Interim Report for Creative Sentencing

Building Resilience into Safety Management Systems: Precursors and Controls to Reduce Serious Injuries and Fatalities (SIFs)

Lianne M. Lefsrud, Fereshteh Sattari, Ian R. Gellatly, Claire Wasel, Rose Marie Charuvil Elizabeth, Amir Abdolmaleki, Samantha Jones, & Thomas O'Neill

David and Joan Lynch School of Engineering Safety and Risk Management

Energy Safety Canada

Alberta Construction Safety Association

Construction Owners Association of Alberta

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Executive Summary

On January 13, 2021, a contractor, Patrick Poitras was operating a John Deere bulldozer on a frozen tailings pond at the Suncor base mine, when the ice broke and the dozer fell through, drowning the operator. Suncor and the contractor Christina River Construction each pled guilty to one count of a violation of Alberta's Occupational Health and Safety (OHS) Act. The purpose of this project is to examine the hazards and precursors of serious injuries and fatalities (characteristics of the work/environment, human and organizational factors, and management system), in Alberta's oilsands industry, identify indicators and controls, and implement system-level assurance of controls.

Shareholders and customers are demanding increased accountability, transparency, and comparability of companies' risk management. Despite the benefits of technological risk management methods to achieve these goals, there is a chasm between companies' safety intent and implementation: 96% appreciate the value of technology, and 77% say safety is part of their corporate culture, but only 32% use leading indicators and just 11% fully use technology. These gaps contribute to serious injuries and fatalities (SIFs).

SIFs have complex precursors that are not easily visible in companies' physical environment, reports, or what workers say – but only in watching the 'work as done' and how it differs from 'work as intended'. Even for routine work, controls are often absent, bypassed, or non-functional. This interim report shares our first year's progress in examining human, organizational, and cultural factors – especially the interactions and differences between owners/operators, contractors, and subcontractors.

We are developing new methods to analyze near misses, audits, inspections, and project data and applying new lenses from psychological models of efficacy and competency to reveal precursors that are often overlooked but useful to predict (and prevent!) serious incidents. We are developing surveys and interviews to better understand the organizational and safety culture, team climate, and human psychosocial factors that may influence safety behavior and SIFs.

We have held two SIF workshops to identify, implement, and monitor critical controls for hazards with the potential for SIFs. During a November 2023 workshop in Ft. McMurray with 115 workers, we developed bowties to visualize the causes, consequences, and controls for six major incident hazards: 1) heavy-light vehicle interaction, 2) lifting and hoisting, 3) active haul operation, 4) confined space, 5) dropped objects, and 6) working at heights. These bowtie models can be used to visualize and understand the systems, causes, and consequences that are often complex and hidden. They will be useful for future training and critical control assurance.

Overview of our planned research over the next year

Human and Organizational Factors as Precursors for Safety Performance:

There is a lack of knowledge regarding the range of person and social/group factors that shape day-to-day safety decisions, behaviors, and outcomes. This is especially true in complex and dynamic work environments where safety hazards impose serious risks to employees and the organization. A data-informed method is needed to explore the key person and social/group factors that impact employee safety performance. This study seeks to identify the human and organizational factors that contribute to the occurrence of SIFs, as well as how these variables may interact to influence day-to-day safety behaviors among work units. The expected results for this study include identifying the most influential person and social/group factors that cause incidents, and subsequent implementation of data-informed decision-making methods to enhance safety practices.

Using Machine Learning and Natural Language Processing to Enhance Safety Performance and Quality of Occupational Health and Safety (OHS) Procedures by Focusing on Missing Socio-Technical Factors in the Mining Industry:

There is a lack of comprehensive studies investigating the socio-technical (ST) factors that influence safety performance among contractors and employees in dynamic work environments like the mining industry, thus highlighting the need for a data-informed method to identify the contributing ST factors. Therefore, this study aims to identify socio-technical factors not captured during safety inspections using machine learning, natural language processing, and text mining techniques. The study's findings aim to provide insights for decision-makers about the strategies needed to enhance safety performance in the mining industry.

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1 Introduction

Alberta's Occupational Health and Safety (OHS) Code contains Canada's most detailed and prescriptive requirements around hazard assessment and control. Employers must assess a work site and identify existing and potential hazards before work begins at the work site or prior to construction of a new work site. Employers must prepare a formal report of the results of a hazard assessment, the methods used to control or eliminate the hazards identified and ensure that the hazard assessment is repeated at reasonably practicable intervals and when work processes or operations change. While much effort has been devoted to articulating and spelling out state-of-the-art safety rules and procedures, far less attention has been given to the implementation of these work rules as day-to-day decisions, actions, and more informal site/field hazard assessments. Understanding why we have a "knowing doing" gap in safety management has been a persistent challenge for Alberta companies. Our research questions: Why do some companies succeed, and others struggle when it comes to safety? How can we build resilience in the industry's safety management systems and reduce serious injuries and fatalities?

A recent survey of the Construction Owners Association of Alberta and their supplier companies offered a glimpse of where the problems might lie (Lefsrud et al., 2022). The findings of this study revealed that companies, many of which were in the oil and gas sector and operating under the same formal safety rules, manifested qualitatively different implementation (safety-culture) patterns. Roughly two-thirds of the companies exhibited shades of an "optimal" safety culture whereby management's commitment to safety was aligned with the communication and use of safety procedures throughout the organization and the companies risk tolerance. However, one-third of the companies exhibited sub-optimal forms of safety culture where day-to-day decisions and acts seemed disconnected from each other or from management commitment to safety.

Another survey of 2000 Albertan workers indicates that compliance with Alberta OHS's hazard assessment and control requirements is uneven (Alberta Workers' Health Centre, 2015). Compliance with OHS's paperwork should not come at the expense of managing high risk tasks in real time. The survey found that 36% of employers seldom or never conduct hazard assessments. Only 19% of workers report that their employer always involves them in the hazard assessment process, 30% of workers report not being told about workplace hazards, and only 18% of workers are moderately or very interested in their company's OHS initiatives because of lack of pay and influence. Despite unsafe working conditions, workers choose to stay because they are receiving relatively good compensation, proud of their work, rationalizing their commitment, or normalizing their risk taking (Pfeffer, 2018).

1.1 Rationale and Outcomes

Hazardous industries face challenges in managing high consequence, low frequency failures. In the US, the total recordable incident rate has declined significantly over the past thirty years, yet worker fatalities have not (Bureau of Labor Statistics, 2018). Conversely, the Canadian oil and gas industry is decreasing its lost time and serious injuries and fatality rates. But serious injury and fatality statistics from mining (more closely representative of oilsands operations) are more difficult to find. Improving the safety of oilsands and conventional oil and gas industry has far-reaching consequences. In 2022, approximately 138,000 people were employed in Alberta's upstream energy sector (Statistics Canada, 2022).

Analysis shows that the causal factors for SIFs are different from those for more frequent, minor injuries (Krause & Murray, 2012; Manuele, 2014; Mattis & Nogan, 2012). SIFs are more likely for work with heights, electrical exposures, confined spaces, struck-by and caught in/between hazards, and hazardous materials. Industries have created lifesaving rules specifically for high hazard tasks, but implementation is uneven across companies (Scotti et al., 2018) and contractors (Walker et al., 2020). Highly hazardous work is often nonroutine and infrequently performed; there are one fifth the observations for high versus low consequence tasks (Manuele, 2008). Yet even routine activities can cause SIFs if there are no/ineffective/bypassed controls (Brady, 2019), poor/risky standard operating procedures (SOPs), or deviation/drift from procedures over time (Martin & Black, 2015). The precursors tend to be human and organizational (psycho-social, culture, management) (Lefsrud et al., 2022), that are less visible – often shown as the 90% of the iceberg that is beneath the surface (Busch et al., 2021). These factors are also more difficult to audit and have complex non-linear interactions, as identified from machine learning (Sattari et al., 2020). Thus, the creation, use, and analysis of precursors and critical controls can be even more difficult to identify and apply.

We identified many of these precursors as part of a previous creative sentence for tailings safety (see Figure 1), through several phases of data collection and analysis (Baker et al., 2019). We will extend this research to deliver the following outcomes:

1.1.1. Create a hazard inventory of 'work as planned' in all oilsands mine operations (mining, extraction, treatment, and tailings) and ancillary activities. Compare this to 'work as done' – as identified by surveys, interviews, and observations
1.1.2. Identify/develop indicators for SIF precursors, controls, and audits.
1.1.3. Determine which activities are most likely to be completed by contractors.
1.1.4. Examine how indicators, controls, and control/barrier assurance vary across owners/operators, contractors, and subcontractors.
1.1.5. Survey the prevailing safety culture within owners, contractors, and subcontractors.
1.1.6. Recommend systems-level, multi-layered, redundant, and auditable controls.
1.1.7. Implement these controls into owners/operators', contractors', and subcontractors' safety management systems. Audit and test the efficacy of these controls.

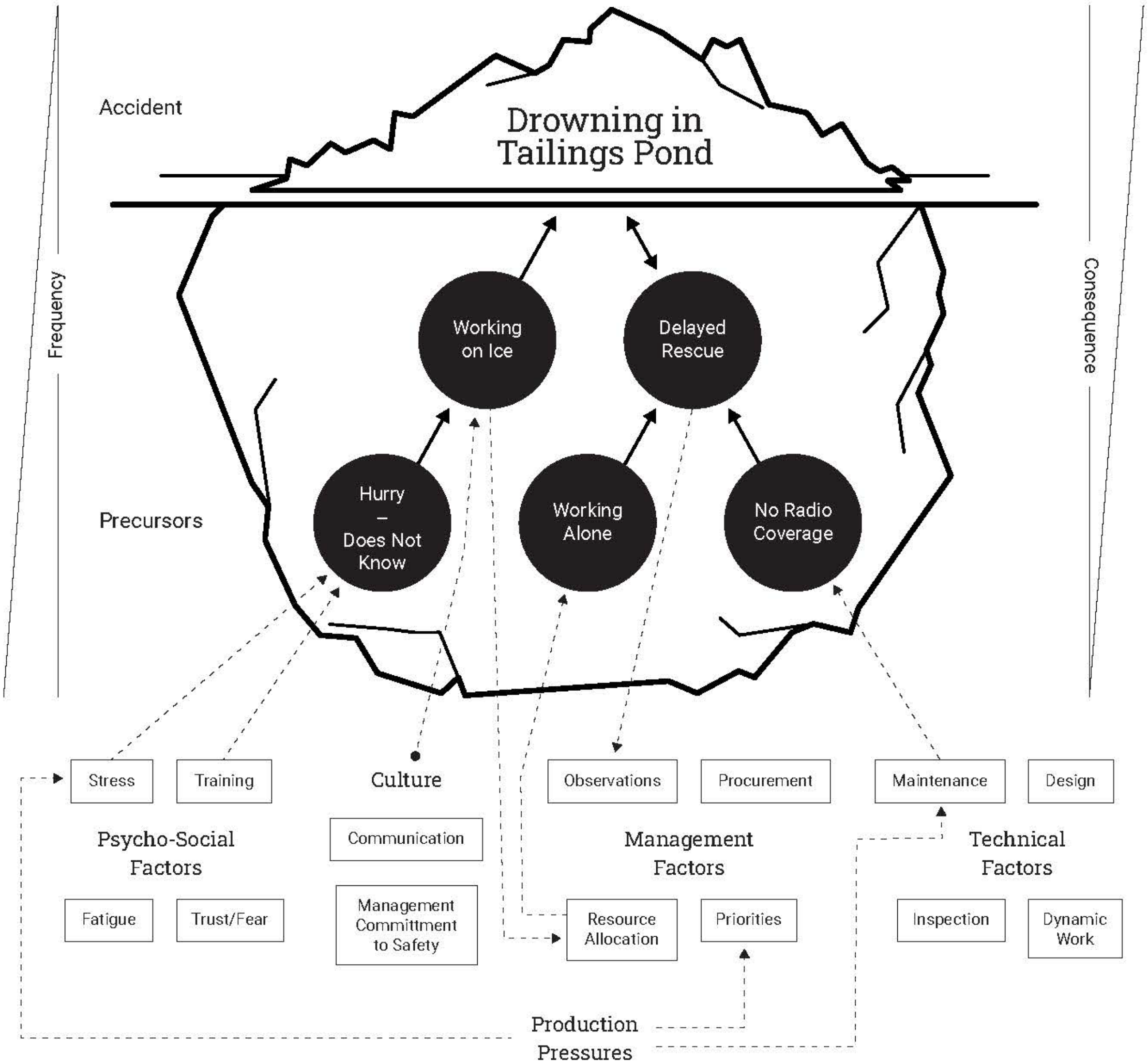

Figure 1. Precursors for drowning in tailings pond

1.2 Project Team

The following is a list of members of the project team based at the University of Alberta, the David and Joan Lynch School of Engineering Safety and Risk Management (ESRM) and the University of Calgary.

Project team at the University of Alberta:

- Lianne Lefsrud, Ph.D., PEng. Principal Investigator. Lynch School of Engineering Safety and Risk Management, Chemical and Materials Engineering.
- Fereshteh Sattari, Ph.D., Lynch School of Engineering Safety and Risk Management.
- Ian R. Gellatly, Ph.D., Alberta School of Business.

- Claire Wasel, BA Honors Psychology., Lynch School of Engineering Safety and Risk Management, Chemical and Materials Engineering.
- Rose Marie Charuvil Elizabeth, MSc., Lynch School of Engineering Safety and Risk Management, Chemical and Materials Engineering.
- Amir Abdolmaleki, MSc., Department of Electrical and Computer Engineering.

Project team at the University of Calgary:

- Thomas O'Neill, Ph.D., Department of Psychology.
- Samantha Jones, MSc., Ph.D. Candidate, Department of Psychology.

1.3 Guiding Framework

For this research, our research team is actively engaged with our practice and policy partners at all phases of scoping, defining our methods, and actively disseminating findings as they become available to aid uptake and implementation. Our approach to this project is guided by our adaptation of the Co-produced Pathway to Impact outlined by Phipps and colleagues (2016). This is illustrated in Figure 2. Their approach explicitly targets the interactive and iterative roles of both the researcher and the community, in both policy and practice, in producing, sharing, and benefitting from research activities to make the biggest impact (see Figure 2). At each stage of the process, researchers and policy and practice partners both collaborate (overlapping spheres in Figure 2) and contribute in their own unique and distinct ways to accelerate the impact of research. This co-creation process also allows for more breadth and depth during the uptake and implementation processes than researchers could obtain on their own, leading to a greater impact overall. This knowledge mobilization methodology encourages ongoing and enduring relationships between partners to generate new questions, knowledge, and see the impacts through as opposed to a more disjointed approach where researchers "give" their findings to their stakeholders.

In our adaptation, we have identified the key parties that will engage in our project as well as the specific benefits of each of the iterative stages (Figure 2). Beyond the co-creation partners currently identified in our model, we see vast opportunities for our research to include additional co-collaborators (e.g., Alberta Mining Safety Association (AMSA) and have a widespread impact across all major heavy industry, beyond oil and gas extraction. Through these partnerships, the research generated will provide benefit through new knowledge, progress new and more advanced research questions, and provide impactful development opportunities for academic trainees (Masters, PhDs, Post-doctoral Fellows). Through this iterative knowledge generation process, all members of the research team, and policy and practice partners have the invaluable opportunity to learn from one another to solve life-altering challenges. It would not be possible to provide the benefits outlined in the model and reduce SIFs in a meaningful way without the combined knowledge and expertise of all the parties involved.

We have expanded our adapted knowledge mobilization model to more specifically highlight the new methods that this work will generate and the new tools and methods that teams, organizations, industries, and society can benefit from. For example, our work will generate new approaches to data fusion across systems, allowing us to see previously underexplored patterns between the precursors and consequences of safety incidents in routine and non-routine work. The benefits of AI machine learning and new analytical algorithms will provide essential insights that we previously haven't had the power to uncover in a meaningful way, given the complex, non-linear interactions of relevant factors. Our work will also generate new data sources and tools for teams and organizations across heavy industry to understand how human and organizational factors are impacting safety behaviors in real-time (e.g., development of custom surveys and reports in ITPMetrics) and new methods of hazard visualization to make elements of safety that were previously hidden, accessible, and identifiable (see Figure 1). Our new methods and tools will provide unparalleled benefit for the understanding of hazardous work, open crucial conversations about topics that were previously not possible, and help teams and organizations work safely.

