



**UNIVERSITY  
OF ALBERTA**

Canadian Centre of Expertise on Rail  
Research

Contract T8009-210202

**DRAFT 2024-25 Annual Research Plan For  
Implementation in 2025-26**

March 18, 2025

## Executive Summary

This document is the annual research plan for contract T8009-210202 and includes

- the updated research priority themes and sub-themes;
- a summary of how stakeholder feedback was incorporated into the research plan based on the Stakeholder engagement processes in 2022-23, 2023-24 and 2024-25.;
- the new and ongoing research projects; and,
- the annual distribution of person-days of research time to each project.

It should be noted that this annual research plan is delivered in Transport Canada's Fiscal Year 2024-2025, but the implementation of the projects in the plan will take place in Fiscal Year 2025-2026.

The projects approved for the 2024-2025 year will be carried out with the methodologies and Junior Researchers described in **§3.1**. The projects approved for 2024-2025 that are currently underway are:

- Detailed Quantitative Model for Rail Transport of Dangerous Goods;
- Ground Hazard Risk Evolution with Climate Change;
- Wildfire Impact, Risks and Mitigation; and,
- Fundamental Steel Behaviour and Properties.

The project approved for 2024-2025 that is currently underway, and expected to be completed within this year of the contract is:

- Resiliency of the Railway Network.

Following consultations with stakeholders over the spring and summer of 2024, the projects approved for 2024-2025 that are currently in-planning are:

- Safety Management Systems (SMS) Key Performance Indicators (KPI); and,
- Root Cause Analysis (RCA) of Human Factors related Occurrences.

The scope of work for these projects will be further developed in coordination and consultation with stakeholders and TC and initiated when the resources (project lead(s), Junior Researcher(s) and research days) are available.

Following the Fall 2024 Railway Research Advisory Board meeting, project proposals were solicited, and the following proposals are in preliminary development:

- Data Analysis for the Technology Demonstrator Railcar
- Deterioration of Rail Ties – Assessing the Role of Climate Variability

During the Fall 2024 RRAB meeting it was noted that the work on Wildfire Impact, Risks and Mitigation should include a railway operational focus to bring further value for RRAB stakeholders. This aspect will be scoped with the RRAB Task Team on Technologies for Managing Wildfire Risk out and may be added as additional future research.

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## 1. Introduction

Since 2012, the Canadian Rail Research Laboratory (CaRRL) has been instrumental in advancing engineering research for the improvement of safety, reliability, sustainability, and economic competitiveness of rail transportation in Canada, as well as helping prepare the next generation of highly skilled science and engineering professionals for careers in rail. The team of experts assembled at the University of Alberta (UofA), led by Dr. Michael Hendry and Dr. Renato Macciotta, will conduct interdisciplinary research that will 1) lead to a robust and innovative platform to advance scientific knowledge at the UofA; 2) develop and evaluate Canadian-led technical and methodological solutions to support and enhance the Canadian railway industry's operations; and 3) allow the UofA to be a source of evidence-based research that will inform the development of railway industry standards, thereby increasing the industrial relevance of the UofA's research programs. The UofA will continue leading in innovation, training, and cooperation with the railway industry and its regulator.

This document is the annual research plan required by contract T8009-210202. The required contents of this annual research plan are listed below:

- the up-to-date research priority themes and sub-themes (**Appendix A**);
- a summary of how stakeholder feedback (e.g., RRAB) was incorporated into the research plan (**\$2**);
- the ongoing research projects that will be continued, including objectives, link to corresponding research priority/theme(s), scope, methodology, research organization/government/industry participants, timelines, relation to policy/regulatory development and/or technology readiness level advancement, and funding allocation (**\$3.11**); and
- the new research projects that will be further developed in coordination and consultation with stakeholders and TC, including objectives, link to corresponding research priority/theme(s), scope, methodology, research organization/government/industry participants, timelines, relation to policy/regulatory development and/or technology readiness level advancement, and funding allocation (**\$Error! Reference source not found.2**);
- the new research projects in development that will be further defined in coordination and consultation with stakeholders and TC, including objectives and proposed preliminary scope; and
- the annual distribution of person-days of research time to each project.

## 2. Stakeholder engagement

Stakeholder engagement is carried out annually during the fall RRAB meetings. Two detailed stakeholder engagement processes were undertaken with the RRAB in 2022 and 2023. These engagement sessions have ranked potential projects and have identified new topics or areas for research of priority for rail industry stakeholders. These projects were ranked, and the results are presented in **Table 2.1**. Responses to the stakeholder engagement were provided by different federal government departments (National Research Council of Canada as well as Transport Canada's (TC) Innovation Centre, Rail Safety, and Transportation of Dangerous Goods Directorates), provinces and territories, US Government representatives and industry representatives (Class I railway, short lines, associations, and suppliers). Organizations represented on the RRAB were asked to delegate their survey input to one representative. The past proposed projects have been developed from the results of these processes.

During the December 5, 2024, RRAB meeting CaRRL leads from University of Alberta presented an overview and update of the program and noted the status of ongoing, new, and completed research

projects for the 2023-24 workplan. Results and status updates were provided for ongoing projects *Detailed Quantitative Model for Rail Transport of Dangerous Goods* and *Ground Hazard Risk Evolution with Climate Change* and new research projects started in 2023-24 *Resiliency of the Railway Network* and *Fundamental Steel Behaviour and Properties*. Detailed presentations were provided for *Wildfire Hazard Identification and Risk Assessment* and *Human Factors of Trespassing and Grade Crossings*. Descriptions were provided for two new human factors projects that emerged following consultations with stakeholders over the spring and summer of 2024; *Safety Management Systems (SMS) Key Performance Indicators (KPI)* and *Root Cause Analysis (RCA) of Human Factors related Occurrences*. The CaRRL overview also highlighted published degrees and theses, journal papers and conference proceedings as well as the outcomes of the 2nd Canadian & Cold Regions Railway Conference held in April of 2024.

