TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Colorado Department of Transportation

INSTRUCTIONS:

Lead Agency contacts should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *(i.e, SPR-2(XXX), SPR-3(XXX) or TPF-5(XXX)* *TPF-5(497)*	**Transportation Pooled Fund Program - Report Period:** ☐Quarter 1 (January 1 – March 31) ☒Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☐Quarter 4 (October 1 – December 31)
TPF Study Number and Title: **Transportation Avalanche Research Pool (TARP) 2.0**	

Lead Agency Contact: **David Reeves**	**Lead Agency Phone Number:** **303-757-9518**	**Lead Agency E-Mail** David.reeves@state.co.us
Lead Agency Project ID: **R22-6.01: TPF 5(497)**	**Other Project ID (i.e., contract #):** **25075.06.01**	**Project Start Date:** 4/27/2022
Original Project Start Date: **4/27/2022**	**Original Project End Date:** **12/31/2027**	**If Extension has been requested, updated project End Date:** Click or tap to enter a date.

Project schedule status:

☒On schedule	☐On revised schedule	☐Ahead of schedule	☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Funds Expended This Quarter	Percentage of Work Completed to Date
$596,930.61	N/A	20%

Project Description:

Avalanche forecasting and mitigation are critical operations for transportation agencies that manage highways and railways that are exposed to avalanches. These operations are an important part of winter operations in many western states and have large implications for public and workers safety.

Objective:
Supporting collaborative research efforts toward avalanche hazard assessment and mitigation within the transportation industry. The goals are to improving public and worker safety, improve operational efficiency, improve and develop informational analysis tools, and explore beneficial avalanche technologies and techniques.

TARP II Projects (PI):

- **497-22-01 - UAS Synthesis** - Unmanned Aerial Systems for Snow Avalanche Risk Mitigation (University of Wyoming –Khaled Ksaibati (PI), Austin Woody (Co-PI))
- **497-23-02 BW Gas Explode**r - Analysis of internal and external overpressure changes of gas based Remote Avalanche Control Systems (RACS) driven by environmental and gas volume variables (Alpine Infrastructure - Eric Bressler (PI)) – Project cancelled, all funds returned.
- **497-24-03 - Avalanche Signs** (Alpine Solutions - Eirik Sharp (PI), Brian Gould (Co-PI) – Final report "CDOT-2025-01 - Avalanche Signage: Avalanche Warning" available on PooledFund.org or upon request.
- **497-24-04 - Effects of Explosives** - Effects of Explosives on Avalanche Frequency and Magnitude (Alpine Solutions – Cam Campbell (PI), Brian Gould (Co-PI))
- **497-24-05 – Avalanche Defense Structures** (David Hamre & Associates, LLC - Francis Meloche (PI), Ron Simenhois (Co-PI, Donald Sharaf (Project Supervisor))
- **497-24-06 - Accelerometer Avalanche Detector** (Viotel – Richard Lynch (PI), Albert Bonela (Co-PI)) – Looking at feasibility of using Viotel's sensors for avalanche detection.
- **497-24-07 - Seismo-infrasonic Systems** (Boise State)
- **497-25-08 - RACS/Detection Assessment** (Alpine Solutions) - Project underway and Notice-to-Proceed sent this quarter
- **497-25-08 - Explosive Effects in Snow** (Wyssen) – Project underway

Progress this Quarter
(includes meetings, work plan status, contract status, significant progress, etc.):

Several projects are currently underway. Details for each active project are appended at the end of this report.

- UAS Synthesis (University of Wyoming) – Draft Report received and distributed to TAC members for comments.
- Frequency magnitude - Effects of Explosives (Alpine Solutions) – Project underway. Details at end of this report.
- Defense Structures (David Hamre & Associates, LLC) – Project underway and Notice-to-Proceed sent this quarter
- Accelerometer Detector (Viotel) – Project is in procurement phase and getting vendor entered into the CDOT accounting system.
- Seismo-infrasonic Systems (Boise State) - Project underway
- RACS/Detection Assessment (Alpine Solutions) - Project underway and Notice-to-Proceed sent this quarter
- Explosive Effects in Snow (Wyssen) – Project underway

Anticipated work next quarter:

Refer to Project QPR's appended below.

Significant Results:

Nothing to report at this time but I will ask TAC Champions to add something next quarter.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

No issues

Potential Implementation:

Nothing to report at this time but I will ask TAC Champions to add something next quarter.