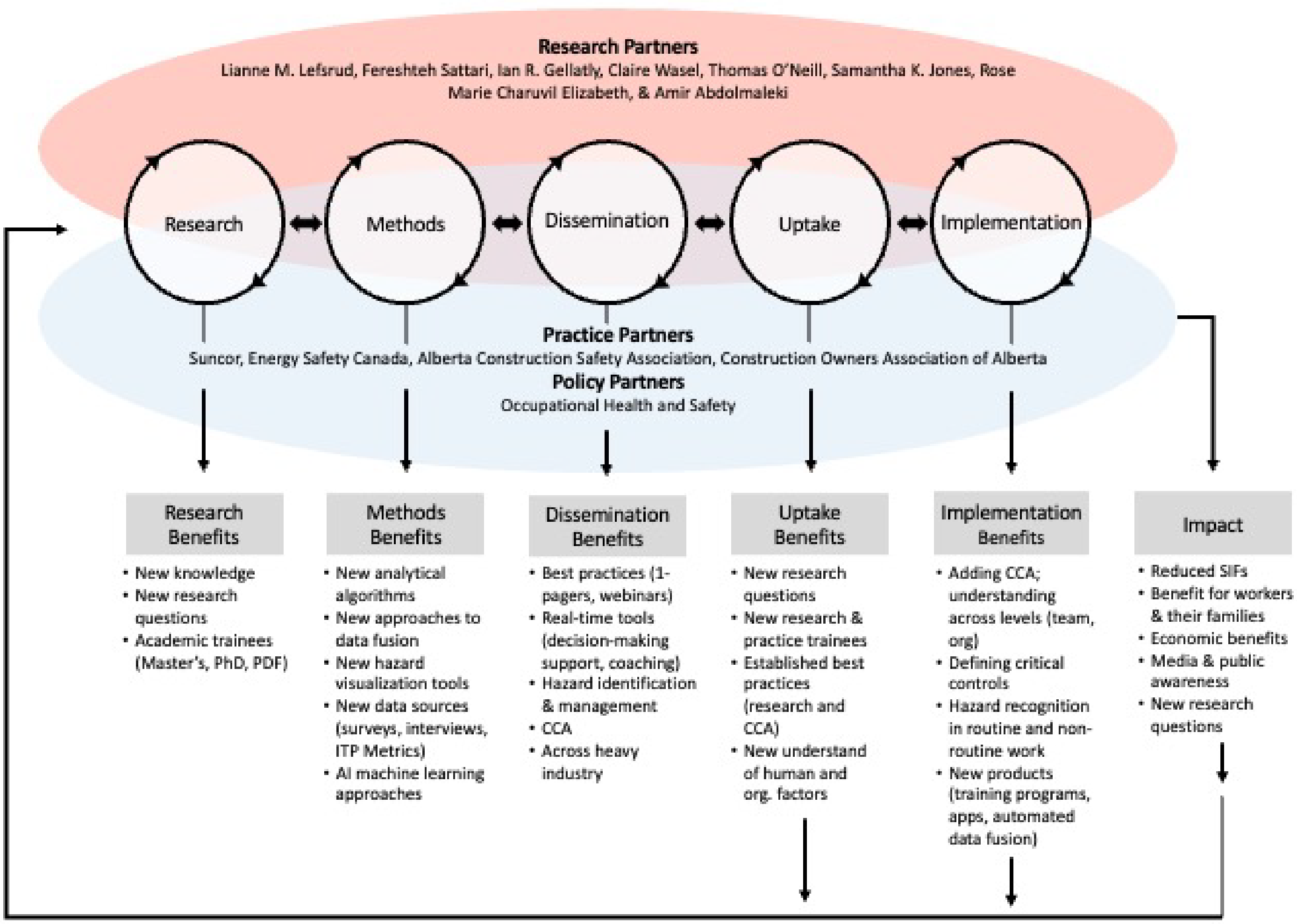

Figure 2. Schematic depicting the framework of knowledge mobilization for the project (adapted from Phipps et al., 2016) Note: CCA – Critical control assurance.

In disseminating the discoveries in this work, we will leverage the expertise and perspectives of our research team and policy and practice partners to provide answers to the questions that are front of mind for organizations and workers (e.g., how do we embed critical controls into everyday work, how do we share this information with contractors in a way that is effective). Co-production in this way ensures that the findings and implications are presented in a way that is meaningful, practical, and accessible to the intended audience. Some of the benefits of this process include sharing newly defined best practices through events like webinars or one-pager summaries that can be circulated to front-line teams and leaders across industry (e.g., energy industry, construction). On-the-job, our new insights can be shared through real-time tools that identify how the team is currently functioning, hazards that might be relevant in routine and non-routine work, and provide coaching for both team and hazard management and decision-making. Identifying critical controls and adding critical control assurance will simplify procedures for workers while making safety the top priority. These learnings and best practices will have far reaching applicability and the power to shift the industry. These tools will provide better predictability and preventability and facilitate organizational learning and resilience.

Through the uptake and implementation of the processes and outcomes of this research, our partners and beyond have the opportunity to leverage many benefits. The iterative process highlighted by this model emphasizes how integrating these findings into everyday work practices and policies can generate new research questions and avenues of exploration that can further bolster the impact of the work. Translating our improved understanding of human and organizational factors related to SIFs to stakeholders will foster the adoption of best practices and the implementation of critical control assurance across levels (e.g., teams, organizations, industries). The implementation of our findings will also generate new products within organizations such as training protocols, apps to identify, monitor, and manage safety factors, and new methods of data fusion across sources to enable continuous insights and improved prediction. These tools, and other benefits of this work, will further support future definitions of critical controls and the continued improvement to the identification of hazards. The use and adoption of the co-created knowledge is a vital step in translating data collection and research activities into real-world benefits and impacts for the beneficiaries of this work.

Lastly, the impact of this research and the culmination of the benefits at each stage is paramount. This work stands to reduce SIFs, save lives, and benefit the well-being of workers and their families. Decreasing the SIF rate by just 10% within these industries would save 30 lives per year and each of the benefits along this co-creation process play an important role in realizing that impact. Our work will also have a broader impact on public awareness and the factors that impact safety in the workplace through online platforms, social media, and blogs to share the findings of the analysis. This will involve creating engaging content, such as infographics, videos, and podcasts that help deepen society's understanding of these occupations and what can, and is being, done to improve safety and well-being. In addition to preventing the loss of lives, reducing SIFs also avoids other direct costs (workers' compensation payments, medical expenses, and legal services) and indirect costs (training replacement employees, accident investigation and implementation of corrective measures, lost productivity, repairs to damaged equipment and property, and lower employee morale and absenteeism) which impact our economy. In total, workplace incidents and the associated losses equate to 4-5% of the annual global gross domestic product; greater than Canada's real GDP growth rate (averaging 1-2% per year over the past 10 years.

Adopting an approach like the Co-Produced Pathway to Impact ensures that the partners that can benefit the most from our work are included in every step of the process and stand to reap the benefits from the initial stages of research creation to the lasting stages of implementation and impact. We aim to make our workplaces safer and value the co-producers that work with us through this process to make that possible.

1.4 Budget and Schedule

As of 15 April 2024, our expenditures are on track. Details are given in Table 1.

Table 1. Expenditures as of 15 April 2024

Funds Available before expenditures (A):		**$370,000.00**
Expenditures		
Salaries and Benefits-BL (students, research associate) *	$229,709.57	
Supplies and Other-BL (printing and supplies for workshops, PPE for site visits)	$5,905.73	
Travel-BL (to Calgary workshop, Fort McMurray workshop/focus group, and site visit)	$26,986.93	
Capital Assets-BL (computer software)	$824.76	
Total Direct Expenses (B)		$263,426.99
Funds Available before Indirect Costs as of 04/15//2024 (A-B):		$106,573.01

* Includes $109,000 subgrant transfer to University of Calgary to cover graduate student research support and other research-related expenses completed to date and for the remainder of Phases 2-4, by Dr. O'Neill's group.

As per our proposed schedule (see Table 2), we are largely on track. Phase 0 – Preparation proceeded as planned. Phase 1 – Host kick off meeting and secure data as also proceeded as planned. However, some tasks have taken longer than expected, such as data access and formatting. Phase 2 – data analysis is proceeding well. Our survey is being developed and we expect this to rolled out in May-June 2024 and analyzed by August 2024. This online survey of individual workers – employees of Suncor, contractors, and subcontractors – will allow us to examine which work is done and by whom; create an inventory of identified/recognized hazards in all oilsands mine operations; identify companies' use of leading indicators, controls, and control/barrier assurance; and safety culture.

Table 2. Project Schedule

	2023									**2024**												**2025**			
Phase	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
0 - Preparation																									
1 - Host kick-off meeting and secure data																									
2 - Identify/ develop indicators for SIF precursors, controls, audits													◆												
3 - Identify and implement best practices in the industry																									
4 - Industry sharing and education																									◆

We describe these activities in more detail in the following sections.

2 September 21, 2023 Symposium: Building Resilience to Serious Injuries and Fatalities (SIFs)

The symposium was held in-person at the University of Alberta - Calgary Campus on September 21, 2023, from 7:30 a.m. to 12:00 p.m.

2.1 Purpose and Objectives

The overarching purpose of this event was to better understand serious injuries and fatalities (SIFs), create better leading indicators, and develop industry collaboration and solutions with regards to oilsands SIF data. Specific objectives of the symposium were to accomplish the following:

- Connect and catalyze engagement amongst companies who are examining SIFs.
- Share challenges in examining the human and organizational precursors for SIFs.
- Enlist companies in developing a research solution framework to improve SIFs.
- Examine how data analytics and psychological models can enhance team learning and competency, hazard identification and management, and contractor coordination.
- Discuss priority outcomes and what a 'successful' research program is for participants.

The research team developed discussion questions aimed at eliciting information and generating feedback from symposium participants to identify where the gaps lie in the industry. To advance the research, the research team was also seeking insight from industry professionals on the following research questions and how they could be improved:

1) What unique socio-technical factors influence the risk among contractors and employees?
2) What are some missing socio-technical factors that are not captured during safety inspections and audits?
3) What recommendations can be made to improve the quality of occupational health and safety (OHS) procedures by recognizing the missing socio-technical factors?

2.2 Participants

About a month prior to the event, the research team circulated an invitation to subject-matter-experts within the industry. Here, people were provided with an overview of the event in terms of its purpose and details, and why their participation was valuable. To encourage open and frank conversations, the invitation clarified that any and all information shared during the event would be used to develop the research program but not attributed to any one person or company. Suggestions for who should attend were included on the invite: *Director of Business Systems, Information Management, Technology/Strategic Planning, Safety Management Systems, Operational Risk Technology, Emergency Management, Analytics and Reporting, Process Safety Engineering, Business Intelligence and Analytics.* The invite was shared with contacts in Energy Safety Canada (ESC), Suncor, the Alberta Construction Safety Association (ASCA), and the Construction Owners Association of Alberta (COAA), who were asked to share the invite with other potential participants including contractor companies. In total, the final confirmed list of participants included 35 people, drawn from fifteen different organizations such as oilsands companies, safety consulting companies, and OHS strategic initiative representatives.

2.3 Symposium Process and Itinerary

2.3.1. Summary: Pedagogy, Technology, and Process

The process was designed in such a way to facilitate open, generative discussion among symposium participants. Session facilitators from the research team used slides to offer context for the discussion questions. One of the pedagogical techniques was to employ an online tool, Mentimeter. In short, questions were displayed on the overhead screen in the room and participants could anonymously submit their answers using their cell phone or laptop. Once response data had been collected, Mentimeter processed the responses in real time and offered an aggregated summary of the responses to symposium participants. Organized in small groups of about eight people (see Figure 3), participants were instructed to discuss the prompting question as well as the aggregated feedback with others at their table. Notes were taken to track the discussion topics and comments. Following the small group discussions, a member of the research team facilitated a large group discussion whereby representatives from each of the tables shared what they had discussed and how it related to the focal questions.

Figure 3. Image by AMIA (2023) illustrating how participants were seated at tables in small groups during the symposium.

2.3.2. Materials: Outline

The symposium outline was shared with registered participants in advance, and they were encouraged to consider the discussion questions ahead of the event.

Part 1: Introduction: Why are we here?
- Describe the purpose of the workshop
- Introductions: Name, organization, interest in SIFs and resilience

Part 2: Interrogating key concepts
- How does your organization define Serious Incidents?
- What are your organization's leading indicators for SIFs? How 'good' do you consider these leading indicators to be? Why?
- What cause-effect-control models does your organization use to understand SIFs?
- How could your leading indicators and cause-effect-control models be improved?

Part 3: Examining human and organizational performance
- What are human and organizational factors? Which are most predictive of SIF? How could you operationalize and better monitor these?
- What psychological models can enhance team learning and competency, hazard ID/management, contractor coordination?
- What barriers does your organization face in operationalizing, identifying, and monitoring these?

Part 4: Building resilience in your risk management system
- Resilience principles
- Present various AI Machine Learning (AIML) methods to test predictive power of various precursors
- Discuss what data and analysis would be of greatest value to your organization

Part 5: Concluding remarks and next steps

2.4 Symposium Process and Content

2.4.1. Process Overview

The following questions were posed to participants during the workshop and their responses were captured using Mentimeter. Participants engaged in roundtable discussions with others seated at their table. A member of the research team was seated at each table to take notes and capture the content of these small group discussions. Facilitated large group discussions followed the small group discussions. Summaries of the Mentimeter responses and group discussions are presented below, as well as a sample of the slide content:

2.4.2. Part 1 (Content): Introduction: Why Are We Here?

The session began with slides describing the purpose of the symposium. Many industries are doing a poor job of understanding high consequence, low frequency failures. Despite the financial benefits of risk management, there is a chasm between companies' safety intent and implementation. The ratio of less to more severe injuries is variable across companies and no constant ratio exists, thus we cannot use Total Recordable Incident Rate (TRIR) / Total Recordable Incident Frequency (TRIF) / Lost Time Incident Rate (LTIR) as predictors for SIFs. Even routine activities can cause SIFs if there are ineffective controls, poor standard operating procedures, or deviation from procedures over time. Instead, we must understand SIF precursors in our organizations, integrate interventions into our existing safety management systems, and enhance incident reporting and investigations to capture SIF potential to predict (and prevent!) serious incidents.

2.4.3. Part 2 (Content): Interrogating Key Concepts

Interrogating key concepts covered SIFs, leading indicators, cause-effect-control models, and precursory conditions. This section began with a Mentimeter question.

Mentimeter question 1: How does your organization define serious injuries?
- Life-altering (acute or chronic) or life-threatening
- Definition based on Alberta OHS and legislation
- Based on risk matrix
- Potential to cause death

Slides on the various ways of defining serious injuries followed. This included defining serious incidents as consequence, as multifaceted consequences based on the degree of severity (health/safety, environmental, reputation, financial), how regulators and researchers are defining serious injuries, the LIFE model of defining serious injuries, and defining serious injuries as a function of major incident/accident hazards.