Feedback was noted from railway members regarding research on *Safety Management Systems (SMS) Key Performance Indicators (KPI)*. Concerns were raised about the appropriateness of this type of research within the context of the RRAB, since it is not focused on technology. Stakeholders agreed to convene a follow up discussion to address concerns before advancing the research.

Following the CaRRL overview presentation, Innovation Centre put forward a discussion on the planning cycle for the Canadian Rail Research Lab. Since the initiation of Phase III of CaRRL, RRAB stakeholders have been engaged to solicit and rank proposed project ideas, resulting in a list ranked from high to low importance. Stakeholders were asked to provide input on this list or to provide any additional emerging topics.

The following emerging topics were noted during the December 5, 2024, RRAB meeting and are in preliminary development *Data Analysis for the Technology Demonstrator of Railcar* and *Assessing the Role of Climate Variability on the Deterioration of Rail Ties*. Additionally, it was noted that the work on Wildfire Impact, Risks and Mitigation should include a railway operational focus to bring further value for RRAB stakeholders. This aspect will be scoped with the RRAB Task Team on Technologies for Managing Wildfire Risk out and may be added as additional future research.

**Table 2.1.** Proposed and ranked (high, medium and low priority) research ideas solicited from stakeholder engagement since the launch of CaRRL Phase III. A description of each project is provided in Appendix B

Studying the Effects of Wildfires on Track Stability
Testing/Assessment of Methods to Reduce Exhaust Sparking and Fire Risk
Capabilities and Opportunities of Digital Twins for Short Lines
Incident Reporting and Inspection through Mobile Phone Application
In-field Pilot Tests of Wearable Technology to Improve Rail Worker Safety
Biofuel Development and Testing
Open Source Library of Images for Machine Learning Purposes
Hand Brake Resistance Monitoring/Testing
Updating Rail Neutral Temperature
Hydrogen Tender Car Safety Research
In Service Rail Stresses (focus on residual stresses)
In-situ Deformation of Track Under Train Load
Framework for Preliminary Assessment of New and Emerging Rail Technology
Evaluation of the Increased Risk of Geohazards Post Wildfire
Permafrost Degradation Mitigation
Retaining Railway Employees
Alternative Track Materials
Evaluation of Tunnels and Rock Bolt Identification Using LiDAR
Fibre Optic Monitoring for Rockfalls and Change Detection
Connectivity on Canadian Railways
Cybersecurity in Rail

### 3. Proposed projects for 2024-2025

The following research projects are proposed for 2024-2025 and will be implemented in 2025-2026.

**Table 3.1.** Projects proposed for 2024-2025 work plan to be implemented in 2025-2026, the estimated (direct costs) funding allocation, and the estimated number of available research days allotted to each project (a total of 250 days required by contract).

Ongoing research projects	Estimated funding allocation	Expected number of research days
Detailed Quantitative Model for Rail Transport of Dangerous Goods	\$48,000	40
Ground Hazard Risk Evolution with Climate Change	\$48,000	40
Wildfire Hazard Identification and Risk Assessment	\$82,000	70
The Resilience of the Railway Network	\$24,000	40
Fundamental Steel Behaviour and Properties	\$28,000	60
<b>New research projects</b>		
Safety Management Systems (SMS) Key Performance Indicators (KPI)	\$18,800	TBD
Root Cause Analysis (RCA) of Human Factors related Occurrences		
<b>New research projects in development</b>		
Data Analysis for the Technology Demonstrator Railcar	TBD	
Deterioration of Rail Ties – Assessing the Role of Climate Variability		
<b>Completed research projects</b>		
Defect simulation on Railcar Components for AMVIS	Completed during 2022-23	
Development of a workload prediction model for Train Operators	Completed during 2022-23	
Human factors of trespassing and grade crossings*	Completed during 2023-24	

The estimated funding allocation is generated by the expected number of days of research performed by the researchers; the actual costs, amounts paid to students, and overhead may vary. Funds may be rebalanced depending on the supports required for the SMS and RCA projects, as well as other program deliverables.

Additionally, the following are constraints on research being undertaken at Canadian universities where the work is primarily conducted by graduate students (MSc & PhD) as part of their degrees and postdoctoral fellows (PDFs).

- Students must be able to complete their degrees and publish their theses;
- Students (MSc & PhD), as well as PDFs, are often recruited for a project, and their start times coincide with the start of terms (and often dependent on the issuance of student visas); and
- Students are learning, and their results typically become evident towards the end of their degree.

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\* A second phase of this work is currently being scoped out with TC stakeholders

### 3.1. Ongoing research projects

#### ***Detailed Quantitative Model for Rail Transport of Dangerous Goods***

**Background:** Rail transport of Dangerous Goods (DG) is a common activity that has been identified as a low-likelihood event with the potential for high consequences. The sustainability of this important activity requires assuring adequate levels of safety, best evaluated through detailed, quantified techniques. This project builds upon our previous research work with TC and the RRAB. The outcomes of this project are anticipated to include a detailed method for the quantitative estimation of risks associated with rail transport of DG; quantify the risk along two rail subdivisions with different risk profiles (anonymized information) to illustrate and calibrate the method; identify information that needs to be collected to enhance the accuracy of the calculations going forward; and identify effective risk mitigation options based on comparative risk estimates using the method.

**Research objectives:** The objective of this project is to develop a detailed, practicable model to quantitatively estimate the risk for rail transport of DG. Specifically, the research will develop detailed process models that will include Fault Tree Analyses (FTA) and Event Tree Analyses (ETA) for rail transport operations. Researchers will then populate these models with available statistical information (e.g., public databases) and expert judgment for an initial estimate of risks and identify the databases that would be required to populate the model based on statistical data in the future.

