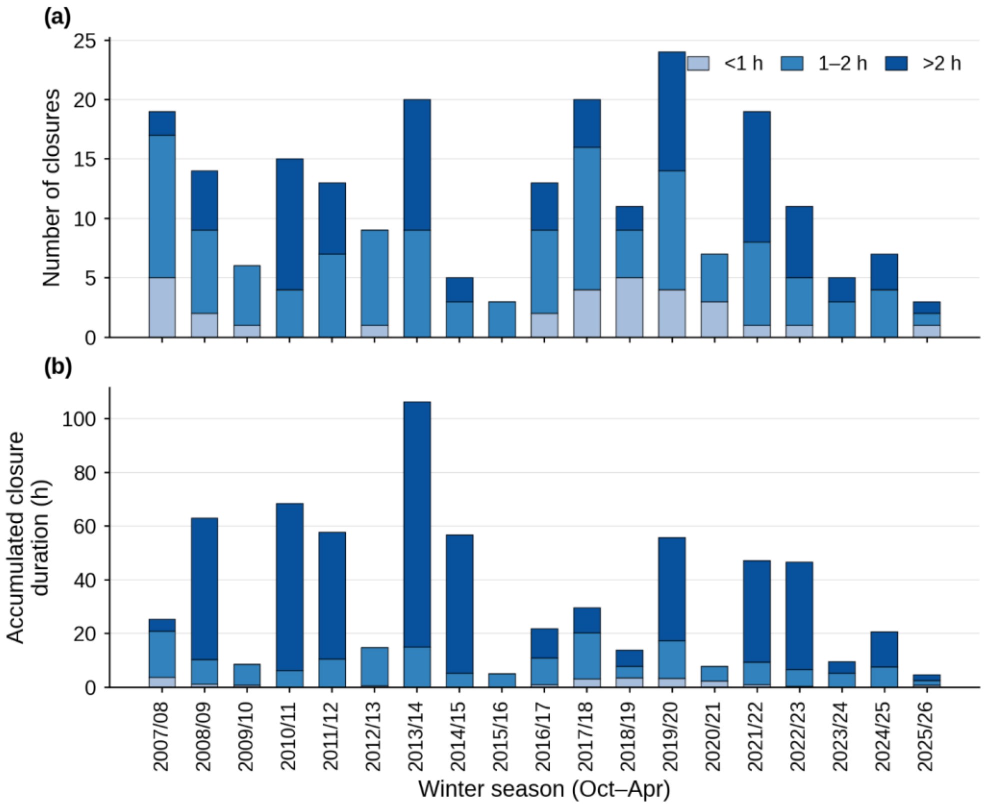

Figure 2: (a) Annual number of closures (upper graph) and (b) closure time (lower graph) for 3VG during 2007-2026, classified by duration of closure in hours.

2.2 Sweep, control and deposit removal times

It is worth noting that the time needed to complete avalanche control with the RACS significantly decreased compared to times when avalanche control was only possible by helicopter. Yet, the time for snow and deposit removal is significant and makes up for the majority of the overall closure time (Figure 3). Nevertheless, snow removal mainly uses resources of the contractor and frees resources of the avalanche control team to focus on other areas within the operation.

In this respect, the very steep 3VG paths also differ from areas with longer runouts, where regular control and the resulting smaller avalanches often stop within the path before reaching the valley bottom and highway. At 3VG, most paths instead produce avalanches that slide directly down to the road, sometimes in a plunging motion.