Mentimeter question 2: How would you like to define serious injuries?
- Multiple SIF categories: Define serious injuries as life-ending, life-threatening, or life-altering with multiple categories including the possibility of having hazards
- Injuries and illnesses (i.e. silicosis; hearing loss) should be captured under SIF category
- Align with University of Colorado's terminology
- Define within risk tolerance
- Consider International Council on Mining and Metals (ICMM) definitions for SIF-related activities
- Consider accumulated health damage that appears over time or after retirement

Mentimeter question 3: What leading indicators does your organization use for SIF?
- Types of PSIs
- Worksite inspection audits and near-miss hazard identification
- Critical control verification and focused hazard identification exercises
- Critical controls assurance in the field
- HiPo near misses
- Incident data
- Qualitative indicators focused on the quality of activities
- Predominantly based on high-risk activities
- Critical risk violations
- Precursors in place with hazards identified and training completed in worker profiles hazard assessment
- Worksite inspections and audits as non-debatable communicators with less subjectivity
    - Focusing on consistency with audits
    - Focused audits on a small piece (e.g. dropped objects)

- Frontline workers choose leading indicators (usually 3-5 for each activity) through conversations with the Assurance team when the risk assessment is conducted at the beginning or end of the shift.
- Deciding leading indicators based on failure descriptions and input from frontline workers, leaders, and insurance groups
- Using the Due Diligence Index as a safety metric

The group discussed numerous leading indicators but expressed concern about information overload. They questioned what hazards should be prioritized among the many potential ones and the consensus of the group was that the focus should be on ‘STCKY’ (stuff that can kill you) hazards rather than minor slips, trips, and falls. Many hazard analyses are too generic and subject to worker biases. Emphasis should be on performance-enhancing hazards, not low-level ones. There was also discussion about the challenges of failing lucky and failing safe, and challenges of employees not reporting the presence of hazards. Encouraging informal hazard discussions and learning opportunities is also challenging.

Hazard identification was brought up during the large group discussion as a leading indicator along with the suggestion of having hazard hunters. Hazards are identified through hazard hunts which involve bringing people from different facilities to a new site where they do a walk through to identify the hazards. Bringing in new individuals to identify the hazards is useful as they have a different perspective on the worksite and may bring things to light that other workers have become accustomed to. Hazard hunts can be thought of as a brainstorming exercise to help build awareness and encourage hazard reporting. A potential downfall of this process could be that the hazards being identified by hazard hunters are generic and subject to bias based on the competency of the person conducting it. Another downfall is that hazard hunts only allow for the identification of visible hazards, and therefore hazard hunts often focus on low energy hazards like ‘housekeeping’. A discussion on the hazard/energy wheel followed.

The energy wheel was suggested during the large group discussion as a tool to visualize risks and hazard identification. It identifies the energy sources and can illuminate hidden hazards. Using the energy wheel can increase hazard recognition by 30% during pre-job assessments.

The group discussed critical control assurance as a leading indicator and highlighted the need to understand the effectiveness of the controls. A gap exists in understanding the effectiveness of corrective actions assigned at work. There should be more focus on consequences (e.g. how are you not going to die today?), understanding what can kill you, and what you can do to minimize the risk among frontline workers.

A compensation problem was discussed among the group. Most employees care about coming back to work the next day and getting paid. Annual incentives are not the same for the people who are doing the work and exposed to the hazard. The incentives are a benefit offered to leaders and salaried employees (but not contractors) who can influence safety and safety decisions but are not the ones exposed to the hazard. This reward may inadvertently result in leaders who encourage non-reporting. It was suggested that maybe safety should not be incentivized at al

Slides on leading indicators were presented following the lengthy group discussion. Characteristics of good leading indicators were identified on the slides, such as “Valid, useful, and predictive - to anticipate, prevent, or eliminate risks and losses,” and “Positively monitor and evaluate achievable performance of what people do, not what they fail to do.”

Mentimeter question 4: What cause-effect-control models do you use to understand SIF?
- Some use taproots, a few use fishbone, and most use bowties
- Bowtie models being used for incident investigation
- Suggestions to look at previous events and develop bowties around them
- Engagement of frontline workers in identifying critical controls within bowties is essential
- There is a need for instruction in how to read and understand bowties, controls and their effectiveness, and how to communicate to frontline workers and executives
- Challenges in developing bowties around personal safety in dynamic work environments

Different cause-effect-control models were shown on slides, including DNV, Taproot, Fishbone, Bowtie, and Iceberg models.

Mentimeter question 5: How could your organization's leading indicators and cause-effect-control models be improved to better predict and prevent SIFs?
- Upgrade in expertise: training on filing (i.e., scaling the level of the consequences), compensation/bonus to employees filing the critical control or fail-safe. Together they provide more data with higher precision for analysis
- Feedback system on safety recognition programs
- How do you get rid of TRIF (Total Recordable Injury Frequency)?
    - Tells you how many workers would get injured for every 100 employees of full-time hours worked. For example, a TRIF of 4 means if you had 100 workers working 40-hour weeks there would be 4 recordable injuries in the year.
    - Majority of the group would rather have a leading indicator program than TRIF because leading indicators (predictors) give a better sense of ‘who is walking through your door’
- Suggestion: BBO (Behavioral Based Observation/incident report) risk matrix. Feel tied to corporate scorecard and incident recordables can’t be disconnected from risk.
- Ideal scenario would be to assess incidents on risk (need to do more of this). Real pressure from senior management to ‘make it green’ presents a problem and the culture is not wanting to reveal problems.
- Due diligence measure

2.4.4. Part 3 (Content): Examining Human and Organizational Performance

The third section of the symposium, examining human and organizational performance, began with a Mentimeter question and group discussions.

Mentimeter question 6: How does your organization define (and perhaps measure) human and organizational factors?
- Some (most) organizations are not yet focused on it

- Others mention having some theory on them but don't have a clear definition or form of measurement in place
- In terms of the five key principles of HOP (High-Reliability Organizing)
- Measurement approaches include fail-safe/lucky incidents and the percentage of leaders that have completed HOP training
- Some are in the early stages of raising awareness and starting conversations about these factors but don't measure them

The group discussed the Human Factors Analysis and Classification System (HFACS) framework (see Appendix A) and how it is often used to look at human errors, but the top levels of the framework (organizational influence and supervisory factors) are often disregarded and not measured. Behavioral-based observations are often focused on unsafe acts but not on the preconditions of unsafe acts.

- ½ of attendees have behavioral-based observation systems but they don't look at preconditions for unsafe acts and focus on the person, not the system
- ⅓ do cultural/safety surveys
- ½ have ethical whistleblower reporting

Group discussion around processes of providing feedback and recognition for safe acts. Participants state email acknowledgements as effective in providing direct feedback to the worker and thanking them for bringing it up.

Messages often get stuck or frozen in the middle of organizations and things do not get reported due to company culture. How do you go about creating psychological safety and eliminating fear? There is a potential glass ceiling with psychological safety and skepticism seems to correlate with an organization level. Examples need to be set by the frozen middle people so the frontlines feel comfortable talking. This requires senior leaders to be willing to accept bad news and trust needs to be established. Amy Edmundson's book on psychological safety was recommended.

Slide content covered the persistence of human failures, potential causes of undesirable events including human factors, the significance of operator mistakes, and the HFACS framework (see Appendix A). Why hazards become normalized was also covered in the slides and included cognition (workers depend on sensory cues to identify hazards), emotions (states of mind), and organizational culture (how things are done within the company). Human and organizational factors were presented as some of the leading indicators most predictive of SIFs, including crew experience working together, supervisors' experience with the crew, maturity of leadership development programs for frontline supervisors, and a total number of workers under a supervisor's purview.

Mentimeter question 7: What psychological models do you use to enhance team learning and competency, hazard ID/management, and contractor coordination?

- Data collection and analytics

Slides covering some psychological models followed, including the Lencioni Model of Team Dysfunctions and how that can be applied to high performing teams, psychological safety and what that looks/feels like within an organization, self-determination/motivation, and the five principles of Human and Organizational Performance (HOP).

Mentimeter question 8: What barriers does your organization face in capturing human and organizational precursors to SIFs?

- The summary of risk activities and preventions from workers and investigators have limited sight due to knowledge background
- How to maintain bias to avoid hyperfocus and ignore some details

2.4.5. Part 4 (Content): Building Resilience

The research team briefly presented slides covering the application of artificial intelligence and machine learning to improve safety and risk management in the mining sector. This included identifying leading indicators in accident rates by artificial intelligence, reducing the accident rates by focusing on asset integrity management, and enhancing safety performance and quality of OHS procedures by focusing on missing socio-technical factors. An example of previous research results was presented to participants, which consisted of a Sankey diagram showing most and least captured indicators in incidents and inspections.

2.4.6. Part 5 (Content): Conclusions and Next Steps

Mentimeter question 9: What next steps would be most useful for your organization: new data collection, analysis, training, changed regulation, SOPs?

- Data collection and analytics, with a need for nuanced expertise and fresh thinking on data
- Identifying SIF precursors and effective leading indicators, along with methods to assess, capture, and report critical control assurance checks
- Detailed analysis of existing data to maximize its utility
- Translation and understanding bowtie models, Quick Reference Guides (QRGs), and videos to convey critical information to the frontline
- Common techniques for data collection and analysis of leading indicators
- A combination of training, analysis, and new data collection
- Consistent training for subcontractors
- A strategic overview with tools to support understanding concepts, opportunities, and data
- Ongoing collaboration and sharing of program and data with industry partners and associations
- Training to address the evolving needs of the workforce
- Continued peer collaboration to share and learn from each other
- Development of a bowtie tool to focus on critical controls and learn from incident findings
- Sharing best practices, SIF strategy development, and implementation of leading indicators
- Identifying common predictors of SIF and strategies for managing and mitigating them
- Establishing an aligned definition of critical leading indicators

The final slides covered the research team's expected results, data required, and planned research methods.

Mentimeter question 10: What topics would you like to discuss next?
- Opportunities for standardization across operators and contractors, and critical control assurance
- Psychological safety
- Critical control assurance

2.5 Symposium Outcomes

The symposium consisted primarily of facilitated group discussion where participants remained engaged and shared openly about their experiences and practices within their organizations. The research team gained valuable insights into gaps that exist in the industry and the challenges faced by organizations attempting to reduce SIFs.

The industry lacks consistency in terms of how serious injuries are defined and the leading indicators used for SIFs. The current culture around hazards and hazard reporting is an area of concern. Common challenges faced include information overload with respect to hazards, hazard analyses being too generic and focused on low-level hazards such as slips, trips, and falls instead of hazards that have the potential to cause serious harm, and employees refraining from identifying and reporting hazards. There is also concern around compensation and incentivizing critical controls in place, and the culture this perpetuates among workers of failing to report and learn from near misses.

Participants were particularly interested in using bowtie models to understand SIFs. Engaging frontline workers in the identification of critical controls within bowties is essential, as well as instruction on how to understand bowties and communicate their value to the frontlines. Dynamic work environments continue to present a challenge for personal safety.

To better predict and prevent SIFs, more incidents need to be assessed on risk. The current culture of not wanting to reveal issues due to pressure from senior management is problematic. A feedback system on safety recognition programs could help shift the culture.

Generally, there is a lack of knowledge around human and organizational factors that impact safety. Organizations do not capture or account for these factors. Creating psychologically safe workplaces and reducing fear is a topic of interest. The group is eager to make progress in these areas and recognizes the importance. There is a shared understanding that workers commonly experience fear of reporting hazards and/or speaking up. Trust with frontline workers must be established by leadership at all levels to encourage open communication.

Useful next steps identified by participants include identifying SIF precursors and effective leading indicators, training on bowtie models and methods of conveying critical information to frontline workers, and continued industry collaboration on best practices.

Participants were interested in attending more industry workshops in the future and continuing the conversation on a regular basis. Suggestions for future topics included bowtie models and critical control assurance, psychological safety, and opportunities for standardization across operators and contractors.

Following the symposium, Mentimeter responses were combined with the research team's notes and shared with participants. A copy of the slides was also shared.

3 November 21, 2023 Symposium: Using Critical Controls to Reduce Serious Injuries and Fatalities (SIFs)

The symposium was held in-person at the Quality Hotel and Conference Centre in Fort McMurray, Alberta on November 21, 2023, from 7:30 a.m. to 12:00 p.m.

3.1 Purpose and Objectives

The overarching purpose of this event was to examine high hazard work, identify critical controls, and discuss methods for measuring and assuring these. How can we make invisible hazards and their controls more visible? Specific objectives of the symposium were to accomplish the following:

- Connect and catalyze engagement amongst companies who are examining SIFs.
- Share challenges in examining the human and organizational factors for SIFs.
- Help the research team to prioritize the important human and organizational factors for SIFs.
- Enlist companies in developing a research solution framework to improve SIF controls.
- Examine methods of critical control assurance.
- Discuss priority outcomes and what a ‘successful’ research program is for participants.

The research team developed activities and discussion questions aimed at eliciting information and generating feedback from symposium participants to identify where the gaps lie in the industry. The research team was particularly interested in receiving feedback on the human and organizational factors that influence day-to-day safety decisions.

3.2 Participants

About a month prior to the event, the research team circulated an invitation to subject-matter-experts within the industry. Here, people were provided with an overview of the event in terms of its purpose and details, and why their participation was valuable. To encourage open and frank conversations, the invitation clarified that any and all information shared during the event would be used to develop the research program but not attributed to any one person or company. Suggestions for who should attend the symposium were included on the invite: *Senior Leaders from Oilsands Contractors, Subcontractors and Suppliers, Oilsands Operators, Project Managers, Project Safety Personnel, Operational Risk Management.* The invite was shared with contacts from the previous symposium held in Calgary, Alberta on September 21, as well as contacts in Suncor, Energy Safety Canada (ESC), the Alberta Construction Safety Association (ASCA), and the Construction Owners Association of Alberta (COAA), who were asked to distribute the invitation to other potential participants including field workers, contractor companies, and subcontractors. In total, symposium participants consisted of 120 people attending in-person and seven online, drawn from thirty-six different organizations in the oilsands, construction and safety management sectors.

3.3 Symposium Process and Itinerary

3.3.1. Summary: Pedagogy, Technology, and Process

The process was designed in such a way to facilitate open, generative discussion among symposium participants. Prior to the symposium, the research team had several meetings with Suncor folks to develop an activity on bowtie models to engage with symposium participants. Suncor folks developed slides to accompany their presentation and guided symposium participants through the activity. Session facilitators from the research team used slides to offer context for the discussion questions and exercises. One of the pedagogical techniques was to employ an online tool, Mentimeter. In short, questions were displayed on the overhead screen in the room and participants could anonymously submit their answers using their cell phone or laptop. Once response data had been collected, Mentimeter processed the responses in real time and offered an aggregated summary of the responses to symposium participants. Organized in small groups of about eight people (see Figure 4), participants were instructed to discuss the prompting question as well as the aggregated feedback with others at their table. Notes were taken to track the discussion topics and comments. Following the small group discussions, a member of the research team facilitated a large group discussion where volunteers from the tables shared what they had discussed and how it related to the focal question or exercise.

It is worth noting that Patrick Poitras' father, Marcel Poitras, and uncle, Joey St-Armand, were present for the final symposium preparations. The research team engaged with them on planned symposium content and activities, and received their approval before moving forward.

Figure 4. Sample image from Heritage Centre (2022) illustrating how participants were seated at tables in groups during the symposium.

3.3.2. Materials: Meeting Agenda

Part 1: Introduction and purpose
- Why we are here: Joey and Marcel address the group (Patrick Poitras' family)

- Industry commitment to make change to improve workplace safety
- Thank attending organizations

Part 2: Learning how to work with bowties: Suncor's bowties and critical control assurance
- Presentation:
    - What is a critical control?
    - How do you use bowties to identify critical controls in organizations?
- Roundtable group activity:
    - Each table chooses one of eight general loss of control scenarios with critical controls they want to discuss (e.g., dropped objects, confined space, etc.)
        - The research team distributes bowtie sheets, sticky notes and pens to tables
    - Each person at a table gets a chance to enhance the critical controls by writing on sticky notes and placing them on the bowtie sheets
- Large group discussion:
    - Summarize the findings and share with the group

Part 3: Human and organizational factors for workplace safety
- Why are hazards not identified or reported?
- Introduction to human and organizational factors
- Review key concepts and have participants rate the importance of each factor for daily safety behaviors
- Return to bowtie activity: Have participants reflect on human and organizational factors that may influence the effectiveness of their bowtie controls

Part 4: Measuring human and organizational factors for workplace safety
- Human and organizational factors as layers of protection needed to improve resilience
- What are we missing in this framework?
- Who should be involved in measuring and assuring critical controls?
- What other databases could be linked to incidents to improve safety performance?