**Research scope and methodology:** This research will focus on federally regulated operations in corridors transporting DG (i.e., freight operations). However, passenger operations will be addressed as potential elements exposed to incidents involving DG. The research will also focus on main track transportation, leaving yard work and loading/unloading facilities outside the scope of the research.

The methodology will include the development of fault tree models based on the Canadian Railway Operating Rules (CROR) and the categories of rail incident causes, including failures in train handling, track and equipment. Out of scope will be trespasser and crossing accidents, as these are heavily influenced by third parties, making the process dependent on factors outside the control of the railway operators. The methodology will also develop event trees to estimate the potential consequences of main track derailment and collisions when transporting DG. Then the methodology will use incident investigations publicly available through the Transportation Safety Board (TSB) and the Railway Occurrence Database system (RODS) to calibrate, to the extent possible, the fault and event trees generated.

#### **Research Team Members:**

1. University of Alberta: Dr. Renato Macciotta, Associate Professor; Dr. Lianne Lefsrud, Professor / Dr. Fereshteh Sattari, Research Associate; Mehdi Hamedanian, PhD student
2. Transport Canada: Daniel Blais, Innovation Centre

**Summary of work to date:** We have completed a generalized model that considers all Canadian railway databases and reflects aggregated operations across the network was completed. This work consisted of the development of fault and event trees to calculate the probability of a train derailment or collision and the potential outcomes in terms of loss of life. In January 2024 the PhD student identified for continuation of this project initiated the program. The student has initiated the development of a more detailed model that considers the characteristics of specific corridors such that risk differentiation can be made across the Canadian railway network. Furthermore, the fault and event trees will be developed for main track derailments as the top event, and optimization will be investigated through other approaches (e.g. non-linear risk models).

### **Timelines:**

- July 2025: Development of a detailed FTA and ETA prototype.
- December 2025: Calibration of the fault and event trees
- December 2026: Testing of the calibrated model.

**Link to Policy/Regulatory Development:** This research is aligned with the following policy and regulatory drivers:

- 2018 Railway Safety Act Review, which focuses on developing technology to assess in-motion train inspection and improving human performance using technology deployment in the railway sector for safer railway transport.
- 2016 Canada Transportation Act Review which calls for Innovative and technological solutions to rail challenges related to: the North and remote areas, high-volume trade corridors, TDG, etc.
- Transportation Safety Board Recommendation 14-02: The Department of Transport set stringent criteria for the operation of trains carrying dangerous goods and require railway companies to conduct route planning and analysis as well as perform periodic risk assessments to ensure that risk control measures work.

### ***Ground Hazard Risk Evolution with Climate Change***

**Background:** The effects of climate change over the last few years have been felt across the Canadian rail network. Examples include the Alberta floods of 2013 and the British Columbia floods in 2021, which severed several rail corridors. These events caused significant stress in the railway system, affecting industries that depend on the rail. This project aims at developing methods to provide quantified estimates of the changes in rail transport risk associated with ground hazard activity changes because of climate change.

**Research objectives:** The objective of this project is to develop a detailed method for the quantitative estimation of risk variability associated with ground hazards that would be a result of climate change in Canada. This method will be illustrated at two sites for its adoption by the railway industry and develop the system to evaluate the need to build resilience against ground hazards considering climate change.

**Research scope and methodology:** Failure modes and landslide characteristics will be evaluated using data provided by CN for the study sites in the Canadian Cordillera. Current and historical weather data will be collected from Environment Canada and other available sources, and their effects on the recorded landslides will be investigated. Then, forward modelling of climate prediction changes and quantifying their effects on the calculated landslide probabilities will be conducted. Weather predictions will be calculated through ClimateAB and ClimateWNA software and ClimateData.ca using different climate models and Representative Concentration Pathways (RCP). Finally, a statistical analysis of weather and failure conditions will be done using general statistical methods to calculate the landslide probabilities and changes in the probabilities considering climate change.

**Summary of work to date:** Nima Mirhadi (PhD) developed tools to quantify the effect of climate on rockfall occurrences along a railway section in BC and forecast expected changes in rockfall hazard with Climate Change. He also developed a method to correlate annual precipitation with volumes of material loss from a rock slope along a highway in central AB. His work was successfully defended in January 2024 and published as a thesis and two journal publications. One journal publication is under review. Ingrid Berru (MSc) developed a method to evaluate the changes in landslide stability with changes in reservoir elevation taking in consideration forecasted rapid drawdowns because of changes in climate in southern Alberta. She successfully defended in March 2024 and her work is published as a thesis. Currently, Essa

Gierc (MSc) is evaluating rockfall frequencies and volumes at a site where a wildfire occurred in 2021. Julian Solano (MSc) is processing change detection data for rock slopes in Alberta to build the database for rockfall sites.

#### **Research Team Members:**

1. University of Alberta: Dr. Renato Macciotta, Associate Professor; Dr. Michael Hendry, Professor, Essa Gierc, MSc student; Julian Solano, MSc student
2. Industry: Trevor Evans (CN); David Brown (CN); Ryan Kozun (CPKC)
3. Transport Canada: Kyle Beaulieu, Innovation Centre
4. Alberta Transportation: Roger Skirrow, Kristen Tappenden

#### **Timelines:**

- February 2025: Updated analyses of annual rockfalls and correlation to weather events and post-wildfire rockfall activity for one site.
- July 2025: completion change detection analysis for new rock slope sites for the first 1-year period.
- December 2025: Completion of detailed case study on rockfall activity post-wildfire and correlation with annual precipitation in the area. Analysis of initial rockfall activity for new sites and evaluation of differences associated with climate and geological conditions.