Colorado Department Of Transportation
Research Study Progress Report

TARP Synthesis Report on UAS for Snow Avalanche Risk Mitigation Study No: 5497-22-01

Description:	**Reporting Period:** 2025 - Quarter 4
TARP UAS synthesis project is nearing completion with a rough draft submitted to project managers on 4/9/25. Managers Stimberis and McKee provided notes and edits on 4/23/25. Edits included minor alteration of specific language in several sections and a request for a cost comparison between UAS vs helicopter based bombing missions. Report was resubmitted to project managers in first week of May 2025 and approved on June 4th, 2025. UAS blasting system descriptions were reviewed and approved by survey respondents throughout month of May, 2025. A final presentation of report findings was delivered to TARP members virtually at their annual meeting in Seattle on May 13th, 2025. Report was submitted to CDOT manager on 6/27/25 for formatting corrections.	**Type:** SP&R **PO: 471002042** **PO Amount: $** **Start:** 06/21/23 **Original End:** 06/07/24 **New End Date:** 06/07/25 **Principal Investigator(s):** -Khaled Ksaibati, University of Wyoming, khaled@uwyo.edu -Austin Woody, University of Wyoming, awoody@uwyo.edu **CDOT Research Project Manager:** -David Reeves, CDOT Division of Transportation Development, 303-757-9518 **Oversight Team Members:** -Matt McKee, Avalanche Forecaster, AKRR -John Stimberis, Avalanche Forecaster, WSDOT *Role = Leader, Tech, FHWA, etc*

Milestones, Tasks, And Deliverables

Planned	% done	Achieved	Description, Discussion, and Related Issues
6/21/22	100	6/21/23	PO Issued/Notice to Proceed
6/26/23	100	06/26/23	Kick-Off Meeting
9/19/23	100	9/19/23	Attended ISSW ‘23
12/20/23	100	12/20/23	Avalanche mitigtiaon UAS system questionnaire distributed via Google Forms
3/6/24	100	3/6/24	Contract extended 6/6/25
7/1/24	100	7/1/24	Study outline submitted and approved by TARP members
3/8/25	100	3/10/25	UAS regulatory meeting held virtually
			(Other tasks & Deliverables)
6/7/25	100	4/9/25	Draft Report submitted to Proj. Mgrs.
5/13/25	100	5/13/25	Final Presention of findings delivered to TARP member
6/7/25	0	6/27/25	Final Report submitted. Finalizing formatting requirements

Significant Events
(latest date first)

- 2018Q4 – Regulatory meeting held, paper draft submitted to proj. managers.
- 2018Q3 – UAS mitigation systems in development surveyed
- 2018Q2 – Finalized outline presented and approve by TARP gorup
- 2018Q1 – Project extension granted

Anticipated Work Next Period

- Project completion

Issues

- Insert issues if any

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH STUDY PROGRESS REPORT

Effects of Explosives on Avalanche Frequency and Magnitude
Short Name: Effects of Explosives
Study No: TARP - 5497-24-04

Description/Abstract:

TPF-5(497) – Project #4 – Trans. Avalanche Research Pool (TARP) 2.0

Artificial release of avalanches using explosives is a common control method in North America. It is assumed that the frequent application of explosives to trigger avalanches results in more frequent but smaller occurrences (Simioni & Schweizer, 2018). However, to our knowledge, no formal publications provide data supporting this assumption. The objective of this study is to examine the effect of explosive mitigation on seasonal avalanche frequency and magnitude in a given set of avalanche paths.

This work will involve completing a literature review of published research on the effects of explosives on avalanche frequency and magnitude. The analysis will start with compiling datasets of avalanche occurrence and explosive use records from participating TARP members with areas where avalanche occurrence data exists from before and after the implementation of an explosives avalanche control program. The analysis will then employ standard statistical techniques to analyze these data to determine how frequent active avalanche mitigation impacts the magnitude and frequency of these events.

The anticipated results will answer the question: How does the frequent application of explosives impact large-magnitude avalanche frequency to elements at risk for operations?