Part 5: Call to action and concluding remarks
- Human factors and safety study: Invitation to participate and overview of research
- Opportunity for questions regarding the research
- What would success look like for you from this research?

3.4 Symposium Process and Content

3.4.1. Process Overview

The following questions were posed to participants during the workshop and their responses were captured using Mentimeter. Participants engaged in roundtable discussions with others seated at their table. Facilitated large group discussions followed the small group discussions. Summaries of the Mentimeter responses and group discussions are presented below, as well as a sample of the slide content:

3.4.2. Part 1 (Content): Introduction and Purpose

The session began with slides describing the purpose of the symposium. Many industries are doing a poor job of understanding high consequence, low frequency failures. Major incidents focus managerial attention on improving workplace safety and creative sentences reinforce these improvements. These effects are strongest in the mining/petroleum and construction sectors.

A photo of Patrick Poitras was displayed to symposium participants while his uncle, Joey St-Armand, addressed the audience and spoke about the importance of workplace safety. He shared memories of Patrick and emphasized how important it is that the industry works together to ensure everyone returns home safely at the end of the workday. Turning anger and sadness into action is the best way to honor Patrick’s memory and make lasting changes to improve safety practices.

3.4.3. Part 2 (Content): Learning how to work with bowties: Introduction to Suncor’s bowties and critical control assurance

Suncor led this section on bowtie models and controls. Slides were used to explain the concept of bowtie models and how to understand them. Bowties are developed for major incident hazards (MIH), which have the potential to cause fatalities and significant damage to the plant, equipment, or the environment. In Suncor, bowties are an illustrative approach to showcase high risk hazards by a schematic portrayal of the preventative and recovery controls that would act to prevent a major incident hazard. Bowties are also used to support operations and maintenance activities by raising awareness and understanding of the controls, and the role of individuals and organizations in operating or maintaining them. Bowties also support the identification and prioritization of actions to strengthen controls, and they help determine assurance activities for the identified controls.

Slides covered the various parts of a bowtie diagram, including the hazard, top event, consequences, threats, controls, prevention controls, recovery controls, degradation factors, and degradation controls.

After presenting the concept of bowties, Suncor led an engaging exercise to elicit new insights on the six Major Incident Hazards (MIHs). Participants were instructed to choose one of the six MIHs to work on with others at their table and identify threats, consequences, and controls on the provided bowtie poster using sticky notes and sharpies supplied by the research team. The six MIH bowties participants had to choose from included: 1) heavy-light vehicle interaction, 2) lifting and hoisting, 3) active haul operation, 4) confined space, 5) dropped objects, and 6) working at heights.

Once each table had a bowtie sheet on their table, Suncor presented slides on critical controls and instructed participants to brainstorm critical controls for their MIH and mark them on the bowtie sheet. See Figure 5 for a visual of this exercise during the symposium.

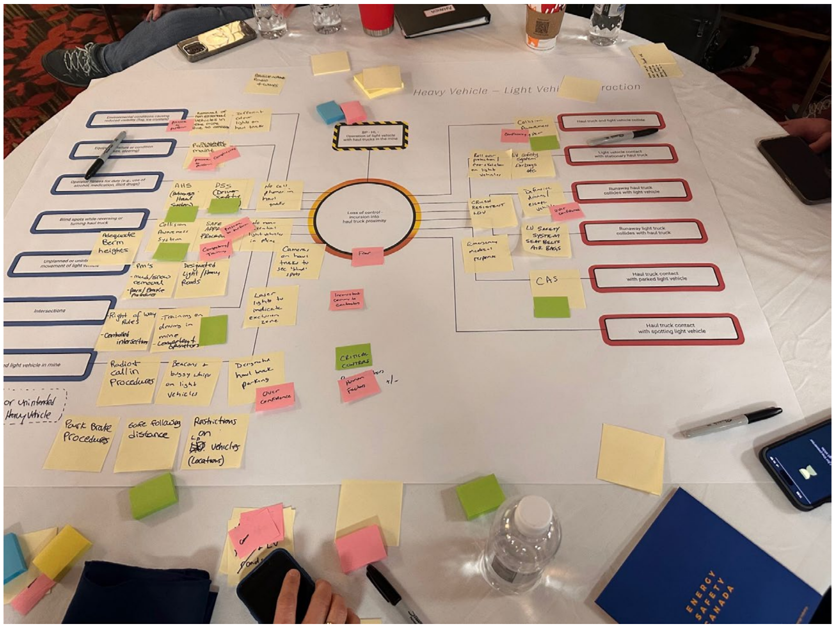

Figure 5. Bowtie exercise in progress during the symposium.

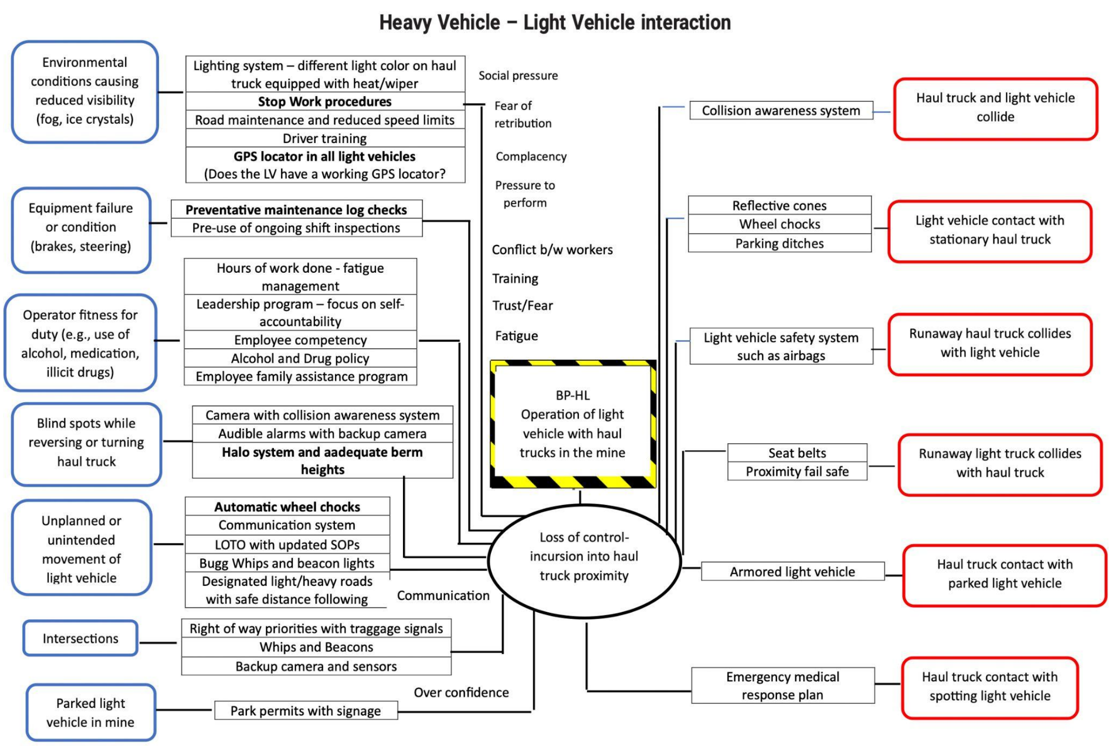

Figure 6. 'Master' bowtie for Heavy Vehicle - Light Vehicle Interaction with controls from each group compiled into one model. See Appendix B for more bowties.

Following the bowtie activity, facilitated group discussion took place where participants were asked to share their thoughts on the exercise. A sample of the feedback follows:

- Useful to visualize bowties; felt capable after visualization.

- Not every control is critical; prioritize the most critical ones.
- Interesting to determine which side of the bowtie controls belong to (left vs right).
- Frontline workforce holds valuable knowledge not in safety manuals.
    - Dynamic workforce adjusts daily for safety.
    - Frontline workers enlightened others on their daily safety practices.
- Left side of the bowtie is easier to prevent; the right side is harder, planning for failure.
    - Recognizing the challenge of planning for failure is a mental shift.
- Critical steps book: Immediate and irreversible consequences define critical steps.
    - Focus on frontline workforce and critical steps, where's the energy, and what consequences come with the next thing you'll do.

3.4.4. Part 3 (Content): Human and Organizational Factors for Workplace Safety

The next section began with a Mentimeter question to encourage participants to begin thinking about the importance and relevance of human and organizational factors for workplace safety. The research team posed this question previously in 2018 and expected the responses to remain the same and consist primarily of human and organizational factors.

Mentimeter question 1: Why are hazards not identified or reported? *Results for this question were displayed using a word cloud* (see Figure 7).

Figure 7. Word cloud responses to Mentimeter question 1, with the most popular responses appearing towards the center.

Following the Mentimeter exercise, the research team presented slides introducing and defining human and organizational factors. Human factors are the personal and team characteristics that drive safety decisions and acts, and they can be difficult to assess and control. Organizational factors are the technical work environment, job demands, and management practices and policies. Organizational factors tend to be easier to assess and understand.

A discussion question was posed to symposium participants regarding their personal experiences of human and/or organizational factors contributing to a safety incident. Participants were instructed to reflect on their experiences and share with others seated at their table, and to record their answers on sticky notes for the research team to collect.

Discussion question: Can you think of a time when a person-related or team-related factor led to a safety incident? *Sticky note responses were summarized by the research team after the symposium. Group discussion topics and sticky note responses are summarized below:*

- Misplaced trust among workers
    - Reluctance to confront leaders; inability to handle conflict
- Inadequate resources provided to the crew
    - Workers reluctant to speak up, using insufficient equipment
- Power control among workers
    - Competing interests, rushing tasks, and taking shortcuts for approval
- Fear among workers
    - Reluctance to speak up due to fear of repercussions
- Emotional intelligence
    - Lack of emotional control, including anger and lashing out during disagreements
- Power struggles and overconfidence
    - Conflict between senior and novice workers resulting in safety issues
- Operational issues
    - Wireline operation multitasking causing tool issues
    - Lack of field presence leading to miscommunication; working on the wrong equipment
- Decision to fast-track procedures and issues with the alarm system/proximity
- Incidents and accidents
    - Collisions, failed equipment due to lack of training, and towing mishaps
- Circumventing processes
    - Attempting tasks outside the scope/permit and not following proper procedures
- Lack of accountability for managing hazards
- Need to emphasize vulnerability as strength
- Inconsistency with rules between sites can be confusing for workers and puts transient workers at higher risk
    - How to measure simplicity? Need to build reliability

Following the group discussion, slide content continued with human and organizational factors likely to impact workplace safety. A few key concepts were presented to symposium participants in the context of how they can impact workplace safety decisions, including emotionality, psychological safety, and resilience.

Emotionality was described as experiencing fear of retribution, fear of blame and punishment, fear of peer judgment, and fear of inadequate training and awareness. This fear may lead to a less secure and more hazardous work environment. Psychological safety refers to an individual's perception of the consequences of taking an interpersonal risk within a specific context, like a team or a company. With high psychological safety (and trust), people feel comfortable expressing their thoughts, ideas, concerns, or making mistakes without fearing negative consequences. In a context of safety, this could mean people feeling comfortable expressing concerns, reporting errors, and suggesting improvements. Resilient teams demonstrate specific behaviors and characteristics that enable them to effectively navigate challenges, adapt to change, and maintain high performance (e.g., adaptability: being flexible and able to respond quickly to change; proactive problem solving: identifying and addressing problems while they are small).

After defining and explaining these higher-level concepts, symposium participants were presented with eight factors, including the three previously described in the slide content, and asked to rate the importance of each one for safety decisions and behaviors.

Mentimeter question 2: Which of these factors resonates with you as being important for understanding day-to-day safety decisions and behaviors? *The following eight factors were presented using Mentimeter and participants were asked to rate the importance of each on a 5-point Likert scale. The average Likert scale ratings for each factor are included below:*

- Emotionality (e.g., fear; anxiety)
    - Weighted average: 4.11
- Personal and Team Resilience (e.g., awareness of issues; ability to learn and resolve problems/conflicts; adapt and respond to setbacks)
    - Weighted average: 4.07
- Psychological Safety/Trust (or lack-there-of)
    - Weighted average: 4.19
- Social Pressure
    - Weighted average: 3.93
- Knowledge Exchange with Respect to Safety (e.g., sharing; hiding)
    - Weighted average: 3.84
- Complacency (with Routines)
    - Weighted average: 4.13
- Pressure to Perform
    - Weighted average: 4.19
- Competency/Training to Perform the Job
    - Weighted average: 4.03

After rating each factor, symposium participants were instructed to reflect on the Mentimeter results with others at their table and consider which of the factors may affect their bowtie controls, and to note them on their bowtie sheets. Participants were given time to complete this exercise while the research team circulated the room to answer questions and guide participants through the exercise. It is worth noting that symposium participants found this exercise somewhat challenging and only a few groups noted these factors on their bowtie models.

<u>3.4.5. Part 4 (Content): Measuring Human and Organizational Factors for Workplace Safety</u>

To begin this section on measuring human and organizational factors, slides were presented about the characteristics of good leading indicators. A good leading indicator should be valid, useful, and predictive – to anticipate, prevent, or eliminate risks and losses. A good leading indicator should also be credible and transparent to those being measured.

The next slide described how human and organizational factors (or socio-technical factors) act as layers of protection needed to improve resilience. These layers of protection include social and technical factors. The social factors are organization performance (e.g., resource management, safety culture), human performance (e.g., situational awareness, well rested), and individual competency (e.g., work experience, education levels and training), and the technical factors include equipment and procedures. A 'swiss cheese' model was displayed to help the audience visualize these layers of protection and how incidents still occur by slipping through the holes in the cheese. After this visual, symposium participants were asked a question using Mentimeter.

Mentimeter question 3: What are we missing in this socio-technical framework?

- Workplace culture characterized by psychological safety where employees feel safe
    - Empowerment for voicing concerns
    - Critical but difficult to measure psychological safety - ITP Metrics was suggested as a method to measure and symposium participants were very interested
- Change management
    - Informal changes like weather conditions
    - Understanding implications of dynamic conditions
- Training and competency
    - Quality and relevancy of training
    - Fit-for-purpose competency assurance
    - A valuable way to assess competency that is useful to employees and employers
    - Competency verifications through inspections and audits, job observations, management observations, hands-on assessments
- Managing shared risks
    - Custody issues in managing controls when they exist in different parts of the organization
    - Need for coordinated work efforts
    - Cross reference of safety controls between operator and contractor
- Leadership - leading by example
    - Leadership commitment to safety - how to measure
    - Impact of leader's behavior on team dynamics and psychological safety
    - Leadership competency for effective communication - instead of promoting technical experts, need leaders that can manage and support workers (people managers vs technical leaders)
    - Building trust through caring leadership - demonstrating care to workers is critical
    - Coaching resources for leaders
- Work planning
    - Meaningful work planning that considers systems, not just the task itself
    - Prioritization of tasks and clear communication
    - E.g., work assigned on the night that would be safer if performed during the day.
- Task prioritization and clear communication
    - Back to the basics; focusing on 2-3 things for critical control assurance
    - The 'what' instead of the 'how' - how do we intend to work safely today vs as a team, what do we need to do today to ensure we all get home safely, what do we need to go check to make sure that happens
    - Prioritize high risk consequence tasks

- Worker morale and mental health/stability
    - Impact on safety compliance - being careless as an act of rebellion against the lack of care the worker may feel
    - Recognition of employee focus and the importance of work-life balance
    - Do leaders know enough about employees to recognize when their focus is lacking
- Team dynamics/team culture
    - Current culture of audio ignorance needs to shift
    - Learning culture and avoiding repeated mistakes
- Motivation and intrinsic and extrinsic rewards - passion for the job
- Pressure to perform - production goals aligned with safety messaging
    - Balancing production goals with safety and being realistic
    - I.e., saying safety is number one but it always takes a backseat to production pressures when push comes to shove
- Environmental factors - consideration of work environment and conditions
    - The reality of the condition's workers experience and the impacts they have
- Procedures
    - Document control for procedures
    - Process and alignment and representation of actual tasks
- Adherence to regulations
- Education - professional development, experience, and training
- Assurance activities
    - Direct control assurance processes
    - Elimination and substitution of work and controls
- Alberta OHS incident investigations
- Project RASCI (Responsible, Accountable, Supporting, Consulted, Informed) - Assignment of roles and responsibilities of each stakeholder in the project
    - Identification of key integrated team members, not proceeding without field workers RASCI chart
- Ensuring proper tools and equipment
- More involvement of frontline workers in inspections, procedure development, and incident investigations
    - In-field engagements to establish a feedback loop from frontline workers
- Qualitative vs quantitative information tracking
- Risk tolerance
- Shift handover interactions
- Control validation and effectiveness
- Company willingness to implement effective solutions as opposed to lower cost fixes

Following the Mentimeter question and group discussion, the research team displayed another question for groups to discuss with others at their table. A facilitated large group discussion followed the small group discussions.