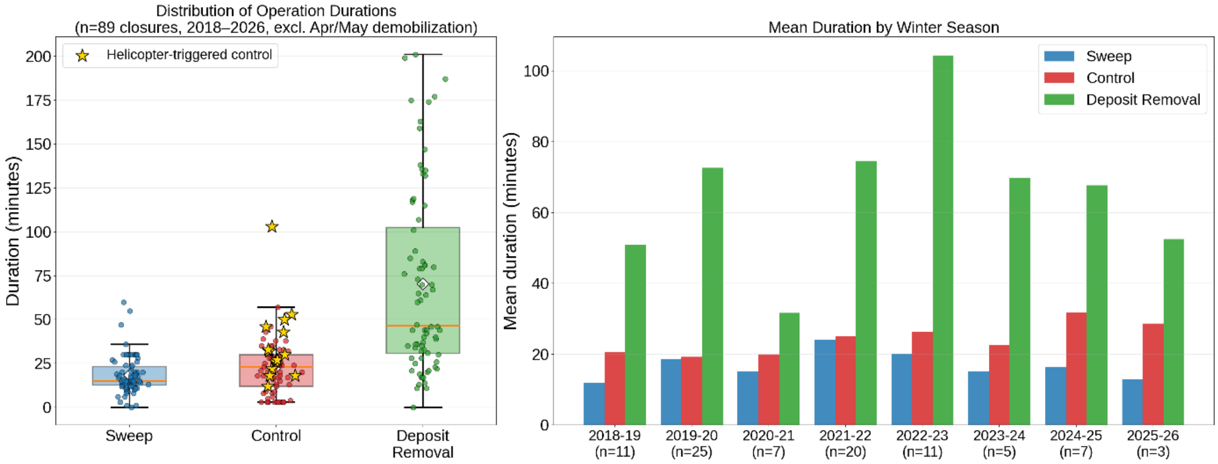

Figure 3: Closure time durations comparing sweep, avalanche control and deposit removal times during 2018-2026. The left-hand graph shows the time distributions individually for sweep, control and deposit removal, while the right-hand graph shows the distribution per winter.

3. OPERATIONAL OPTIMIZATIONS & LEARNINGS

3.1 Optimizations of the recent installations at 3VG

Over the first ten years of operation, the original RACS design has needed no significant modification, and none of the units needed to be relocated. Technical refinements have instead focused on operational reliability: snow deflection roof modifications were added to shed accumulating snow and prevent load buildup on the units, and a power-saving mode was developed and remotely deployed to the system firmware to address reduced solar input during the early-season months.

In 2018, MOTT released a tender to supply and install specialized attenuator rockfall nets in a pilot program. These nets are approximately 120 m long and 15 m tall and were initially installed in an area that crosses the 19.7 avalanche path. After performing successfully under rockfall and snow loading during the first winter of operation (2018-2019), the attenuator system was lengthened over multiple subsequent construction phases along the bluffs. The main goal was to reduce rockfall hazard by intercepting rocks with a specialized net design suspended on 5 m tall posts. The energy of the falling rocks is dissipated by the attenuator, and the rocks slide between the bluff wall and the net into the ditch.

The nets also have had an effect on the accumulation of avalanche debris: in most events, debris is observed passing directly through the nets into the catchment ditches below, and even in high-snowfall winters, when debris accumulates behind the nets, the overall character of the flow appears unaffected. A new section of netting was installed in fall 2025 at Path 19.5. During construction, rock blasting and scaling enlarged the catchment area available for deposits, reducing the immediate impact of small avalanches on the highway.

Figure 4: Attenuator rockfall nets installed primarily to reduce rockfall hazard to the highway. Avalanches both flow through the nets and are directed downward to the catchment, and to date have not adversely affected the performance of the nets.

3.2 Managing closures and decision criteria

While traffic volume is always a consideration, the timing of avalanche control at 3VG is governed primarily by threshold height of snow (HS) and 24-hour height of snow (HST) values, current and forecast weather, and the availability of road maintenance personnel. More frequent patrols through the area can be requested from plow operators, and dispatch relays new avalanche observations made during these patrols directly to the avalanche control team.

An automatic weather station at highway elevation 10 km East of 3VG as well as a station at release area elevation (recording temperature, wind and snow depth) are used. The threshold for triggering the RACS system is generally 20 mm (water equivalent) of new snow once avalanche tracks are established, though this threshold is adjusted case by case based on surface form, temperature, and wind.

If Glacier National Park (Rogers Pass) has been closed for avalanche control – typically for 8 to 12 hours during full Revelstoke to Golden closures – the team will initiate avalanche control near the threshold HST to avoid a second closure immediately following the release of traffic from the Rogers Pass.

Control at 3VG, the adjacent Panther control area, and other paths along the corridor is often conducted during Revelstoke-to-Golden closures to reduce disruption once the highway reopens – as illustrated by the atmospheric river event of March 15–21, 2026, which required 65 hours of closure for high avalanche hazard and control operations.