Reporting Period: 2025 - Quarter #2
Type: SP&R

PO: 411041178
PO Amount: $55,772.50
Start: 02/24/25
Original End: 06/30/26
New End Date: 06/30/26

Principal Investigator(s):
Cam Campbell, Alpine Solutions
ccampbell@alpinesolutions.com

Brian Gould, Alpine Solutions
bgould@alpinesolutions.com

CDOT Research Project Manager:
David Reeves, CDOT Office of Applied Research, david.reeves@state.co.us

Oversight Team Members:
Ethan Greene (CAIC) – Champion
Steven Clark(Utah DOT) - Champion
All TARP TAC members – Study Panel

Roles = Champion, Study Panel, Tech, FHWA, etc

MILESTONES, TASKS, AND DELIVERABLES

Planned	% done	Achieved	Description, Discussion, and Related Issues
	100	2/24/25	PO Issued/Notice to Proceed
4/2/25	100	4/2/25	Kick-Off Meeting
4/14/25	100	4/14/25	Data request to participating TARP members
4/30/25	100	5/13/25	Data Management Plan (DMP) – Develop a written DMP conforming to the guidance provided by the National Transportation Library
5/15/25	20		Literature Review – Conduct a comprehensive review of existing literature and research.
5/15/25	90		Data Collection – Collect avalanche occurrence and explosive use records from participating TARP members.
6/30/25	30		Database Development – Develop and populate queryable database of avalanche occurrence and explosives use data.
8/31/25	0		Fieldwork - Dendrochronological and other field observations to fill gaps in historical occurrence records.
9/30/25	0		Data Analysis – Hypothesis testing to identify any statistically significant effects of explosives control on avalanche frequency and magnitude for individual paths or groups of paths.
10/31/25	0		Deliverable 1 – Draft Report
11/6/25	0		Deliverable 2 – Presentation Files/Data
11/30/25	0		Deliverable 3 – Final Report

SIGNIFICANT EVENTS
(latest date first)

- 2025Q4 – Details
- 2025Q3 – Details
- 2025Q2 – Details
    - Developed a written Data Management Plan (DMP) conforming to the guidance provided by the National Transportation Library. Presented the DMP to Project Champions.
    - Requested data from participating TARP members.
- 2025Q1 – Details
    - 04/2/25 – Project Kick-off Meeting
    - 4/14/25 - Data request to participating TARP members

ANTICIPATED WORK NEXT PERIOD

- Ongoing literature review
- Ongoing Data Collection: Identify representative avalanche paths or areas and any associated data gaps. Fill data gaps with historical air photo analysis, anecdotal evidence, and dendrochronological field observations.
- Ongoing Database Development: Develop and populate queryable database of avalanche occurrence and explosives use data.

ISSUES

- No issues have been encountered to date.

Colorado Department Of Transportation
Research Study Progress Report

Avalanche Defense Structures
Study No: 5497-05

Description:

Recent insights into avalanche release and dynamic (slope scale) crack propagation indicate that arresting crack propagation across the slope may be a cost-effective solution to manage the avalanche hazard in some avalanche paths. We propose a research project that applies recent developments in understanding avalanche release and develops and evaluates a novel, lightweight design for avalanche defense structures in start zones. The purpose of these structures is to prevent cracks from traversing across a start zone, thereby limiting avalanche size and runout distance and, therefore, reducing the impact of the avalanche on the roadway. Compared to traditional defense structures, these new designs, oriented up/down the slope, do not bear the slope's full-depth snow load, allowing for less robust and costly construction.

Initally, we need to provide a proof of concept with numerical modeling. This will start with 2-dimensional modeling of a slab and weak layer across a slope with an impedance barrier (fence) bisecting the snowpack. Varying the slab depth and stiffness will provide insights into barrier design in different snow climates. The subsequent 2D modeling will involve the slab overtopping the barrier. Once these 2D simulations have been run, the next step will be modeling in 3 dimensions using the Material Point Method. Final steps for this project include identifying potential field locations for a prototype and generating a list of structural design recommendations for the impedance barrier.

Reporting Period: 2025 - Quarter 2

Type: SP&R

PO: 411041516
PO Amount: $70,784.09
Start: 04/14/2025
Original End: 06/30/26
New End Date: 06/30/26

Principal Investigator(s):
Name, Agency, email and/or phone
Donald Sharaf (Project Supervisor)
David Hamre and Associates, LLC
dave@avalancherisksolutions.com

Francis Meloche, DHA (Principal Investigator)
Francis.Meloche@uqar.ca

Ron Simenhois, CDOT (Investigator)
ron.simenhois@state.co.us

CDOT Research Project Manager:
David Reeves, CDOT Division of Transportation Development, 303-757-9518
david.reeves@state.co.us

Oversight Team Members:
Name, Agency (Role)
Ethan Greene, CDOT (Project Champion)
Brian Gorsage, CDOT (Project Champion)