Discussion question: Who should be involved in measuring and assuring critical controls?

- Frontline workers responsible for planning and designing tasks

    - The person performing the critical activity should ensure controls are in place before they begin, with a double-check by someone else
- Two individuals: one assuring the critical controls and another with knowledge of the controls
- A mix of people to offer different perspectives and foster critical thinking
- A competent person is needed to ensure controls are in place and the work is safe; triangulating from different data sources to achieve a comprehensive safety assessment

Following the group discussion, slides with research questions and an example of previous research results were displayed. This consisted of the Sankey diagram showing the most and least captured indicators in incidents and inspections to give symposium participants an idea of what the research team can produce with data.

Mentimeter question 4: What other databases could be linked to incidents to improve safety performance?

- Conversation analytics from safety toolbox
- Site congestion reports
- Efficacy of controls data to assess control effectiveness
- Contractor data to check if they work with different organizations simultaneously (since each organization has different rules that could cause confusion)
- Linking OHS regulation data with Workers Compensation Board (WCB) records
    - WCB incident claims data
    - Overlaying OHS and regulatory inspection reports with incident data
- Global industry or geography-level reporting for benchmarking
    - Sharing databases across the industry for trend analysis.
- iCAB (CogniSense) assessments compared to incident outcomes
- U.S. Chemical Safety Board incident data
- Combining contractor and operator databases
- More construction company incident reports
- Database for critical control health and control effectiveness; also, for corrective actions linked to incidents
- Consistency of controls across sites and industries
- High Energy Control Assessment (HECA) data
- Linking construction schedules to calendars to define critical control work
- Shift schedules and consecutive shift data
- Collecting data on worker happiness, satisfaction, mental health, and fitness for duty
- Worker demographics data, including training, experience level, and age
- Attendance records
- Focus audits, including previous audit reports of the work area where an incident occurred
- Measure of Human and Organizational Performance (HOP) theme effectiveness in corrective actions
- Data from Emergency Services Command (ESC)
- Data from oil and gas sites
- Planned or unplanned work data (e.g., rework)
- Equipment health and GPS systems data

- Competency data and training records
- Observations, including behavioral-based observations and interventions by supervisors
- Reading operator and maintenance logbooks, bypass, and alarm management reports, and permit-to-work audits.
- Capturing at-risk behavior and activities logs
- Field-level hazard assessments and hazard ID data
- Pre-qualification data
- Data from project planning Enterprise Resource Planning (ERP) systems
- Scheduled work activities data for exposure assessment
- Conflict meters data
- QR codes on equipment for manuals and maintenance records
- Contractor safety culture survey results
- Data related to permitting, especially concurrent work risks
- Legal due diligence requirements assessment

Following the Mentimeter question and group discussions about other potential databases, a few final slides were displayed as a final closing to the symposium.

3.4.6. Part 5 (Content): Call to Action and Concluding Remarks

In the final section of the symposium, slide content covered the research being conducted by the research team. The slide stated that the research team is seeking industry participants to offer a contractor perspective on the human factors that pertain to safety management, and that data collection is planned for 2024 and will consist of surveys and interviews. A list of human and organizational factors was presented as a sample of the concepts the research team may investigate in their study. Expected results and data required was also presented to symposium participants. Using machine learning, natural language processing, and text mining techniques, the research team can identify the most influential socio-technical factors that cause incidents among contractors and employees, identify, rank, and prioritize the missing socio-technical factors that are not captured during safety inspections and audits, and implement data-informed decision-making methods to enhance safety practices and allocate resources efficiently.

A final Mentimeter question was posed to symposium participants as the session came to a close.

Mentimeter question 5: What would success look like for you from this research?
- More legislation on equipment/people working around and on water, ice, and soft ground conditions
- Simplified information for frontline workers
- Reduction of documentation to focus on critical tasks
- Industry-wide consistency and focus on critical controls
- Alignment at an industry level, starting with Energy Safety Canada’s Life Saving Rules Program and expanding
- Collaborative creation of a safety culture and belief system
- Standardized critical controls and critical control assurance
- Enhanced critical control assurance and training
- Clear understanding of critical controls and their performance criteria
- More training on bowtie analysis for workers

- Predictive analytics and leading indicator data for incident prediction
- Practical recommendations based on data
- Full team alignment, trust, and culture change
- Lowering SIFp and SIFa events
- Inclusivity of field-level input in data and decision-making
- Input from workers on supporting the frontline and eliminating SIFs
- Results usable for reflective conversations with the crew
- Data shared in a meaningful and easy-to-understand format for frontline workers
- Better understanding of incident causation
- Quantification of organizational culture
- Actionable advice on addressing human factors
- Consideration of an individual's mental state in incident analysis
- Bridging the gap between planning and field execution
- Employing new and effective safety strategies
- Commitment to one effective safety approach
- Owner and organizational involvement
- Availability of tools and knowledge for addressing risks
- Visibility into worker errors and controls improvement
- Building a strong health, safety, and environment (HSE) program for staff safety and business success
- Increased opportunities for industry forums and sharing of best practices
- Making data publicly accessible for coaching and improvement
- Understanding motivating factors before incidents
- Correlation analysis of planned work, unplanned work, and management of change (MOC)
- Mitigating the unexpected and proper planning
- Eliminating language that doesn't prioritize safety
- A reduction in serious incidents within the oilsands by failing safely
- The goal of everyone going home safely
- Zero fatalities

3.5 Symposium Outcomes

The symposium consisted of a group activity working with bowtie models, as well as facilitated group discussions where participants remained engaged and shared their perspectives on the gaps that exist in the industry. The research team gained valuable insights regarding the primary concerns of industry workers and methods to enhance safety on the frontlines. The knowledge gained from this symposium will inform the research team's research questions, research design and focal concepts, as well as potential topics for future symposiums.

The concepts of bowties were presented very well by Suncor representatives who also led an engaging exercise and elicited new insights on the six major incident hazards. The feedback the research team has received includes the following:

- "I was very interested in the Bowtie exercises as it really forces you to think ahead and plan accordingly, what a great concept."

- "I did leave yesterday with a bit of an 'ah ha' moment and am excited to share what I learned with my people (especially that idea of 'failing safely' and that whole right side of the bow tie)."
- "More training on bowties, involving direct workforce on controls identification as they are problem solvers and not the problem"

Following the symposium, the research team summarized the symposium bowtie sheets into digital 'masters' for each major incident hazard. The 'master' bowties contain all controls suggested by symposium participants during the group activity. The research team is now examining these controls (shown as black boxes in Appendix B) to determine which are 'critical controls' and can independently prevent or mitigate consequences to ensure 'failing safely'. By planning to fail and focusing on methods to 'fail safely', the industry can take a new approach to reducing the frequency of incidents.

Symposium participants were keen to acknowledge the importance and impact of human and organizational factors for workplace safety. They ranked all factors presented to them as being important for workplace safety decisions and behaviors, with the least important factor being knowledge exchange with respect to safety (e.g., sharing, hiding) at 3.84/5. Psychological safety/trust (or lack-there-of) and pressure to perform were both ranked the highest at 4.19/5 on their level of importance. While participants could easily acknowledge that these factors play a role in their day-to-day safety experiences, they seemed to have a harder time marking these factors on their bowtie models as having the potential to impact the effectiveness of controls. Perhaps there is a gap in understanding how these factors manifest to have real impacts on workplace safety and what this looks like.

Symposium participants provided many suggestions for factors to include in the socio-technical framework for incidents. Some common themes appeared in the responses with many participants mentioning training and competency (and how to assess), the impact of leadership, and worker morale/feelings of psychological safety.

There seems to be industry-wide agreement that frontline workers should be involved in measuring and assuring critical controls, and that having more than one individual involved in checking the controls is necessary.

There were many suggestions for alternate databases that could be linked to improve safety performance. Participants were interested in seeing OHS regulation data linked with WCB incident claims, inspection reports, and incident data to see what improvements have been put in place and whether they make a difference for safety. There is also interest in sharing across the industry for benchmarking purposes and to learn from others.

A common theme that came up throughout the symposium was the confusion and risk that arises from different sites having different rules and procedures in place. There is a call for more consistency and simplicity across the industry.

A copy of the slides, 'master' bowties for the six major incident hazards, and the Mentimeter notes were shared with participants.

3.6 Next Steps: Working with Bowties

Materials produced from the symposium include six bowtie models: 1) heavy-light vehicle interaction, 2) lifting and hoisting, 3) active haul operation, 4) confined space, 5) dropped objects, and 6) working at heights (see Appendix B). The bowtie models can be used by OHS, ESC, ACSA, and others for the following purposes and benefits:

3.6.1. Understanding the causes of failures and precursory conditions in both routine and non-routine work.
3.6.2. Understanding consequences and how to mitigate harm when failures do occur.
3.6.3. Visualization of systems, causes, and consequences that are often complex, non-linear interactions and hidden.
3.6.4. Training workers to understand critical control assurance with the help of visualizations.
3.6.5. Communicating with contractors and sub-contractors who may be unfamiliar with the work at hand and the associated causes, consequences, and controls.
3.6.6. Monitoring and verification of critical controls to prevent the likelihood of failures.
3.6.7. Understanding the role played by human and organizational factors, and how these factors may impact the effectiveness of controls.
3.6.8. Leveraging best practices and consolidating expertise across companies and across industries.
3.6.9. Developing future trainings/workshops on bowtie models to understand major incident hazards (MIHs).
3.6.10. Using a bowtie model to create a basis for Bayesian network analysis to test hypotheses about interactions between variables.
3.6.11. Supporting difficult conversations around previously forbidden topics (i.e., fear). Bowties make hazards and consequences visible, which makes them easier to discuss. This improves safety culture.
3.6.12. Developing and building competencies at the individual, organizational, and agency level.

4 Future Research: Identifying and Assessing the Human and Organizational Factors that Influence Safety Performance

Claire Wasel, Ian R. Gellatly, Samantha Jones, Thomas O'Neill, Lianne Lefsrud, Fereshteh Sattari

4.1 Summary

The mining industry has one of the highest accident rates among all sectors and is responsible for approximately 15,000 occupational accidents per year (Baraza et al., 2023; Zhang et al., 2020). Traditionally, efforts to improve workplace safety focus on technical factors and controlling the physical work environment. Detailed procedures and processes outline the safest way to perform work tasks and minimize worksite hazards. When an incident occurs, technical factors such as procedures are investigated and updated to prevent similar incidents from occurring in the future. To date, tremendous gains in safety science and management have been realized through an increased awareness of relevant hazards within the job situation, and on managing controls that reduce the likelihood of hazards as well as the consequences of the safety event. In spite of these developments, the field remains overly fixated on technical as opposed to human factors. Presumably, this bias results because it is simply easier to detect equipment malfunction, problems with the handling and use of tools, and the known challenges of working in high-risk technical environments such as construction and oil and gas. Or it could be that our current way of thinking about safety is incomplete.

Despite all of the research attention devoted to improving overall safety performance, too many accidents are still occurring (Hofmann et al., 2017), especially those resulting in serious injuries and fatalities (SIFs). What is missing? As we move forward in this research, the aim is to go beyond an exclusive focus on technical factors to one that incorporates the roles played by human and social factors. A clear message coming out of the symposium results and our conversations with subject-matter experts at these events is that work is needed to identify and measure a select set of employee-level (e.g., anxiety and fear; attitudes towards safety; complacency) and group-level factors (e.g., safety norms; resilience; conflict) that create both a context for safety-related decisions and behavior, and improve the prediction of SIFs.

To support this objective, we anticipate using a mix of research designs and data sources. We anticipate reconciling data from online quantitative assessments and semi-structured interviews to provide more robust and in-depth results (Hesse-Biber & Leavy, 2010). Leveraging complimentary methodological and analytic strategies allows for a more holistic picture of the findings. Given the imperative to tie measures of human and organizational factors to actual safety behavior, we expect a primary data source will include mandated safety records (e.g., incident reports; SIFs) at the individual and group levels. Online assessments/surveys as well as interview data from selected individuals and groups within participating organizations will be another primary data source. We will make every attempt to use state-of-the-art assessment tools (e.g., ITP Metrics; NSS-FactorLab) that can be integrated within easy-to-use smartphone apps. When a participating organization does not have reliable and valid measures of our focal concepts, we will use the expertise within the project team to identify suitable measures from the

literature or we will develop our own assessments. Finally, as noted above, we plan to supplement our quantitative assessments by conducting semi-structured, focus group style interviews with a subset of the participants. Interview questions will explore more about the perceptions of the context in which incidents are more likely to occur and dive deeper into some of our focal variables (e.g., psychological safety, conflict management, attitudes towards safety) and their perceived role in SIFs. Integrating and interpreting a range of data sources will allow the research team to offer recommendations with respect to safety practices, including interventions and education on the importance of human and organizational factors and their role in workplace safety and incidents.

5 Using Machine Learning and Natural Language Processing to Enhance Safety Performance and Quality of Occupational Health and Safety (OHS) Procedures by Focusing on Missing Socio-Technical Factors in the Mining Industry

Rose Marie Charuvil Elizabeth, Amir Abdolmaleki, Fereshteh Sattari, Lianne Lefsrud, Thomas O'Neill, Ian R. Gellatly

5.1 Introduction

The mining industry is known to be one of the most dangerous and riskiest industries worldwide since it accounts for a substantial proportion of occupational incidents, particularly fatal accidents (Nowrouzi-Kia et al., 2018; Zhang et al., 2020). In the US, the mining, quarrying, and oil and gas extraction industry reported an overall fatal injury rate of 14.2 per 100 full-time equivalent workers in 2021 (U.S. Bureau of Labor Statistics, 2022). In Canada, the total recordable injury frequency rate in the mining industry has remained steady (0.3-0.9) over the past decades, indicating oversight in enhancing safety performance (Alberta Mine Safety Association (AMSA)., 2024). In addition, research shows that the reduction in serious injuries and fatalities (SIFs) rates has been fairly stagnant, hence raising concerns about the safety of workers (Ivensky, 2016; Cooper, 2019). Therefore, new safety management strategies are needed to prevent the occurrence of SIFs and improve safety performance.

Most mining organizations' safety performance depends on their contractors' safety programs and cultures (Gharedaghi & Omidvari, 2019; Salas & Hallowell, 2016). Contractors are more prone to risks and have contributed to the majority of accidents in the industry (Muzaffar et al., 2013; Theophilus et al., 2017; Nwankwo et al., 2022). This stems from the prevalent practice of outsourcing work to contractors to minimize workforce and equipment costs and mitigate any associated risks and liabilities. Another reason for high risks among contractors is that they are not affiliated with any particular organization and may face challenges in adapting to the work patterns and disparities in safety standards and processes of different host organizations (Griffiths, 2017).

Several studies emphasize looking deeper into social and technical (ST) factors within safety management (Drews et al., 2020; Busch et al., 2021). Within the literature, there are numerous methods that have been used to analyze safety performance and reduce incident rates using machine learning (ML) and natural language processing (NLP) (Kurian et al., 2020; Naji et al., 2022; Sattari et al., 2022). However, these methods have been studied in isolation (Oguz Erkal et al., 2021), lacking integration of other factors such as social, crew, or project demographics and additional sources of data such as safety inspections. Safety inspections are crucial in lowering incidents; the results of inspections are, however, rarely analyzed more than once to serve as performance indicators or to reveal any unsafe patterns (Lin et al., 2014). Therefore, a comprehensive study incorporating a wider range of datasets along with incident reports is needed to identify underlying ST factors and improve safety performance.