**Link to Policy/Regulatory Development:** This research is aligned with the The Pan-Canadian Framework on Clean Growth and Climate Change which calls for adapting and building resilience to climate change.

#### ***Wildfire Hazard Identification and Risk Assessment***

**Background:** Climate change has significant adverse effects on built and natural environments. In Canada, the rate of warming is more than double the global average, leading to a rise in major disasters such as floods, hurricanes, and wildfires, with increased frequency in recent decades. Particularly, wildfires are significantly impacting communities and critical transportation corridors, and the railway industry has been impacted by wildfires in various ways. Therefore, the railway industry, being susceptible to various impacts from wildfires, stands to benefit tremendously from the timely development of methodologies to assess wildfire-related risks and hazards.

**Research objectives:** The objective of this project is to develop an automated framework to assess wildfire-related risks to railway infrastructure using remote sensing data, and imagery collected from Hi-rail vehicles.

#### **Research scope and methodology:**

There are two aspects to this research topic:

- Establishing a risk assessment methodology based on wildfire hazards, exposure, and vulnerability to the railway and its critical infrastructure within Alberta;
- Developing an automated image processing framework to evaluate the condition of vegetation adjacent to a railway's right of way using satellite images and ground-level images captured.

As a case study, the proposed wildfire risk assessment framework is being implemented along CN's Edson subdivision, from milepost 62 to 72 between Edmonton and Edson in Alberta. The vegetation in this area consists of three common fuel types: conifer trees, deciduous trees, and grass. The recent wildfires in this region further highlight the ongoing risk.

**Summary of work to date:** We have compiled and evaluated a dataset of satellite images for vegetation fuel detection. Various deep-learning convolutional models were trained and tested to determine the architecture with the best performance. Given the limited availability of winter satellite images, we investigated multispectral data as a reliable proxy for fuel classification, enabling us to differentiate between various fuel types. The results related to deep learning and remote sensing for fuel detection are currently being finalized for submission as a journal paper. Additionally, we captured a dataset of high-resolution trackside and drone images for the region of interest in Alberta, with plans for further analysis in the next stage. We also processed LiDAR point cloud data from the area to extract geometric characteristics of the surface fuel near the rail track, including canopy height models.

**Timelines:**

- March 2025: Validation of deep learning method for classifying fuel types in summer and winter imagery.
- May 2025: Submission of journal paper related to fuel type classification.
- August 2025: The analysis of LiDAR point cloud data for vegetation attributes.
- November 2025: Processing of Hi-Rail truck inspections and drone footage using AI models and integration with the satellite imagery analysis to evaluate for dynamic fire-risk assessments

It is anticipated that the integration of data fuel, topographical analysis and regional weather information, to wildfire risk maps for railroads and critical infrastructure, along with publications and reporting are expected to be completed during the 2025-2026 funding period.

**Link to Policy/Regulatory Development:** This research is aligned with the Pan-Canadian Framework on Clean Growth and Climate Change which calls for adapting and building resilience to climate change.

**Research Team Members:**

1. University of Alberta: Dr. Mustafa Gül, Professor; Dr. Michael Hendry, Professor; Dr. Maziar Jamshidi, Postdoctoral Fellow; Dr. Nima Shirzad Ghaleroudkhani, Assistant Industrial Professor; Dr. Kent Jones, Postdoctoral Fellow (part time, expected start date February 1, 2025).
2. Industry: David Brown, CN
3. Transport Canada: Liam Vass and Sasan Ebrahimi, Innovation Centre

***The Resilience of the Railway Network***

**Background:** Resilience is the ability to prepare for and adapt to changing conditions as well as to withstand and recover rapidly from disruptions. It is during the pre-disaster context, however, that most of the work of railway resilience takes place. Achieving the transformative outcome of a stronger and more resilient railway requires a paradigm shift and the fostering of a new “culture of disaster resilience”. It requires a suite of engineering, adaptive and transformative resilience strategies which have different scales of time, effort and funding required for achieving these different constructs of resilience as well as varying degrees of longevity and effectiveness.

**Research objectives:** This project aims to improve the resilience of the railway network in the context of natural and human-induced disasters. The objectives of the project include the 1) assessment of the current usage of Canadian railway networks; 2) identification of critical junctions of railway networks; 3) compilation of historical disruptive events; and 4) quantification of post-disruption recovery of critical railway networks considering historical database.

**Research scope and methodology:** To quantify the attributes and determinants of resilience, the project adopts the resilience framework developed by the Multidisciplinary Center for Earthquake Engineering

Research (MCEER) for infrastructure resilience under seismic impacts. Through conducting a literature review (both academic publications and incident reports), this project will identify critical network junctions in terms of current traffic and recovery performance of historical disruptive events. In particular, the scope focuses on the post-disaster recovery of previous disruptive events (e.g., after derailment due to the 2013 Alberta floods). Data integration will be implemented through conceptualized illustration (i.e., subway map type) and as an interactive layer in the Geographic Information System (GIS).

**Summary of work to date:** A generalized metro-style railway network map was completed; this map reflects aggregated operations across the network, including the location and track details of the network to assess redundancy within the railway network system. The research has continued with the development of critical joints and routes with the identification of possible resources (for recovery) and re-routing options (for recovery) for all critical junctions. These characteristics will be measured quantitatively and integrated into the resilience assessment for the Canadian railway system.

**Timelines:**

- March 2025: Literature/report review and a volume-based transit map of critical routes/junctions at a national scale.
- June 2025: An incident-based transit map to identify critical routes/junctions.
- August 2025: Review of historical events and recovery assessment of critical routes.