Milestones, Tasks, And Deliverables

Planned	% done	Achieved	Description, Discussion, and Related Issues
4/14/25	100	4/14/25	PO Issued/Notice to Proceed
4/17/25	100	4/17/25	Kick-Off Meeting – Deliverable 1A
5/31/25	100	5/31/25	Equipment Purchased and Delivered – Deliverable 1B
12/31/25	0		Deliverable 2 – List of Structural Design Recommendations
08/30/25	25		Deliverable 3.1 – Width comparis of the structure with a slab on top that could potentially disrupt propagation to the other side of the structure by pure tension in the slab
08/30/25	0		Deliverable 3.2 – Width/Height comparison of the structure with different slab thickness on top
10/31/25	0		Deliverable 3.3 – Repeat the 3.2 simulation in 3D MPM
12/31/25	0		Deliverable 3.4 – Potential field locations for field testing
03/05/24	100	03/05/24	Deliverable 4.1 – Research Briefs = TARP Problem Statement and Proposal
12/31/25	25		Deliverable 4.2 – QPR to CDOT and TARP
01/31/26	0		Deliverable 4.3 – Final Report – Francis
01/31/26	0		Deliverable 4.4 – Final Report - Ron
01/31/26	0		Deliverable 4.5 – Final Report – DHA review and editing
01/31/26	0		Deliverable 4.6 – Presention to TARP and CDOT?

Significant Events
(latest date first)

- 2025 Q2 – June 01, 2025 Simulations commence
  2025 Q2 – Equipment purchased and delivered
  2025 Q2 – Kick off meetings
  2025 Q2 – NTP

Narrative:
2025 Q2: Following the "Notice to Proceed" on April 14, 2025 we met virtually to discuss the plan moving forward. Our kick off meeting was on April 17th with Ethan Greene, Brian Gorsage, Ron Simenhois, Francis Meloche and Don Sharaf. One month later Ron, Francis, Don and Johan Gaume met to discuss modeling variables and methodology. By early June all equipment have been purchased and delivered for the project and from that point it has been in Francis's hands to start running simulations.

To date Francis has run multiple simulations with different slab stiffnesses and thickness variables to help determine the thickness and width of the impedance wall. These are 2D simulations that will lead to subsequent simulations of the wall being buried by a slab. The project is well under way and has a clear way forward.

Anticipated Work Next Period

- Run many more simulations in 2D, which should lead to 3D simulations at the end of the next quarter.
- Monthly progress/status updates from Francis to Ron and Don and his advisors Johan Gaume and Gregoire Bobillier.

Issues

- So far so good.

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH STUDY PROGRESS REPORT

Title: Robust detecting, tracking, and quantification of snow avalanches using integrated seismic and infrasonic remote detection systems
Short Name: Seismo-infrasonic Systems
Study No: 497-24-07

Description: Snow avalanches produce both infrasound and seismic waves. The Boise State University research team plans to record this radiation using co-located seismic and infrasonic sensors (as part of arrays) to explore the benefits of the seismo-infrasonic approach. The research team intends to use the Little Cottonwood Canyon (LCC) in Utah as a natural laboratory where regular avalanches provide ample signal for analysis and decent installation sites are already available and permitted. The research team plans to utilize both broadband seismology (using three-component, low-frequency sensitive seismometers) and arrays of geophones (using higher frequency low-cost seismometers spaced tens of meters apart) to assess the detection capabilities of snow avalanches as a function of distance and avalanche size. The research team plans to validate the effectiveness of the seismic approach using the existing infrasonic monitoring infrastructure at LCC. An anticipated outcome is development of a model where seismic and infrasonic information can be used to estimate avalanche size and flow type, e.g., dense wet flows versus powder clouds. Validation of observations using forecaster reports along with installed time lapse cameras will help to develop novel empirical relationships. A primary project goal is to provide forecasters with a robust tool to remotely quantify snow avalanche size.	**Reporting Period:** 2025 - Quarter #2 **Type:** SP&R **PO: 471002281** **PO Amount: $ 173,350.35** **Start:** 05/07/25 **Original End:** 05/06/27 **New End Date:** MM/DD/YY **Principal Investigator(s):** Jeffrey Johnson (PI), Boise State University, JeffreyBJohnson@boisestate.edu Jerry Mock (technical engineer), Boise State University jerrymock@boisestate.edu **CDOT Research Project Manager:** David Reeves, CDOT Office of Applied Research, david.reeves@state.co.us **Oversight Team Members:** Steven Clark, Utah DOT (Champion) stevenclark@utah.gov, TARP TAC members