During major storm events that close the Revelstoke–Golden section of highway, 3VG is prioritized by MOTT to keep the western route open. This typically involves stationing a technician at the 3VG hotel for continuous monitoring, observing sloughing, and maintaining readiness to close the highway on short notice. Technicians receive Emergency Traffic Control (ETC) training which permits a technician to close the highway for up to 2 hours, and each MOTT avalanche truck is equipped with Traffic Control Person (TCP) signage to safely stop traffic when required. TCP resources are often limited during extended closures involving multiple control missions, and having TCP staff on standby for a rapid-response closure is not always feasible. Availability is assessed continuously, and out-of-town crews have on occasion been called in when Revelstoke-based TCP staff have reached their duty-time limits.

3.3 Shifting control times

Analysis of the past years of operational data indicates that non-helicopter related control with the RACS has been conducted at any time of the day, but with a shift toward a bimodal distribution of control timing, with missions concentrated in the morning and in the late-afternoon/early-evening periods (Figure 5). This shift positions control operations outside peak traffic windows, reducing the traffic impact of associated closures. When threshold conditions are approached near the end of the working day, the team generally proceeds with control to avoid overnight monitoring and to allow commuter traffic to clear first; this timing can provide sufficient buffer to defer further action until early the next morning, when a second control mission may be required. Operational experience favors erring toward early control: shooting slightly ahead of threshold is preferable to risking a motor vehicle incident (MVI) resulting from a powder avalanche or sloughing event that stops traffic in a run-out zone as hazard is increasing.

Helicopter control has been retained as a targeted supplemental method, mainly to control adjacent paths that do not have RACS installations and for late-season charge conservation to avoid the need to reload the RACS, rather than eliminated entirely. Since the helicopter is limited to daylight flying conditions, these missions often have to be conducted during peak traffic hours. A decreasing trend in helicopter missions has been observed in recent years, but is expected to remain a useful tool in the future.