To address these limitations, this study aims to leverage ML and NLP techniques to identify: (1) the unique ST factors that influence the risk among contractors and employees; (2) some missing ST factors that are not captured during safety inspections; and (3) provide recommendations that can be made to improve the quality of occupational health and safety procedures.

5.2 Literature Review

ST factors play a crucial role in enhancing safety performance. The following sections provide a literature review of ST factors and introduce an ST factors framework illustrated in Figure 9. Using previous studies, this section brings together insights that can help analyze SIF events within the mining industry.

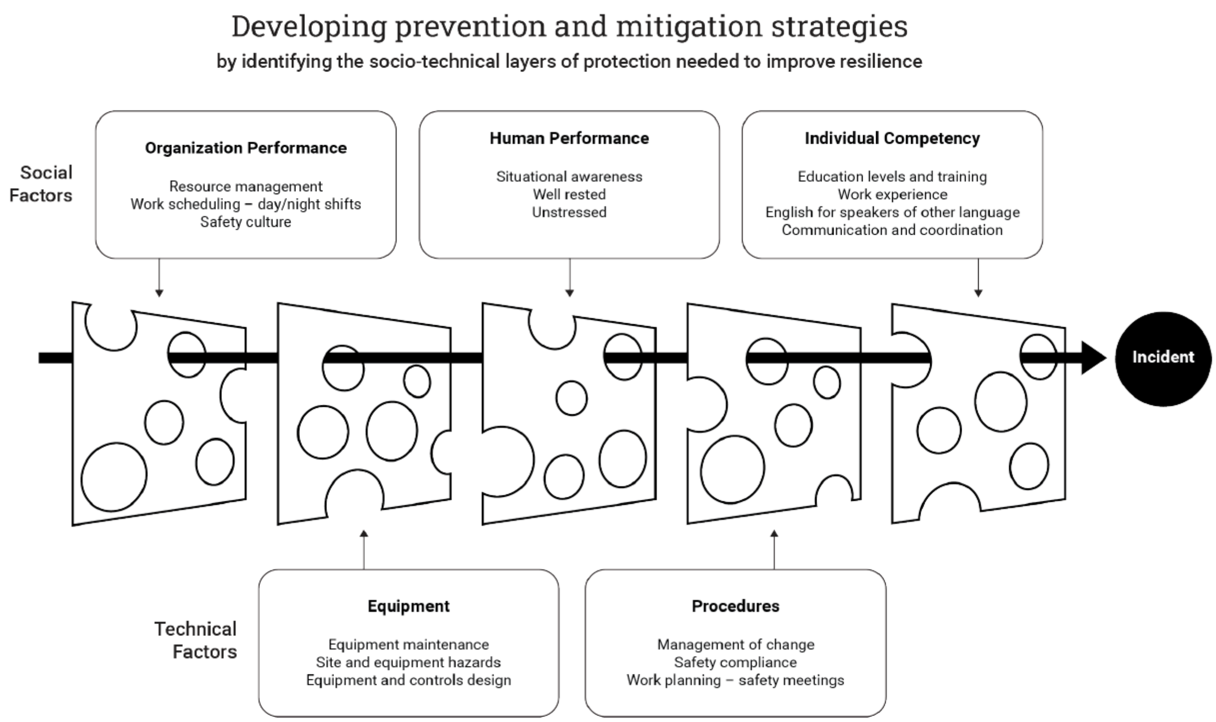

Figure 9. Socio-technical factor (ST) framework as layers of protection, used for this study.

5.2.1. Socio-technical Factors

In the realm of workplace safety, ST factors include both social (human-related) and technical (non-human) aspects. Social factors include aspects like resource management, work scheduling, fatigue, stress, situational awareness, educational level, work experience, English as a second language, and communication. Resource management refers to organizational-level decision-making regarding the allocation of assets such as equipment and monetary resources (Xia et al., 2018). Improper resource management can cause inadequacies in operational planning that can lead to incidents (Liu et al., 2018). Shiftwork refers to the variety of work time arrangements (Knutsson, 2004). Shift work, in combination with long work hours, has been found to have detrimental effects on safety performance. For instance, in the mining industry, some studies identified that night shift workers experience higher occupational injuries (Legault et al., 2017; De et al., 2020; Tian et al., 2022). On the other hand, others have found that morning shift workers observed high incidents (Stojadinović et al., 2012; Stemn, 2019). Workers in the mining industry generally have rotating shifts, where workers alternate between different work schedules which challenges the body's natural ability to adapt to a consistent sleep-wake cycle, thereby increasing the risk of incidents during periods of reduced alertness – either in the morning or night shifts. Fatigue is defined as a physiological state of reduced mental or physical performance that results from sleep loss, circadian phase, and workload (Mehta et al., 2017). Given the complexity of the work environment in the mining industry, fatigue can come from repetitive motion and strain due to heavy workloads, uncomfortable working postures, heat from the environment, or long working hours (Soares et al., 2019; Yu et al., 2019).

The third social factor is work stress. Stress is inherent to the mining industry because of the high working demands and can impact the safety performance of workers. Several studies have reported that job characteristics such as job autonomy, ambiguity, and role conflict can cause stress among workers (Hoboubi et al., 2017). Situational awareness, the following social factor in the context of the mining industry, can be characterized as being aware of what is happening around the workplace, which involves the ability to process vital safety information and find solutions to manage any merging risk (Anggraeni et al., 2022). With the emergence of automation in complex ST systems such as the mining industry, situational awareness is imperative since the workers are required to perform more cognitive tasks, such as responding, monitoring, diagnose tasks (Li et al., 2017). The following social factors reviewed in this study are educational background and work experience. Workers who lack the necessary educational level and work experience may struggle to comprehend the safety protocols and technical information, which can lead to incidents (Bhattacherjee, 2014; Chen et al., 2019; Zhang et al., 2020). Furthermore, workers who have English as their second language may face challenges in understanding information which may impede their ability to communicate effectively and perform tasks safely. Addressing language barriers and communication is crucial to mitigate risks and promote a safe work environment.

Some technical factors considered in this study are equipment maintenance and design, management of change, and safe work planning. Equipment maintenance refers to the management of equipment to ensure that it works with optimal performance. Maintenance steps generally involve routine inspections, preventive maintenance and repairs and lack of maintenance of equipment has caused incidents in the mining industry (Sanmiquel-Pera et al., 2019; Liu et al., 2023). Management of change, on the other hand, refers to modifications to chemical processes, technology, equipment, or procedures in a facility that affect a covered process (Theophilus et al., 2017). Failure to document and communicate the changes can result in conditions for accidents to occur (Levovnik & Gerbec, 2018). Safe work planning involves systematically outlining the steps to execute tasks, documenting associated hazards, and implementing the controls required to mitigate the hazards.

5.3 Methodology

This section details the research methodology that will be employed in the study to identify ST factors contributing to SIFs in the mining industry. The initial SIF dataset contains 822 incident reports from 2018 to 2023 from a mining industry located in Alberta, Canada. A critical aspect of the methodology involves data cleaning. A total of 51 incident records were removed from the analysis since they contained French descriptions and had blank incident descriptions. Therefore, overall, 771 SIF incidents (48% employees and 52% contractors) will be analyzed in this study.

5.3.1. First Research Question

The first research question attempts to identify the unique ST factors that influence the risk among contractors and employees using ML techniques. Figure 10 shows the methodology that will be adopted for ST factor analysis. The first step of ML analysis is data pre-processing. Therefore, stop words such as ‘a, and ‘the’ will be removed. However, certain stop words such as ‘not,’ ‘didn’t’ or ‘wasn’t’ — will not be removed to avoid misinterpretation of the incident or inspection descriptions. Special characters such as periods, colons, and commas will be removed, and words will be converted to lowercase representations to reduce the vocabulary size and simplify the text to make it consistent, using the natural language toolkit (NLTK) Python library. Finally, lemmatization will be conducted to reduce words down to their base forms or lemmas as it simplifies the vocabulary and facilitates semantic work association (Madeira et al., 2021). The dataset will then be randomly split into two independent sets of training (70%) and testing (30%) using train_test_split function in Python.

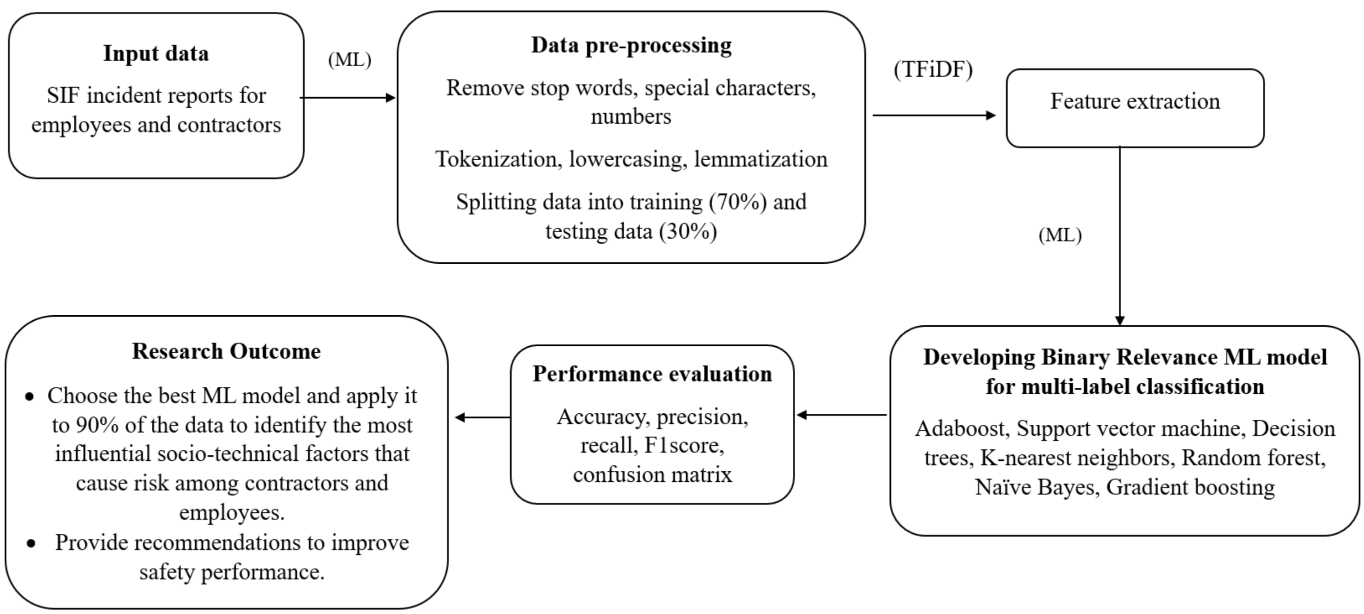

Figure 10. Methodology for the first research question. Note: ML – machine learning; TFiDF - Term Frequency-Inverse Document Frequency.

Of the training set, manual classification will be conducted on 10% (77 incidents) of the dataset. This process will involve the use of keyword analysis, with each incident assigned to more than one relevant ST factor. By allowing for the assignment of more than one factor to each incident, the ML model accommodates the inherent complexity of data and offers insights into the various contributing factors that cause incidents. The ST factor framework that will be used in this study is shown in Figure 10.

To help overcome the obstacle of data imbalance, class weights will be given so that any under-represented ST factors have more weight and importance. The following equation calculates the class weights (Picek et al., 2019):

$$CW_i = \frac{N_{tot}}{n_{classes} \times n_i}$$

Where CW_i is the class weight for class i, N_{tot} is the total number of samples, $n_{classes}$ is the number of classes (seven PS factors), and n_i is the number of samples in class i.

Seven different ML classifiers, including Adaboost, support vector machine, decision tree, K-nearest neighbors, random forest, Naïve Bayes, and Gradient boosting will be used in the study. These models are then evaluated using accuracy, precision, recall, F1 score, and confusion matrix (Table 1). Accuracy is defined as the proportion of data that were correctly classified. Precision is the ratio of the number of true positives (TP) to the sum of TP and false positives (FP). TP denotes correctly predicted positive incidents, while true negative (TN) refers to accurately classified negative incidents, both representing correct incident classifications. FP means that an adverse incident was predicted to be positive, and vice versa for false negatives (FN). Recall is the ratio of the number of TP to the sum of TP and FN. An F1 score is the harmonic average of precision and recall, and support is the number of true occurrences. A confusion matrix is a visual representation of a classification model's performance. Finally, the model with the highest accuracy will be chosen for the prediction of SIF incidents.

Table 3. Performance metrics are used for the evaluation of ML models.

Performance Metric	Formula
Accuracy	$\frac{TP+TN}{TP+TN+FP+FN}$
Precision	$\frac{TP}{TP+FP}$
Recall	$\frac{TP}{TP+FN}$
F1 Score	$\frac{2\times Precision\times Recall}{Precision+Recall}$

5.3.2. Second Research Question

The second research question aims to identify some missing ST factors that are not captured during safety inspections. The overall methodology is shown in Figure 11. Data pre-processing will be done on the incident and inspection descriptions and then each incident will be linked to its corresponding past one-month inspections. The reasoning for linking incidents to past inspections is that site conditions usually are improved after an incident. Therefore, an inspection prior to the occurrence of the incident is deemed representative of the site conditions (Poh et al., 2018). Considerations need to be made to ensure that the location and project number are the same for both incidents and inspections.

Universal Sentence Encoder (USE) will be leveraged to generate high-dimensional vector representations for incident and inspection reports. USE is a pre-trained model that is designed to encode text into vectors while also capturing semantic information, thereby making it effective in understanding the contextual meaning of sentences (Cer et al., 2018; Yang et al., 2019). This allows us to understand the different themes mentioned in incident and inspection reports. Pearson correlation, Manhattan distance, and cosine similarity scores will be used to measure similarity scores. Pearson correlation measures the linear correlation between two sets of embeddings and assesses the strength and direction of linear relationships (Sheugh & Alizadeh, 2015). Manhattan distance, on the other hand, computes the sum of absolute differences between corresponding elements of the embeddings (Suwanda et al., 2020). It reflects the "distance" between the vectors in terms of the sum of absolute differences. The cosine similarity score measures the cosine angle between two vectors, with scores ranging from -1 (completely dissimilar) to 1 (identical) (Pavitha et al., 2022). Therefore, a high cosine similarity score indicates that there is a greater similarity in the semantic content of texts, whereas low similarity scores indicate dissimilarity. The method that provides the best accuracy will be used for further analysis. The incidents that have low similarity scores will be further selected, and a root cause analysis will be done to identify the missing ST factors that are missing capturing hazards during inspections. The missing ST factors will then be ranked and prioritized to provide preventive and mitigative strategies.