MILESTONES, TASKS, AND DELIVERABLES

Planned	%done	Achieved	Description, Discussion, and Related Issues
8/1/24*	100	5/7/25	Task1- Project Management, Kickoff Meeting, QPR'S, and Work Plan:
10/31/25	30**	10/30/24**	Task2- Preparation of seismic hardware for installation:
11/30/25	30**	4/30/25**	Task3 - Initial deployment of sensors in LCC:
4/30/26	30**	4/30/25**	Task4- Maintenance visits to LCC to download data and verify operation hardware retrieval
6/30/26	20		Task5- Signal analysis and development of analytical software:
9/30/26	0		Task6- Presentation of results at meetings / journal publications:
11/30/26	0		Task7- Tech transfer:
12/31/26	0		Task8- Final report:
*indicates initial proposal project timeline (summer 2024); a notice to proceed was granted 5/7/25 and the work plan schedule was adjusted accordingly			
**indicates tasks accomplished prior to funding initiation; data that were collected toward the objectives of the project during winter 2024-2025 are already being utilized			

SIGNIFICANT EVENTS
(latest date first)

- 2025Q2 (period ending June 30) – A notice to proceed was issued on May 7th, 2025. Following the kickoff meeting with CDOT Research Project Manager (D. Reeves) and Boise State University sponsored programs the team members Jeffrey Johnson and Jerry Mock began analysis of signals collected during the winter 2024/2025 season. These data included continuous seismic array data (task #3) acquired in Little Cottonwood Canyon in conjunction with infrasound. Infrasound data had been simultaneously collected by partners Snowbound Solution and Little Cottonwood Canyon staff and provided to the Boise State University team along with catalog of avalanche activity. Seismic data were collected using instrumentation purchased and prepared during the fall of 2024 (task #2**). Those data have already been processed for initial analysis and results will be presented at an upcoming TARP monthly meeting. A major focus of Q2 work has been signal analysis of the conjoint seismo-acoustic data along with the forecaster catalog (task#5). Despite delays in project start date, the collection of data in 2024/2025 has permitted a quick start to the data analysis portion of this project. Given the delayed project start a new work plan schedule was developed during Q2 to ensure that all primary goals will be reached during the project timeline.
- 2025Q1 (period ending March 31; contract not yet issued)

ANTICIPATED WORK NEXT PERIOD

- 2025Q3 ends on September 30. Results of ongoing signal analysis using 2024/2025 data will inform the preparations for the 2025/2026 winter deployment. Additional seismic hardware preparation is expected along with time lapse camera systems. Johnson and Mock will work with project champion Steven Clark to develop a targeted field campaign plan and deployment expectations for November 2025. PI Johnson is planning to update TARP members with current results of work during their September (2025) monthly meeting.

ISSUES

- The delayed project start has impacted the timeline for hiring a graduate assistant researcher. PI Johnson and technical engineer Mock have assumed some of the analytical roles intended for the graduate student.

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH STUDY PROGRESS REPORT

Accelerometer Detector
Study No: 497-24-06

Description: The research effort is intended to determine the possibility of utilizing inexpensive standalone accelerometer nodes to detect avalanche flow at or near critical transportation corridors. We are doing this to improve employee and traveler safety by developing an inexpensive detector that could be widely deployed to cover entire transportation corridors in an effort to receive timely, around the clock detection and alerts for avalanches that have impacted transportation corridors. This project will collect in-situ data from 3 accelerometers, and analyze this data in conjunction with avalanche event observations made during the study period. If we can successfully derive and test a simple algorithm to reliably detect signatures of avalanche activity, then we could use this in a future implementation of routine monitoring.	**Reporting Period:** 2025 - Quarter #2 **Type:** SP&R **PO:** 411042649 **PO Amount:** $24,922.44 **Start:** 08/05/25 **Original End:** 12/31/27 **New End Date:** 12/31/27 **Principal Investigator(s):** Name, Agency, email and/or phone Richard Lynch (PI), Viotel, richard.lynch@viotel.co Craig McCloskey (Co-PI), Viotel, craig.mccloskey@viotel.co **CDOT Research Project Manager:** David Reeves, CDOT – Office of Applied Research, david.reeves@state.co.us **Oversight Team Members:** Name, Agency (Role) Matt McKee, AKRR, (Champion) Brian Gorsage, CDOT (Co-Champion) Steve Cohn, CDOT (Panel Member) TARP TAC members (Panel Members) *Role = Leader, Tech, FHWA, etc*