**Research Team Members:**

1. University of Alberta: Dr. F. Albert Liu, Assistant Professor; Dr. Michael Hendry, Professor; Prabin Acharya, PhD student, Corrina Qian, MSc student.
2. Industry: TBD
3. Transport Canada: Kyle Beaulieu, Innovation Centre

**Link to Policy/Regulatory Development:** The National Supply Chain Task Force, launched by the Minister of Transport, was established to consult with industry experts and make independent recommendations regarding short and long-term actions to alleviate supply chain congestion. The Supply Chain Task Force recognized climate change as a driver of instability in transportation supply chains. The task force found that wildfires in July 2021 reduced railway operations by 30%, representing around \$163 million per day in terms of blocked shipment value. It also found that flooding in November 2021 hindered the movement of goods estimated to be more than \$170 million per day due to lost train capacity and increased congestion at the Port of Vancouver. The congestion at the port severely impacted the export and import of key commodities such as grain, coal, forestry products, fertilizers, and containerized goods. Major Canadian exports of high-volume bulk commodities (such as energy, agriculture, and key natural resources) depend heavily on rail to get to port and loaded onto ships destined for international markets. Disruptions to the transportation of any of these major commodities are prime examples of what can go wrong within Canada's transportation supply chain. Climate change also continues to intensify, and extreme weather events are happening more frequently, further increasing the risk of disruptions to the transportation supply chain — and the corresponding financial and economic impacts across Canada.

***Fundamental Steel Behaviour and Properties***

**Background:** Transverse cracking has long been considered to cause rail fracture that leads to train derailments. Although train derailments do not occur frequently, each occurrence always generates negative publicity for the rail industry. Therefore, extensive studies have been conducted to understand the causes of transverse cracking and to develop effective means to prevent derailments. From these studies, it is believed that several factors and their combinations could be attributed to transverse

cracking, including increases in axle loads, excessive train speeds, irregular inspection and maintenance schedules and presence of unidentified defects in rail steels. The proposed study will focus on two aspects, that is, identifying defects in rail steels that could be responsible for transverse cracking and understanding mechanisms that are responsible for the transverse crack development. As a massive amount of rail steel is used in the industry and the occurrence of transverse cracking is rare, a major challenge for this study is the collection of information relevant to the presence of defects and evidence of their links to transverse cracking.

**Research objectives:** The long-term objective of the proposed study is to develop a protocol to collect material properties on a regular basis and after each railway incident so that a database of material properties could be established for in-service rails. Using this database, defects in the rail steels could be identified and possible effects of their presence on the occurrence of transverse cracking established. The specific objective for the research plan of the proposed study is two-fold: (i) to evaluate the validity of measuring mechanical properties for rails in service without any destructive means in the sampling practice that is currently used, and (ii) to design a protocol for the mechanical property measurement in order to establish a database of mechanical properties for the rails in service.

**Research scope and methodology:** Establishing the above-mentioned database is possible because of our recent success in developing a non-destructive, indentation testing technique to measure mechanical properties such as elastic modulus, strength and fracture toughness. The indentation test could be conducted on rails without any interruption of railway service. The current standard test methods for the same purpose, on the other hand, require a destructive means of material sampling for the measurement.

**Summary of work to date:** The proposed project has successfully completed the development an indentation method using a flat-ended indenter, based on which fracture toughness of rail steel can be determined using single indentation test. The method has been verified using three types of rail steel, namely CZ, EV, and JP rails which were the initial rail steels used in the beginning of our study in this area. This achievement has led to completion of Stephen Okocha's PhD program in July 2024. This work has been submitted to peer reviewed journals.

Dr. Okocha has continue with this study as a Postdoctoral Fellow starting September 2024, and started the laboratory testing of the developed indentation testing to evaluating the fracture toughness change of in-service rails, and its use to evaluate welds.

**Research Team Members:**

1. University of Alberta: Dr. Ben Jar, Professor; Dr. Michael Hendry, Professor; Dr. Stephan Okocha, PDF; Brian Simon-Etim, Undergraduate co-op student.
2. Industry: TBD
3. Transport Canada Innovation Centre: Christine Backs

**Project Timelines:** Although the project has the above breakthrough in the technical work, there has been some difficulty in recruiting highly qualified personnel (HQP) to continue the study due to visa delays.

### **3.2. New research projects**

The following two projects emerged from stakeholder consultation during the spring and summer of 2024 as noted areas of research on human factors. The scope and approach of the project on Safety Management Systems (SMS) Key Performance Indicators (KPI) is currently under discussion with RRAB stakeholders.

## ***Safety Management Systems (SMS) Key Performance Indicators (KPI)***

**Background:** An effective Safety Management Systems (SMS) and a robust safety culture are critical elements to reducing incidents in high hazard industries. There are links between these two aspects of safety. Leveraging information collected during SMS audits could present a snapshot of where railways sit on a continuum from a poor to an excellent safety culture and could provide paths for safety culture improvement.

In 2021, TC's Rail Safety published a Safety Culture Policy Statement. This Statement includes a safety culture framework which consists of six positive and four negative characteristics. It may be possible to link SMS Effectiveness KPIs to the characteristics that comprise the safety culture framework to focus a strategy for safety culture improvement.

**Objective:** The objective of this project is to map the SMS effectiveness KPIs for each of the 12 SMS processes onto the safety culture characteristics identified within Rail Safety's Safety Culture Policy Statement. This information may help to assess where organizations are on the continuum from a poor to excellent safety culture and could outline safety culture improvement strategies

**Proposed Scope of Work:** A student will be assigned to undertake the following tasks:

- Understand SMS Regulations, 2015 and the SMS effectiveness KPIs for each process and determine the type of information that will be yielded by each of the indicators,
- Understand each of the characteristics contained in Rail Safety's Safety Culture Policy Statement,
- Establish a correlation between the characteristics and SMS effectiveness indicators (if a correlation can be made),
- Select an appropriate safety culture maturity model,
- Document all findings, and methodologies, and prepare a comprehensive report.