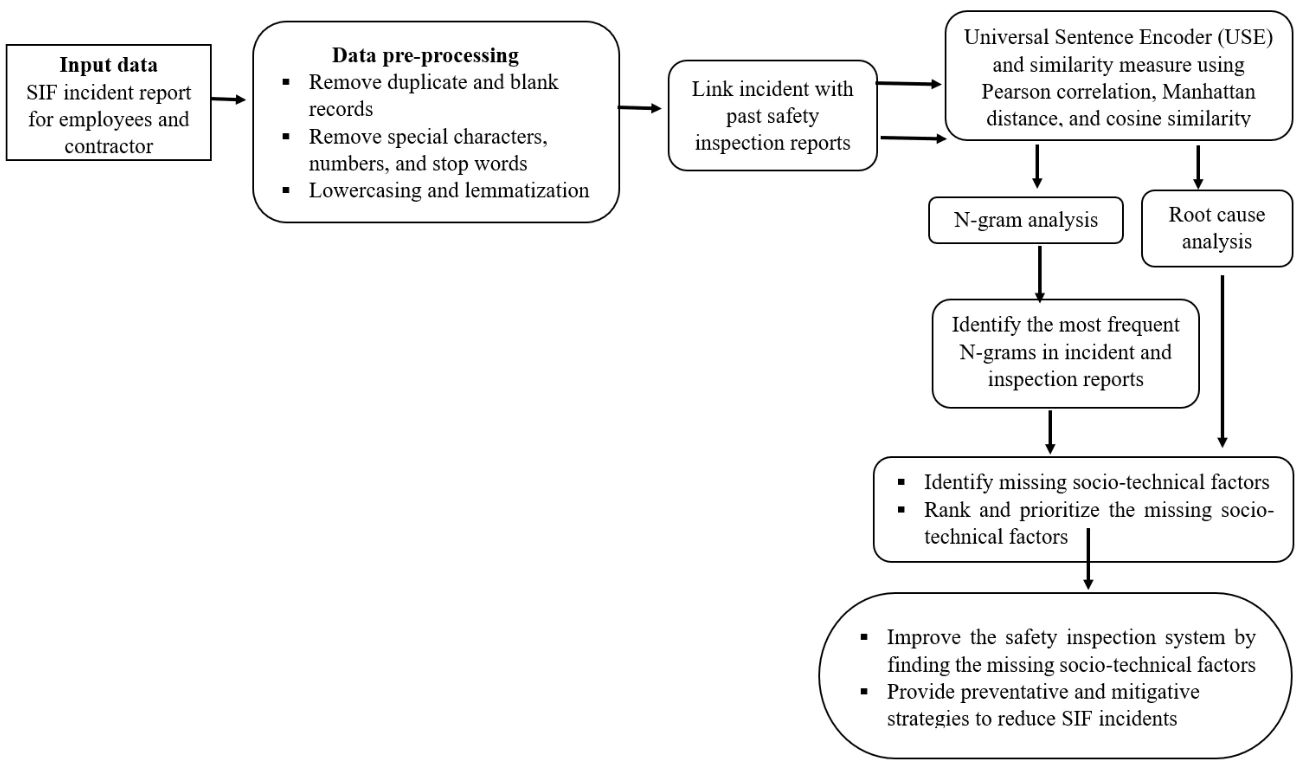

Figure 11. Methodology for the second research question.

Simultaneously, N-gram analysis will be generated to mine any recurrent topics and linguistic structures in incident and inspection reports, and Sankey diagrams will be used for visualization using an open-source online tool, SankeyMATIC (sankeymatic.com). N-gram refers to a set of N-adjacent words (Bird et al., 2009). A uni-gram tokenization breaks a sentence into one-word tokens. Similarly, a bigram is a token of two words, and a trigram is a token of three words.

All the data analysis steps mentioned in the above sections will be performed using the latest Python version, 3.11.6, in the Anaconda environment.

5.3.3. Third Research Question

The third research question looks at what recommendations can be made to improve the quality of occupational health and safety (OHS) procedures. The overall methodology that will be adopted is shown in Figure 12. Data fusion techniques will be applied to combine the quantitative results of the first research question (the most influential ST factor that is causing SIF events) and qualitative results of survey with subject matter experts.

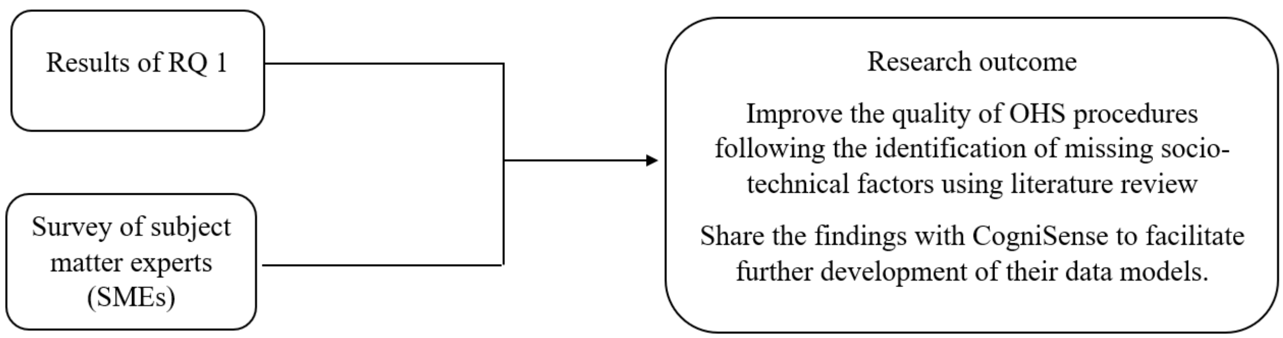

Figure 12. Methodology for the third research question.

Data fusion involves integrating multiple records from different sources into a single and consistent format (Bleiholder & Naumann, 2009). Combining qualitative and quantitative approaches provides a holistic perspective that allows one to grasp the underlying patterns associated with the data. To further understand the gaps within the mining industry, a survey will be created and distributed to the subject matter experts. The subject matter experts could include frontline supervisors, crew members, and/or HSE officers. Different weights will be given to each participating member based on their work experience, position, educational background, etc. to ensure that the results accurately reflect the populations characteristics (Lavallée & Beaumont., 2015).

Each question will be asked to be rated based on a five-point Likert score, ranging from 1 (strongly disagree) to 5 (strongly agree). The data will be collected and managed using a secure University of Alberta software program, REDCap (Research Electronic Data Capture). REDCap offers 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for data integration and interoperability with external sources (Harris et al., 2019). The ST factors identified will be ranked using the relative important index (Muneeswaran et al., 2020), which is calculated using the following equation:

$$\textbf{RII} = \Sigma \frac{W}{A\,.\,N}$$

Where w is the average weight given to each factor, A is the highest, and N is the total number of respondents.

Using the data fusion and literature review results, recommendations will be made to improve the quality of occupational health and safety procedures. In addition, the results will be shared with CogniSense to facilitate the development of their competency models further.

5.4 Expected results

This study leverages ML, NLP, and text mining techniques to improve safety performance at human and organizational levels within the mining industry. The expected results of this study are to:

1. Identify the most influential socio-technical factors that cause incidents among contractors and employees.
2. Identify, rank, and prioritize the missing socio-technical factors that are not captured during safety inspections.
3. Implement data-informed decision-making methods to enhance occupational health and safety procedures and allocate resources efficiently.

6 Conclusion

In Sum, we have held two productive workshops where we engaged with industry professionals to make progress towards reducing SIFs and improving workplace safety practices. The September 21, 2023, workshop in Calgary, Alberta provided insight to where the current gaps lie in the industry, including the lack of consistency in terms of how serious injuries are defined and the leading indicators used for SIF, as well as a lack of understanding around human and organizational factors that impact safety decisions. Participants were interested in learning more about bowtie models, which guided the research teams focus for the second workshop held in Fort McMurray, Alberta on November 21, 2023. The second workshop had a larger audience and focused on critical controls to reduce SIFs. During this workshop, we developed bowties to visualize the causes, consequences, and controls for six major incident hazards: 1) heavy-light vehicle interaction, 2) lifting and hoisting, 3) active haul operation, 4) confined space, 5) dropped objects, and 6) working at heights. These bowties are attached (see Appendix B). We are now examining these controls (shown as black boxes) to determine which are ‘critical controls’ and can independently prevent or mitigate consequences to ensure that we ‘fail safely’. In the future, these bowties can be used for further training and workshops to develop individual, organizational and/or agency level competencies for understanding critical controls and critical control assurance. The research team used the knowledge and feedback of workshop participants to improve the research questions, identify focal concepts to measure during data collection, and to craft survey and interview questions.

The first research study detailed in this report leverages a mixed-methods approach consisting of quantitative surveys and semi-structured interviews to identify the human and organizational factors that contribute to incidents within the mining industry. In addition, the study aims to identify the most influential factors and implement data-informed decision-making methods to enhance safety practices and allocate resources efficiently.

The second research study dealing with ST factors aims to enhance safety performance by leveraging ML, NLP, and text mining techniques to identify the key ST factors that contribute to incidents among contractors and employees in the mining industry. In addition, the study seeks to rank and prioritize any previously overlooked ST factors in safety inspection reports. The efforts aim to improve occupational health and safety procedures for efficient resource allocation and develop a robust safety management system.

Next steps for this project include another symposium planned for April 3rd, 2024, in Edmonton, Alberta. This symposium will focus on the human and organizational factors that lead to unsafe or risky behavior, such as low psychological safety, poor conflict management, low accountability, and more. Contractors and sub-contractors will be the target audience for this event.

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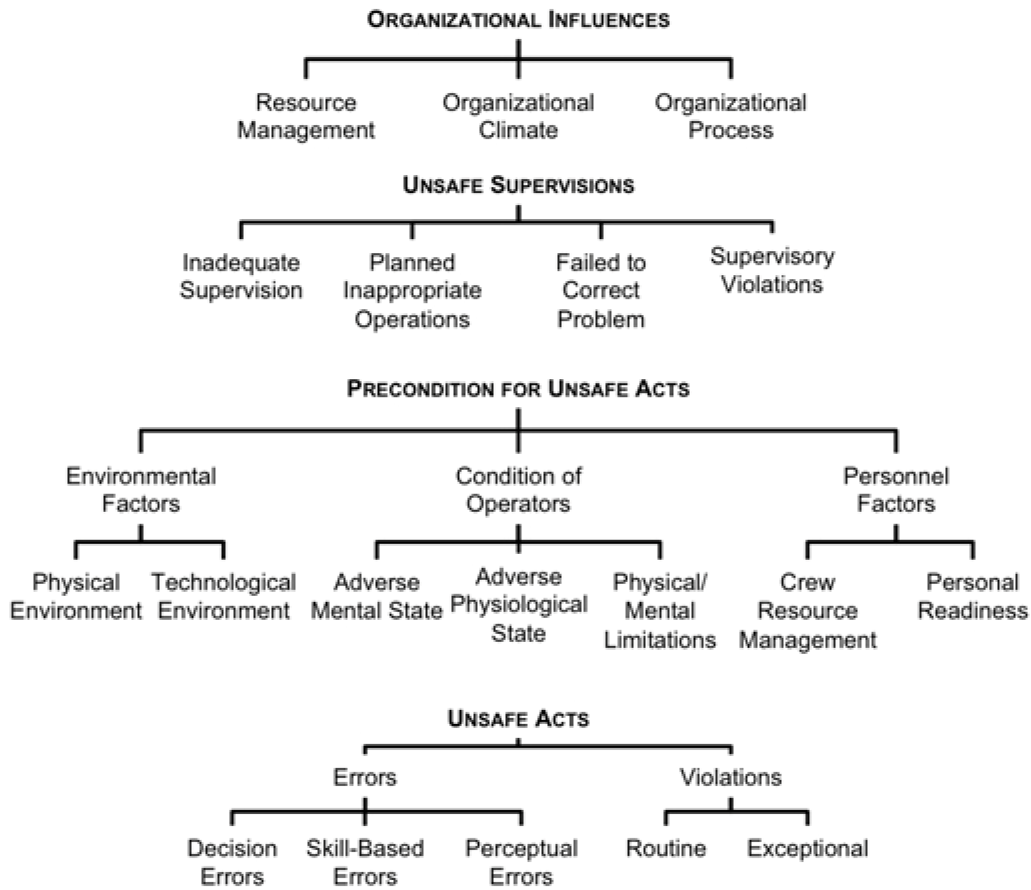
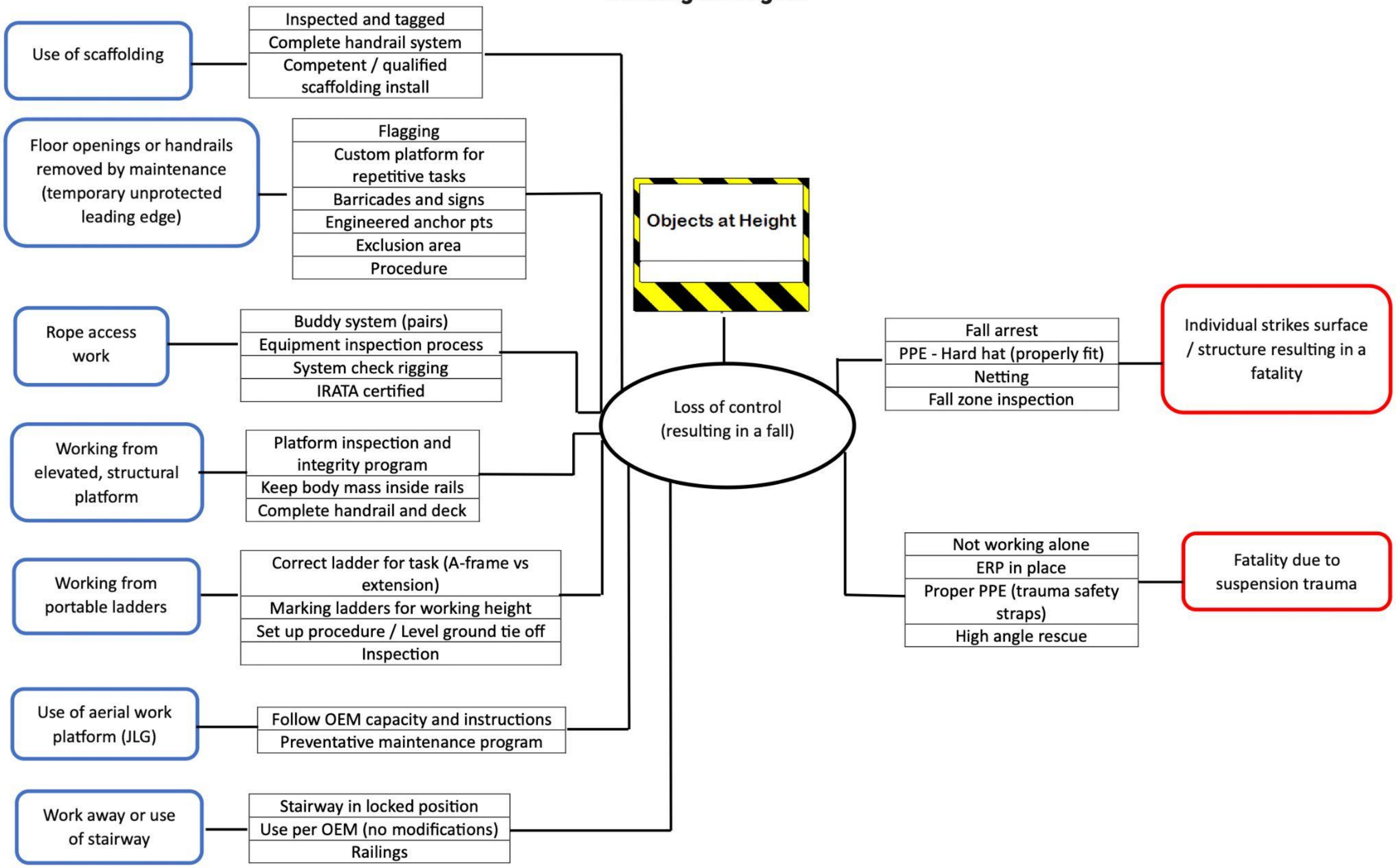
Appendix A - The HFACS Framework