MILESTONES, TASKS, AND DELIVERABLES

Planned	% done	Achieved	Description, Discussion, and Related Issues
m/d/y	100	8/6/25	PO Issued/Notice to Proceed
8/21/25	100	8/21/25	Kick-Off Meeting (Richard and Matt)
8/22/25	0		Initial project documentation
10/1/25	50		Task 1a – finalise required equipment: preparation, testing, shipping
11/1/25	0		Task 1b – installation of 3 accelerometer stations
12/1/25			Task 2 – Record observation data on nearby avalanches
5/1/26			Task 3 – retrieve equipment
5/1/26			Task 4 – collect and analyse seismic data
6/1/26			Task 5 – design embedded detection algorithm
6/15/25			Task 6 – specify requirements and algorithm for embedded firmware
7/30/26			Task 7 – Reporting and Presentation of results
			(Other tasks & Deliverables)
7/15/26	0		Deliverable 7.1 – Draft Report
7/30/26	0		Deliverable 7.2 – Presention Files/Data
8/1/26	0		Deliverable 7.3 – Final Report (WCAG compliant as both MS Word and PDF)

SIGNIFICANT EVENTS
(latest date first)

- 2025Q3 – Project Go-Ahead received; Kick-off meeting and follow-up meeting with Matt - test area identified, accelerometer locations planned, power system planned. Meta data (videos, photos and other records) discussed – doesn't seem a problem to collect the required meta-data.

ANTICIPATED WORK NEXT PERIOD

- finalise and ship equipment (accelerometers), complete planning.
- Install accelerometers, get data streaming continuously to the cloud
- Preliminary analysis of seismic data from accelerometers
- Start recording meta-data, wait for avalanches

ISSUES

None at this time.

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH STUDY PROGRESS REPORT

Guidelines for the use of Remote Avalanche Control Systems (RACS) and Automated Avalanche Detection Systems in North America
Short Name: RACS Detection
Study No: TARP - 5497-25-08

Description/Abstract:

TPF-5(497) – Project #8 – Trans. Avalanche Research Pool (TARP) 2.0

This research project is aimed at developing guidelines for the use of Remote Avalanche Control Systems (RACS) and Automated Avalanche Detection Systems (AADS) in North America. The effective deployment and maintenance of RACS and AADS are critical for mitigating avalanche risks across diverse climatic regions. Selecting and implementing these systems requires balancing a variety of considerations, including effectiveness, safety, and cost.

This study involves a literature review and stakeholder surveys to gather data on RACS and AADS practices and performance metrics. Data analysis will focus on pattern and theme recognition with respect to when and where RACS and AADS are currently used. The analysis will also include a high-level cost comparison matrix and development of a cost-benefit framework for evaluating future projects. The anticipated results will equip stakeholders, that include transportation avalanche program managers and associated decision makers, with the knowledge and tools to make informed decisions about the deployment and upkeep of RACS and AADS, optimizing safety and cost-effectiveness in avalanche-prone areas.

Reporting Period: 2025 - Quarter #2
Type: SP&R

PO: 411041422
PO Amount: $49,700
Start: 03/27/25
Original End: 06/30/26
New End Date: 06/30/26

Principal Investigator(s):
Cam Campbell, Alpine Solutions
ccampbell@alpinesolutions.com

Brian Gould, Alpine Solutions
bgould@alpinesolutions.com

CDOT Research Project Manager:
David Reeves, CDOT Office of Applied Research, david.reeves@state.co.us

Oversight Team Members:
Paul Harwood (BC Ministry of Transportation and Transit) – Study Champion
Timothy Glassett (Alaska DOT) Co-Champion
Harlan Sheppard (WSDOT) Co-Champion
Brian Gorsage (CDOT) Study Panel
Steve Cohn (CDOT) Study Panel
All TARP TAC members – Study Panel

Roles = Champion, Study Panel, Tech, FHWA, etc

MILESTONES, TASKS, AND DELIVERABLES

Planned	% done	Achieved	Description, Discussion, and Related Issues
	100	3/31/25	PO Issued/Notice to Proceed
4/16/25	100	4/16/25	Kick-Off Meeting
5/15/25	20		Literature Review – Conduct a comprehensive review of existing literature and research.
5/15/25	100	6/13/25	Stakeholder Surveys – Design and distribute an online survey targeting operators and manufacturers.
6/30/25	50		Preliminary Survey Data Analysis – Identify data gaps.
7/31/25	0		Follow-up Interviews – Conduct remote interviews with open-ended questions to explore and expand upon survey findings.
8/31/25	0		Data Analysis – Includes pattern and theme recognition, cost comparison, and cost-benefit framework.
9/30/25	0		Deliverable 1 – Draft Report
10/2/25	0		Deliverable 2 – Presentation Files/Data
10/31/25	0		Deliverable 3 – Final Report