**Timelines:** Timelines will be determined as the proposed project is developed and as potential student researcher are available.

### **Research Team Members:**

1. University of Alberta: Dr. Renato Macciotta, Associate Professor; Dr. Lianne Lefsrud, Professor; Dr. Michael Hendry, Professor
2. Industry: TBD
3. Transport Canada: Daniel Blais, Christine Backs, Johanne Penington, Kim Ostapyk

## ***Root Cause Analysis (RCA) of Human Factors related Occurrences***

**Description:** Understanding the root causes of incidents is essential for developing effective preventive measures and fostering a safer working environment. Root Cause Analysis is the determination of the cause, that if it is corrected, will not only prevent the recurrence of this particular set of circumstances, but also similar ones.

This project will deliver a detailed Root Cause Analysis framework to identify and address underlying causes that, if corrected, can prevent the recurrence of specific incidents and similar ones in the future. The framework will distinguish root causes, which have broader, systemic implications, from direct and contributing causes, which are more immediate factors in events.

**Objective:** The objective of this research is to support the railway industry in adopting an RCA approach to incident and accident investigation to better understand the underlying causes and determine effective mitigations.

### **Proposed Scope of Work**

A student will be assigned to undertake the following tasks:

- Review the current challenges the industry faces in addressing the root causes of incidents and accidents involving human factors using (but not limited to) TSB data and reports.
- Identify and evaluate root cause analysis methods currently used by railways and other high hazard industries; identify the advantages and limitations to the use of these approaches.
- Develop a guidance document for the railway industry containing best practices in root cause analysis.
- Document all findings, methodologies, and improvements. Prepare comprehensive reports to share with industry stakeholders and regulatory bodies that will provide guidance to the railway sector on how to use RCA most effectively.

**Timelines:** Timelines will be determined as the proposed project is developed and as potential student researcher are available.

### **Research Team Members:**

1. University of Alberta: Dr. Renato Macciotta, Associate Professor; Dr. Lianne Lefsrud, Professor; Dr. Michael Hendry, Professor
2. Industry: TBD
3. Transport Canada: Daniel Blais, Johanne Penington, Kim Ostapyk

### **3.3. New research projects in development**

The following emerging topics were noted during the December 5, 2024, RRAB meeting. Scopes of work, commitments from stakeholders and identification of student researchers are all in preliminary development.

#### ***Data Analysis for the Technology Demonstrator of Railcar***

**Description:** Transport Canada (TC) is collaborating with the National Research Council of Canada (NRC) to develop a technology demonstrator railcar designed to inspect and collect data from railway tracks. The geometry data is gathered through the Automated Track Geometry Measurement System (ATGMS), while an instrumented wheelset measures rail forces. Additionally, cameras, ground-penetrating radar, or LiDAR may be installed on the railcar to collect supplementary data.

All collected data is anonymized and integrated into a platform developed by the NRC. There is an opportunity to develop analytical models and derive actionable insights from the data to enhance the monitoring and maintenance of railway tracks.

**Objective:** The objective of this research is to assist NRC and TC in analyzing the large datasets collected from the technology demonstrator railcar and in developing models to support the monitoring and maintenance of railway tracks.

### **Proposed Preliminary Scope of Work**

A student will be assigned to undertake the following tasks:

- Analyze the datasets collected from the technology demonstrator railcar, focusing on track geometry, rail forces, and other supplementary data.
- Propose and Develop models and tools to support the monitoring and maintenance of railway tracks, incorporating insights from the analyzed datasets.
- Document all findings, methodologies, and outcomes, and prepare detailed reports to share with industry stakeholders and regulatory bodies, offering actionable recommendations to enhance track maintenance and safety.

**Timelines:** Timelines will be determined as the proposed project is developed and as potential student researcher are available.

### **Research Team Members:**

1. University of Alberta: Dr. Renato Macciotta, Associate Professor; Dr. Lianne Lefsrud, Professor; Dr. Michael Hendry, Professor
2. Industry: TBD
3. Transport Canada: TBD

### ***Deterioration of Rail Ties – Assessing the Role of Climate Variability***

**Description:** Railway ties support rails, maintain track geometry, and ensure safe train operations. Tie failure occurs due to the forces generated by the interaction between wheels and rails; the stress levels at the rail base where it meets the tie can be significant. When these stresses exceed the tie's capacity, deterioration occurs, potentially leading to rail rollover and derailment.

Environmental factors, particularly those linked to climate change, play a significant role in tie degradation. Increased exposure to extreme wet-dry cycles and freeze-thaw cycles, increased by changing climate patterns, accelerates the deterioration process. These cycles can cause splits in the ties, which may propagate from one end to another. Precipitation, ice, or ballast entering these splits can expand the damage, compromising the tie's ability to hold spikes or support loads effectively. Monitoring the condition of ties is essential to mitigate these risks and adapt to the challenges posed by climate change. According to the Railway Tie Association (2024), 20 to 22 million rail ties are replaced annually in North America, emphasizing the scale of the issue and the importance of addressing the environmental factors accelerating tie degradation.

**Objective:** The objective of this study is to analyse the deterioration patterns of railroad ties and their correlation with climate change. The condition of the ties is evaluated using temperature and precipitation data collected over a period of years to assess the impact of these climate variables. The work involves analysing the historical data of the tie inventory by examining factors such as age, current condition, geographic location, precipitation, temperature, and other data based on the availability.