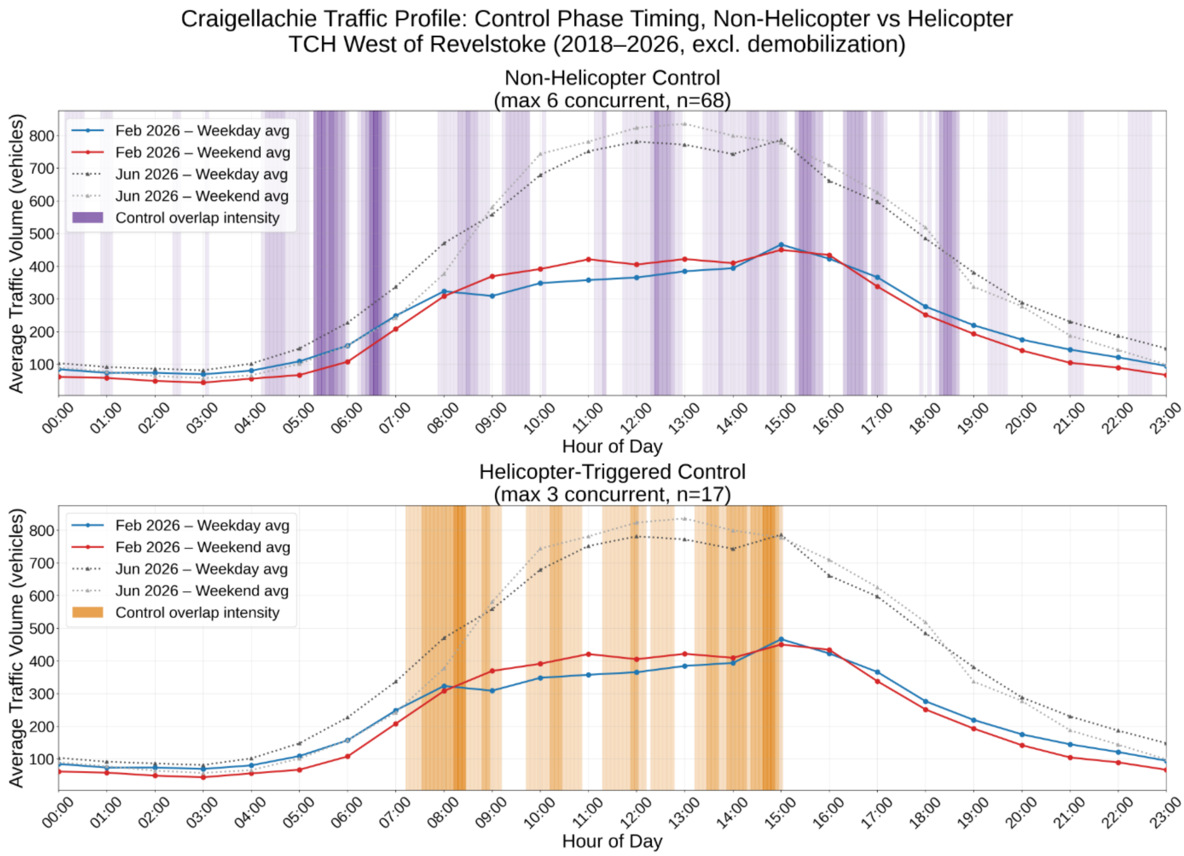

Figure 5: Periods of time needed for control work (excluding times for sweep and deposit removal) displayed as intensity (representing the frequency of closures at the specific time) for RACS control closures (purple colors) and helicopter control closures (brown colors). Average traffic volume (vpd) for February 2026 (solid lines) and June 2026 (dashed lines). Excluded: time needed to detonate surplus charges at end of season.

3.4 Surplus charges

Disposal of surplus charges at the end of the winter takes approximately 145 minutes, depending on the number of charges that need to be detonated. This reflects the current regulatory requirements in British Columbia for detonator removal and charge disassembly, as well as the limited shelf life of loaded charges using emulsion explosive products. These disposal events take considerably longer than the roughly 30-minute closures typical of standard control missions. Although year-end disposal contributes to total highway closure time, detonation of remaining charges is generally conducted within 20-minute highway delays rather than full closures, and clearing the highway of deposit following these detonations is rarely necessary. Also, this event can be timed during periods with lower traffic volume, which results in less impact to the travelling public.

Unlike in Europe, where charges are commonly stored over the summer, this practice is currently not permitted for British Columbia, requiring disposal at the end of each season. Discussions with provincial authorities have been positive about easing this requirement in the future. With ongoing advances in charge container design allowing for longer safety fuse assembly lengths, 2-component charges, replaceable igniters, and cast primers, the program anticipates moving toward a disassembly-based end-of-season procedure rather than detonation, particularly during low-snowfall winters. Latest discussions with provincial authorities indicate that disassembly-based end-of-season procedures will be permitted going forward. Shortened safety fuse assemblies will still need to be destroyed after disassembly but serviceable explosive product can be returned to the magazine for summer storage. This approach eliminates the need for routine seasonal detonation while maintaining safety and regulatory compliance.

3.5 Post control releases

Post control releases in the form of powder avalanches to the highway (or “dusting” associated with wet or moist, plunging avalanches) are common during periods of heavy snow. A technician is stationed to monitor sloughing while a second avalanche control mission or highway closure is prepared. Maintenance contractor plow drivers also report recent activity.

4. CONCLUSIONS

Ten winters of RACS operation at 3VG confirm that the operational gains documented after the first two and six winters have held, and in several respects improved further, even as winter traffic volume has grown by roughly 60% over the same period. Comparing the pre- and post-RACS periods (2007/08–2015/16 vs. 2016/17–2025/26):

- **Average control mission time** dropped from up to 60 minutes (helicopter-based control) to roughly 23 minutes.
- **Average closure duration** fell from 3.9 hours to 2.4 hours, a 39% reduction.
- **Average annual closure hours** dropped from 45.1 to 25.3 hours per season, a 44% reduction — despite closure *frequency* declining only modestly (11.6 to 10.6 closures/year), confirming that the gain comes from shorter closures rather than fewer of them.

Beyond the headline metrics, ten years of use have shown the program's resilience: the original RACS towers have required no relocation or major redesign, attenuator netting has performed reliably against both rockfall and avalanche impacts and debris accumulation, and operational practice has matured toward a bimodal, traffic-aware control schedule that keeps most missions outside peak travel windows. Remaining challenges, e.g. late-season charge management, surplus-charge disposal, and coordination with Rogers Pass closures, are procedural rather than technical, and regulatory movement toward disassembly-based end-of-season procedures should further reduce closure time in future winters. The freed-up capacity from RACS efficiency continues to benefit MOTT's broader avalanche management mandate across the wider Revelstoke corridor.

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