SIGNIFICANT EVENTS

- 2025Q4 – Details
- 2025Q3 – Details
- 2025Q2 – Details
    - Compiled a list of program managers and leads with experience in deploying RACS and AADS.
    - Inventoried RACS and AADS systems currently deployed in North America, noting their specific applications and environments.
    - Designed and distributed an online survey targeting operators and manufacturers of RACS and AADS.
    - Preliminary survey data analysis to identify data gaps and inform the follow-up interviews.
- 2025Q1 – Details
    - 04/16/2025 – Project kick-off meeting scheduled for 04/16/2025

ANTICIPATED WORK NEXT PERIOD

- Ongoing literature review
- Continued preliminary survey data analysis to identify data gaps and inform the follow-up interviews.
- Follow-up interviews
- Survey and interview data analysis
- Reporting

ISSUES

- No issues have been encountered to date.

Colorado Department Of Transportation
Research Study Progress Report

TARP Explosive Effects in Snow
Study No: 5497-25-09

Description:	**Reporting Period:** 2025 - Quarter #2 **Type:** SP&R **PO: 411041256** **PO Amount: $40,000** **Start:** 03/11/2025 **Original End:** 12/31/25 **New End Date:** 06/30/26 (Proposed) **Principal Investigator(s):** Beni Meier, Wyssen Avalanche Control, Beni@wyssen.com, +41 33 676 76 64 **CDOT Research Project Manager:** Name, CDOT Division of Transportation Development, 303-757-9518 **Oversight Team Members:** Tim Glassett, Alaska DOT, Project Champion Andrew Jones, MOTI, Project Champion
This project builds on work previously done by Wyssen AG and TARP that was conducted at Alta, UT in April of 2024. Those tests measured explosive pressure waves with the TARP owned Seitz sensor array and a commercial sensor array owned by Wyssen. Comparable results were measured but the Wyssen system had a significantly higher resolution. Further measurements were collected by Wyssen with an array of 4 geophones. The geophones measured the movement of the snow created by the pressure wave from an explosive detonation. The analysis of the signals and peak pressure vs. distance etc. was compared to various historical studies and a new model was developed and with subsequent measurements partly falsified. At the 2024 ISSW in Norway, Wyssen presented several findings which came from this project. Most importantly, the hypothesis that snow interacts differently with different frequencies generated by explosive detonations. To quantify the effect an explosive detonation has on snow, it is important to better understand which frequencies are generated by different explosives and the effect they have on a snowpack in a variety of conditions. Furthermore, it is suspected that each snowpack has a frequency response and to compare effective ranges of Remote Avalanche Control Systems (RACS) one must first understand clearly how the pressure wave of these systems interacts with the snowpack.	

Milestones, Tasks, And Deliverables

Planned	% done	Achieved	Description, Discussion, and Related Issues
			RIC Approved
			Oversight Team Scoping Meeting
			RFP Sent
			PI Selected
02/01/25	100	03/11/25	PO Issued/Notice to Proceed
02/15/25	100	03/18/25	Kick-Off Meeting
03/01/25	100	06/01/25	Task 1 – Design and produce sensor arrays
05/01/25	15		Task 2 – Design and conduct experiments
07/01/25	0		Task 3 – Data analysis and reporting
07/01/25	0		Deliverable 1 – Draft Report
08/01/25	0		Deliverable 2 – Present findings to TARP committee
08/01/25	0		Deliverable 3 - Files/Open Sourced Data
09/01/25	0		Deliverable 4 – Final Report

Significant Events

- 2025Q2 – Sensor arrays designed, built, tested, and calibrated
- 2025Q1 – PO received, kick off meeting conducted

Anticipated Work Next Period

With task 1 complete and the task 2 experment design finalized, Wyssen's next steps are to conduct the experiments during good testing conditions in the winter months. Wyssen plans to present current progress to the TARP membership in August or September of 2025. Presentation will include details on the sensor arrays and experiment design.

Issues

- Delays in receiving the purchase order and notice to proceed reduced the opportinuiteis to conduct the experiments during winter. The European Alps had very little snow during March, April, and May further reducing the opportunbites to conduct quality experiments. With the contracting delays, and lack of snow in the Alps during the spring of 2025, Wyssen USA requests a 6 month extension to the project. The sensor arrays are built and ready, the experiment design is done, and the explosives have been purchased and staged at the testing sights. Wyssen only requires good testing conditions with snow and winter conditions. A modified project schedule is included below. A 6 month extension will allow Wyssen to deliver the best possible results to TARP and CDOT.