### **Proposed Scope of Work**

A student will be assigned to undertake the following tasks:

- Examine historical records of railroad tie inventory, including their age, condition, and geographic location, to identify patterns in tie deterioration by using advanced analytical methods like clustering techniques such as K-means clustering.

- Evaluate the effects of climate variables such as temperature fluctuations, precipitation levels, freeze-thaw cycles, and The Climate Moisture Index (CMI) on tie degradation over time by using the data from Environment Canada.
- Develop correlations between tie condition and climate data to quantify the impact of environmental factors on tie performance and identify potential failure risks.
- Document all findings, methodologies, and improvements. Prepare comprehensive reports to share with industry stakeholders.

**Timelines:** Timelines will be determined as the proposed project is developed and as potential student researcher are available.

**Research Team Members:**

1. University of Alberta: Dr. Renato Macciotta, Associate Professor; Dr. Lianne Lefsrud, Professor; Dr. Michael Hendry, Professor
2. Industry: TBD
3. Transport Canada: TBD

**4. Conclusions**

Stakeholder engagement is carried out annually during the fall RRAB meetings. Two detailed stakeholder engagement processes were undertaken with the RRAB in 2022 and 2023. This process elicited research project ideas and priorities from different departments of the federal government, industry members and academics at the University of Alberta. These projects were ranked, and the results are presented in **Table 2.1**, the table with a description of each project and their ranking score is provided in Appendix B. During the the December 5, 2024 RRAB meeting Stakeholders were asked to provide input on the projects listed in **Table 2.1** list or to provide any additional emerging topics.

The projects approved for the 2024-2025 year (**Table 3.1**) will be carried out with the methodologies and Junior Researchers described in **§3.1**. The projects approved for 2024-2025 that are currently underway are:

- Detailed Quantitative Model for Rail Transport of Dangerous Goods
- Ground Hazard Risk Evolution with Climate Change
- Wildfire Impact, Risks and Mitigation
- Fundamental Steel Behaviour and Properties

The projects approved for 2024-2025 that are currently underway, and expected to be completed within this year of the contract are:

- Resiliency of the Railway Network

The projects approved for 2024-2025 that are currently in-planning are

- Safety Management Systems (SMS) Key Performance Indicators (KPI)
- Root Cause Analysis (RCA) of Human Factors related Occurrences

The scope of work for these projects will be further developed in coordination with stakeholders and TC and initiated when the resources (project lead(s), Junior Researcher(s) and research days) are available.

The following emerging topics were noted during the Fall 2024 RRAB meeting and are in preliminary development *Data Analysis for the Technology Demonstrator of Railcar* and *Assessing the Role of Climate Variability on the Deterioration of Rail Ties*. Additionally, it was noted that the work on Wildfire Impact,

Risks and Mitigation should include a railway operational focus to bring further value for RRAB stakeholders. This aspect will be scoped out and may be added as additional future research.

## **Appendix A - Research Themes**

*The following is an excerpt from the Request for Proposals (RFP) issued by the Government of Canada that resulted in the contract T8009-210202. This excerpt is **Appendix A: Research Themes** from that RFP and represent the currently approved research themes for the contract.*

### **Theme 1: Climate Change and Environment**

- a. Climate change risk mitigation and adaptation techniques, practices, and technologies
- b. Sustainability/resiliency
- c. Zero emission and low-carbon propulsion technologies
- d. Environmental performance and lifecycle analysis
- e. Planning and environmental impact considerations
- f. Design/construction/maintenance practices

### **Theme 2: Operations**

- a. Operation, maintenance, and network optimization
- b. Intermodal or multi-modal rail operations and interactions
- c. Data driven maintenance planning
- d. Communications
- e. Improved interline reliability and supply chain transparency

### **Theme 3: Cold Regions Engineering**

- a. Frozen soils, permafrost, and frost heave
- b. Rail break mitigation and detection technologies
- c. Train braking systems and performance
- d. Switch performance
- e. Cold weather impacts on containers used to transport Dangerous Goods

### **Theme 4: Human Factors**

- a. Railway transportation safety
- b. Grade-crossings
- c. Trespassing
- d. Training
- e. Safety culture

### **Theme 5: Innovations in Railway Engineering**

- a. Advanced technologies for monitoring and inspection
- b. Materials technology and innovation (e.g., geotextiles)
- c. Design/testing/construction/maintenance
- d. Data asset management

### **Theme 6: Risk and Reliability**

- a. Vehicle/track performance and degradation
- b. Risk modeling and big data analysis
- c. Climate change and related hazard risk assessment
- d. Risk assessment of new technologies and practices
- e. Transportation of Dangerous Goods risk analysis
- f. Ground hazards risk analysis

## **Theme 7: Enhanced Train Control**

- a. Technology performance analysis
- b. Automation
- c. Communications and signaling
- d. Security

## Appendix B – Results of December 2024, Stakeholder Engagement

Two detailed stakeholder engagement processes were undertaken with the RRAB in 2022 and 2023. This process elicited research project ideas and priorities from different departments of the federal government, industry members and academics at the University of Alberta. These projects were ranked, and the results are presented in the table below along with descriptions. During the the December 5, 2024 RRAB meeting Stakeholders were asked to provide input on the projects listed in the table list or to provide any additional emerging topics.

The ranked list of projects was shared with RRAB members following the December 5 RRAB meeting, for any additional feedback, or input or to provide any additional emerging topics.