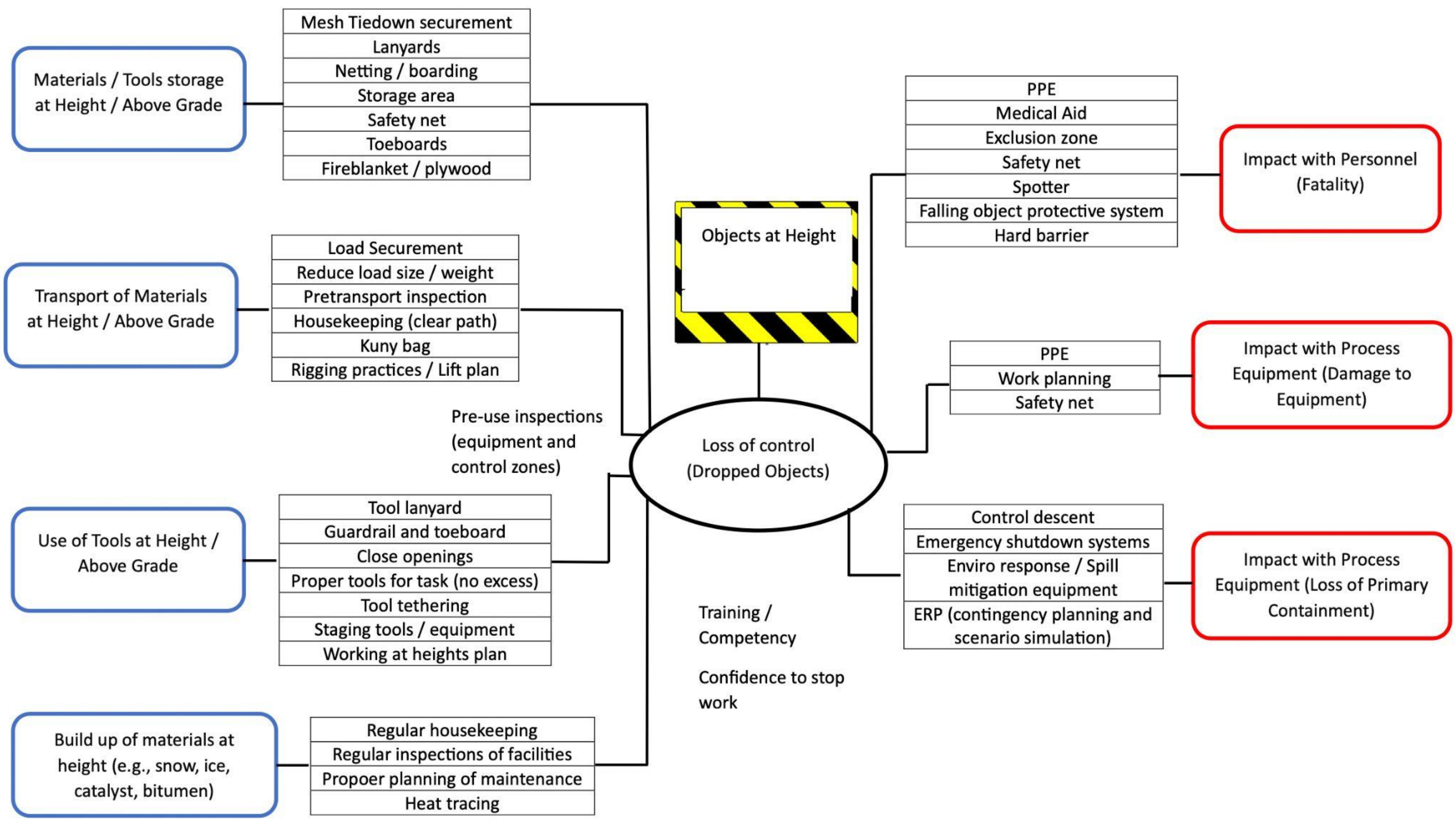


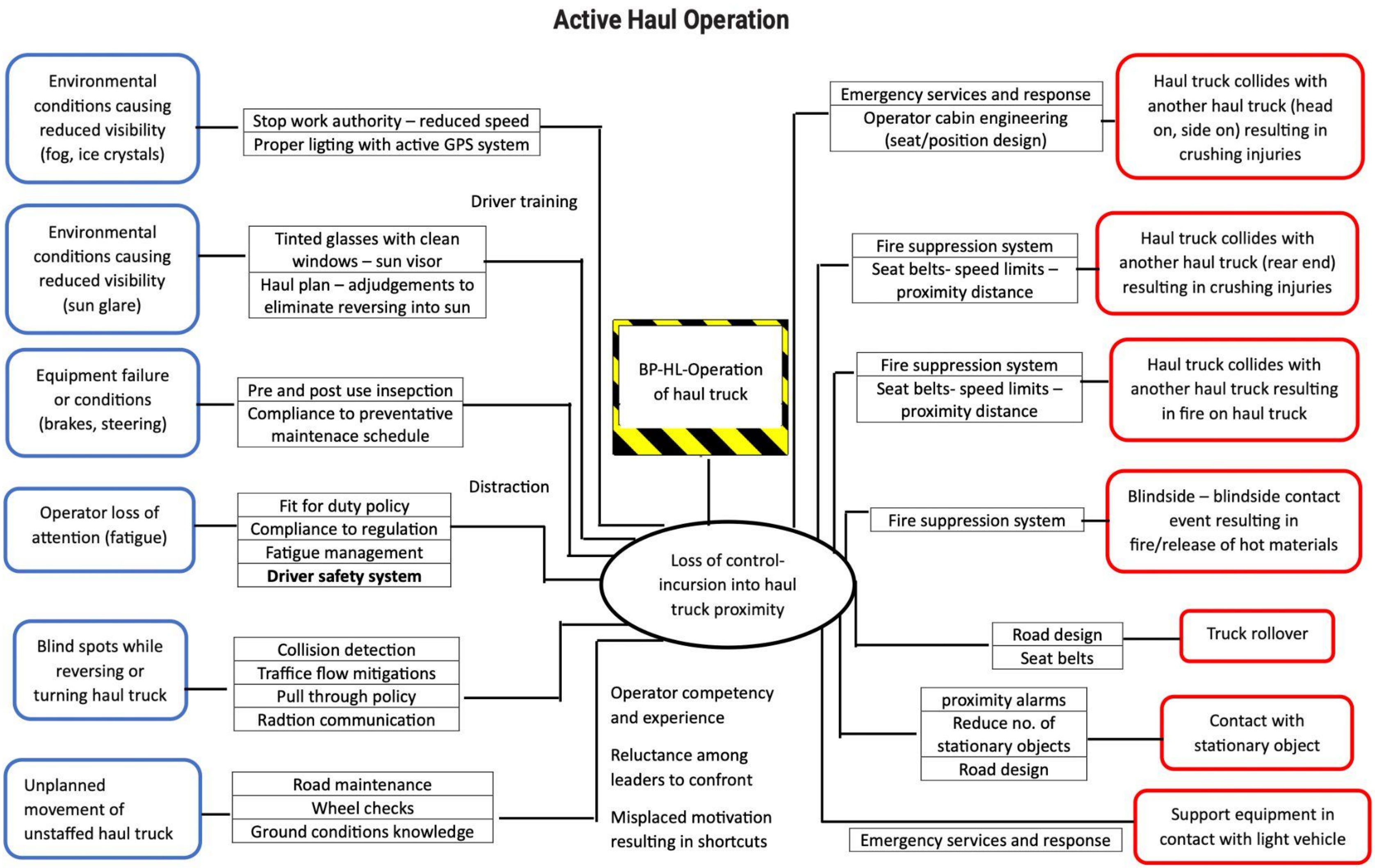
Appendix B - Bowtie Models from the November 21, 2023 Symposium

Working at heights



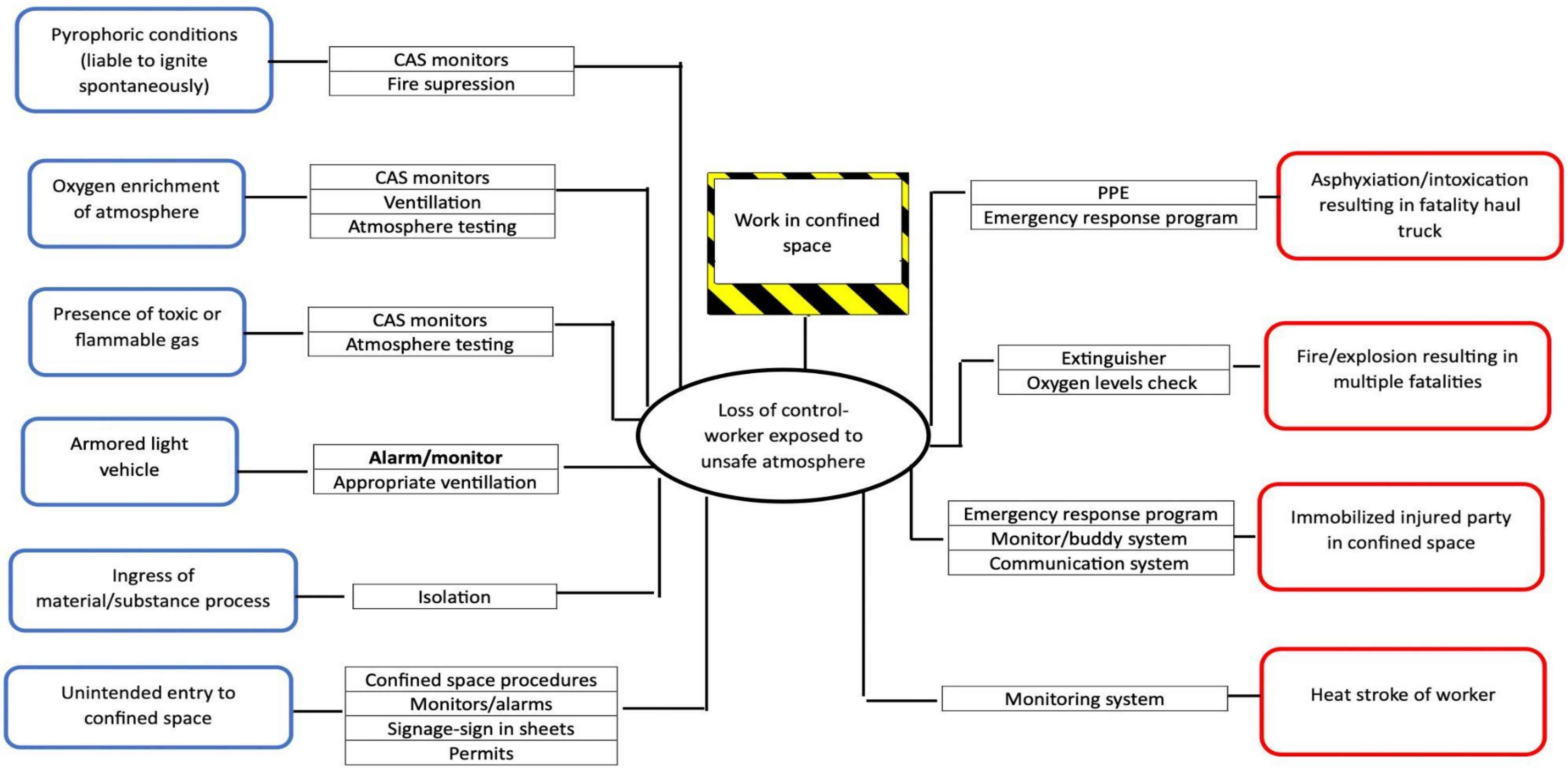
Dropped Object



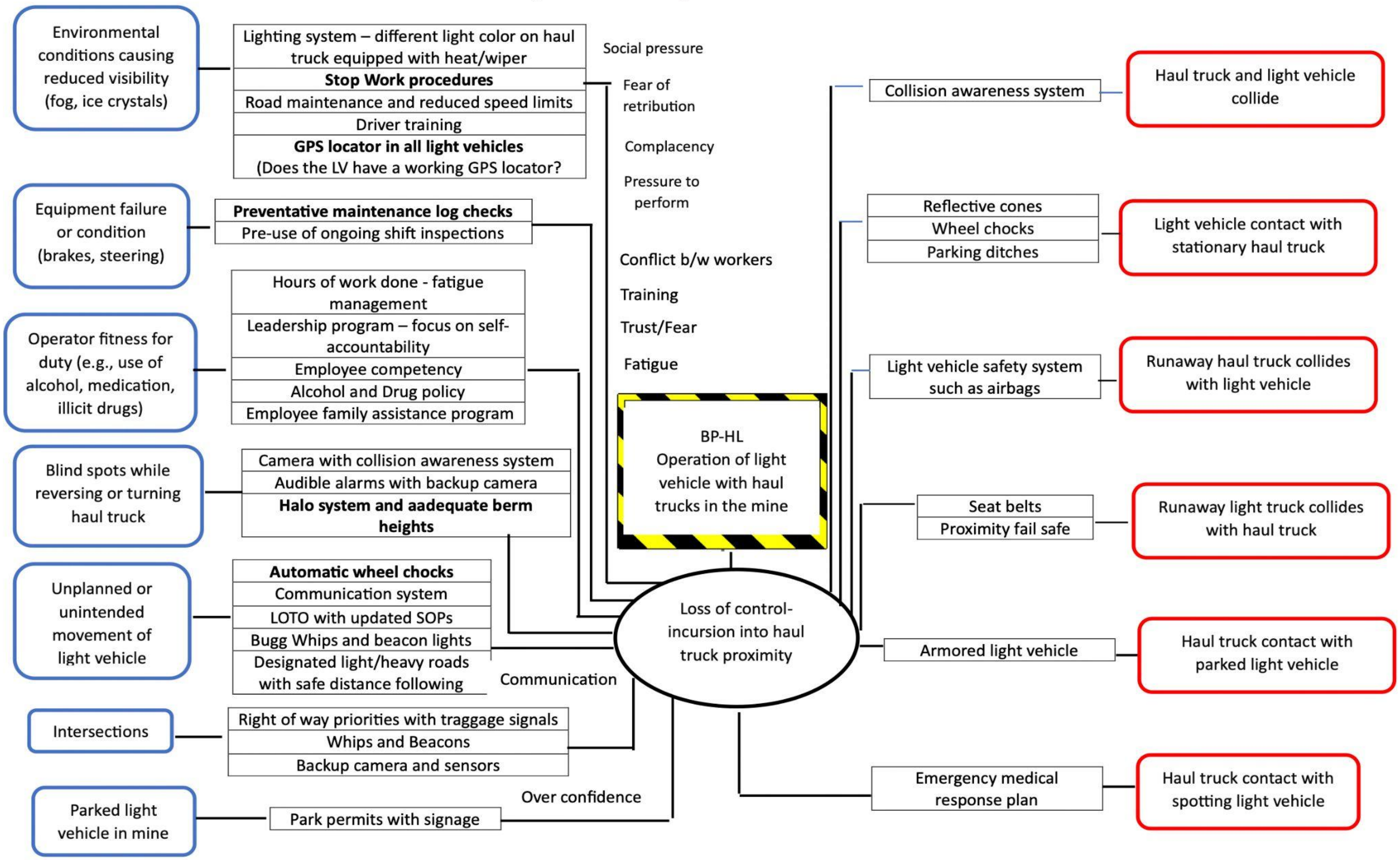


Active Haul Operation
Environmental conditions causing reduced visibility (fog, ice crystals)
Stop work authority – reduced speed
Proper ligting with active GPS system
Driver training
Environmental conditions causing reduced visibility (sun glare)
Tinted glasses with clean windows – sun visor
Haul plan – adjudgements to eliminate reversing into sun
Equipment failure or conditions (brakes, steering)
Pre and post use insepction
Compliance to preventative maintenace schedule
Distraction
Operator loss of attention (fatigue)
Fit for duty policy
Compliance to regulation
Fatigue management
Driver safety system
Blind spots while reversing or turning haul truck
Collision detection
Traffice flow mitigations
Pull through policy
Radtion communication
Unplanned movement of unstaffed haul truck
Road maintenance
Wheel checks
Ground conditions knowledge
BP-HL-Operation of haul truck
Loss of control-incursion into haul truck proximity
Operator competency and experience
Reluctance among leaders to confront
Misplaced motivation resulting in shortcuts
Emergency services and response
Operator cabin engineering (seat/position design)
Haul truck collides with another haul truck (head on, side on) resulting in crushing injuries
Fire suppression system
Seat belts- speed limits – proximity distance
Haul truck collides with another haul truck (rear end) resulting in crushing injuries
Fire suppression system
Seat belts- speed limits – proximity distance
Haul truck collides with another haul truck resulting in fire on haul truck
Fire suppression system
Blindside – blindside contact event resulting in fire/release of hot materials
Road design
Seat belts
Truck rollover
proximity alarms
Reduce no. of stationary objects
Road design
Contact with stationary object
Emergency services and response
Support equipment in contact with light vehicle

Confined space



Heavy Vehicle – Light Vehicle interaction



Lifting and Hoisting