Task	Estimated Start Date	Duration
Task 1: Kick off meeting. Design, produce, & calibrate pressure sensors. Produce geophone test equipment	Original: March 2025	30 Days (Complete)
Task 2: Design and conduct experiments	December 2025-April 2026	120 Days
Task 3: Data analysis & reporting	May-June 2026	60 Days

Project status report

Explosive Effects, TARP Project

1 Introduction

This is a status report for the project “TARP Explosive effects in snow” funded by TARP and Wyssen Avalanche Control AG.

The project is executed by Wyssen Avalanche Control AG and review is done by Sam Verplanck, Montana State University.

As the scope of work describes the work can be roughly split into the following steps:

1. Pressure sensors: Design the sensor and produce 25 sensors
2. Geophones: Produce geophone test equipment (16x)
3. Experiment design
4. Experiments
5. Data analysis
6. Reporting

The structure of this status report follows these steps.

2 Status

The project is currently behind schedule. The reason is a late project start combined with an extremely low precipitation winter in the alps. This has made experiments impossible so far.

On the positive side we can say that the equipment is ready and the “high altitude testing location” is starting to look good as precipitation from summer weather is cumulating.

To summarize: the project needs to be extended for at least a few months so that the actual experiments can be conducted in the next winter season.

2.1 Pressure sensors

The pressure sensors are based on a proprietary design from an existing Wyssen product. The design was adapted specifically for this research application. The main differences between the research sensors and the original Wyssen product are:

- Possibility to synchronize multiple sensors allowing for time-synchronized measurement
- Additional memory to store up to 2 million samples (approximately 90s of recording)
- Changes to the firmware to interface multiple sensors on a common bus
- Special 3D printed casing to accommodate the electronics and to be mountable on a 10mm wooden stick in multiple orientations for a quick and easy setup in the field

The sensors were produced, tested and calibrated.

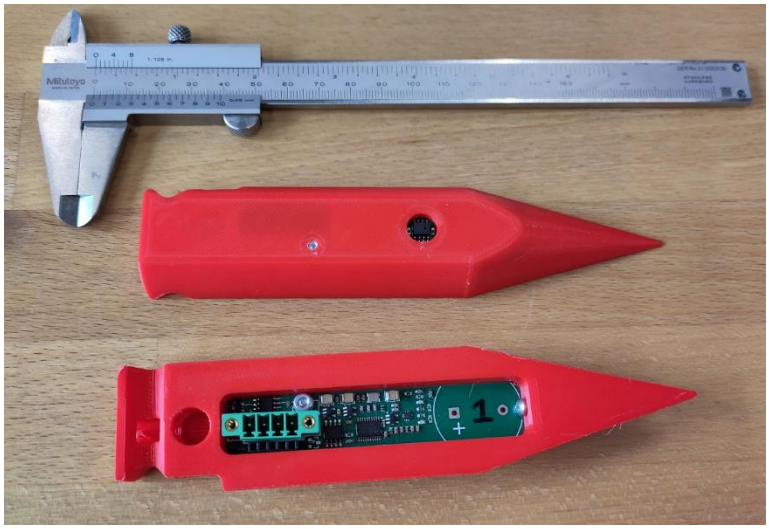

Figure 1: Pressure sensors mounted in their casing.

Also, we prepared wiring that allows for a quick setup for the designed experiments.

Figure 2: Pressure sensor on wooden pole

2.2 Geophones

The electronics that were developed for the pressure sensors were slightly adapted to acquire data through a geophone instead of an air pressure sensing element.

The geophone measures movement in one axis.

A 3D printable casing was designed to accommodate the geophone together with the electronics. For good coupling of a stress wave in snow with the sensor, the case was built such that the overall density of the enclosed sensor is like that of snow.

Figure 3: Geophone enclosed and with cable.

We produced 16 such geophones as planned.

Figure 4: Prepared wires for a quick setup in the field

Also, we prepared wiring that allows for a quick setup for the designed experiments.

2.3 Experiment design

The experiments were carefully designed with many different objectives in mind while keeping several limitations in mind.

The experiment design was refined and reviewed by Sam Verplanck.

2.4 Experiments

As the equipment is ready and the experiment design is done, the only thing missing is snow and opportunity.

So far, no experiments were conducted due to an extremely low precipitation winter in the alps.

2.5 Data analysis

Data analysis will start as soon as the first experiments are done.

2.6 Reporting

The report will be done once all the experiments are done, however we were already able to lay some groundwork for the report and put together an introductory section.