Title and Description
<p><b>Studying the Effects of Wildfires on Track Stability</b> <i>Score: 3.71</i></p> <p>Studying the effects of wildfires on track stability along with ways to remediate and reduce risks following a fire.</p>
<p><b>Testing/Assessment of Methods to Reduce Exhaust Sparking and Fire Risk</b> <i>Score 3.64</i></p> <p>Sparks from locomotive exhausts can ignite fires in nearby vegetation. Testing the effectiveness of spark reduction methods such as exhaust filters, and fuel additives could help reduce this fire risk.</p>
<p><b>Capabilities and Opportunities of Digital Twins for Short Lines</b> <i>Score 3.64</i></p> <p>A study to describe the concept of creating digital twins of shortline railways and to provide an understanding of the capabilities and opportunities. Digital twins can take various forms (visual, LIDAR, GIS layers or a combination there of) and could potentially be used for pro-active maintenance, operational planning or risk profiling and mitigation. A next phase of the work would involve application of the concept to a partnering shortline railway.</p>
<p><b>Incident Reporting and Inspection through Mobile Phone Application</b> <i>Score 3.64</i></p> <p>Explore the applicability of developing a cellular app for short line railways that gives railway workers the capability to report incidents and issues while out of cellular coverage. The app should have the capability to report, with text and photos, a variety of incidents and close calls, and rolling stock and track conditions.</p>
<p><b>In-field Pilot Tests of Wearable Technology to Improve Rail Worker Safety</b> <i>Score 3.64</i></p> <p>Continue research of wearable technology for rail workers. Assess their effectiveness with a pilot test to see concrete outcomes of their use.</p>
<p><b>Biofuel Development and Testing</b> <i>Score: 3.57</i></p> <p>Assessment of the performance of biodiesel in use in cold weather conditions.</p>
<p><b>Open Source Library of Images for Machine Learning Purposes</b> <i>Score: 3.50</i></p> <p>Creating a data bank of images that could be used for machine learning for flaw detection and infrastructure problems within the context of a visual digital twin of the railway.</p>

**Hand Brake Resistance Monitoring/Testing** *Score: 3.43*

The development and testing of hand brake resistance monitoring/testing technologies to determine how many brakes on stationary cars need to be set to secure them safely/adequately.

**Updating Rail Neutral Temperature** *Score: 3.43*

With significant changes in our climate, rail infrastructure will be exposed to extreme temperatures in years to come. These changes may make the current rail neutral temperature (RNT), the temperature at which rail internal forces are zero, irrelevant. An analysis of near future climate could inform an update to the RNT.

**Hydrogen Tender Car Safety Research** *Score: 3.43*

Contribute to the on-going research efforts to develop and design safety criteria for hydrogen tender cars. Though there is on-going testing of tender cars by CPKC and the FRA, there is potential for collaboration, exploring risks, safety concerns and operational characteristics of the concept.

**In Service Rail Stresses (focus on residual stresses)** *Score: 3.36*

There are still gaps in our understanding of the stresses in rails, specifically residual stresses. Objective would be to evaluate/trial technologies to measure residual stresses in rail.

**In-situ Deformation of Track Under Train Load** *Score: 3.36*

The testing and or development of technics to measure the In-situ deformation of track under train load where works are being undertaken that could result in the deformation of the track. It appears that fiber optics and or SlopeAccelArray technologies would be applicable to this situation. The challenge is the detection and quantification of measurable track movement with sensors that will not be damaged by railway operations or track maintenance where the background “noise” of railway operations can be differentiated from measurement of the track movement.

**Framework for Preliminary Assessment of New and Emerging Rail Technology** *Score: 3.36*

Research and development can bring forward new and innovative solutions for rail safety but lacking a method to evaluate the idea as a whole can lead to work that ultimately would struggle to be implemented. This project would develop a framework for assessing new technology innovations from a variety of perspectives, including aspects such as safety benefit, cost, life-cycle disposition, and key metrics of operational feasibility (e.g. manufacture, inspection, survivability), so that decisions on whether to continue development can be based on the overall likelihood to succeed and be implemented by industry.

**Evaluation of the Increased Risk of Geohazards Post Wildfire** *Score: 3.36*

Evaluation of the increased risk of geohazards post wildfire, including debris flows and rock falls.

**Permafrost Degradation Mitigation** *Score: 3.36*

Assessment of approaches and methods to mitigate permafrost degradation’s effect on track. This could include trials of different methods and monitoring the performance of those methods with remote tools like InSAR. This would need to be a long-term project over 5 to 10 winters.

**Retaining Railway Employees** *Score: 3.36*

There are challenges in retaining employees in the railway sector. Losing employees cause the immediate pressure of less resource but also a significant financial loss due to time and resources spent on training and certification of new hires. Obtaining a better understanding of what is causing employees to leave the rail sector could help to find ways to strengthen employee retention.

**Alternative Track Materials** *Score: 3.29*

Exploring the financial and operational impacts of replacing current rail track materials with those which have a lower carbon footprint. This would require financial analysis, and material stress and fatigue testing.

**Evaluation of Tunnels and Rock Bolt Identification Using LiDAR** *Score: 3.21*

LiDAR data can be collected from rail vehicles. The objective of this work would be to adapt 'change detection' methods developed for rock faces to tunnel walls, and to automatically identify rock bolts.

**Fibre Optic Monitoring for Rockfalls and Change Detection** *Score 3.07*

Technology is available for monitoring very long section (multiple miles of track) for deformation and rockfall impacts. The technology still requires testing for use in the rail environment.

**Connectivity on Canadian Railways** *Score 2.86*

A feasibility study to further analyze the capabilities of different wireless communication networks like 4G/LTE, 5G, 6G, and Satellite (Starlink). The information from this study could be used in the development of the Railway Internet of Things (RIoT) or for enhanced train control systems.

**Cybersecurity in Rail** *Score 2.50*

With increasing digitization and deployment of technology in the rail sector, there is a need to better understand the threats, vulnerabilities and risk related to cybersecurity in the sector. This work would help to understand the threats, vulnerabilities and risk related to cybersecurity in rail transportation as well as tools and best practices for prevention and mitigation.