Final Report

FOR CREATIVE SENTENCE

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

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in partnership with

Energy Safety Canada (ESC)
Alberta Construction Safety Association (ACSA)
Construction Owners Association of Alberta (COAA)

FINAL REPORT

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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. As a joint submission during sentencing, Suncor asked that penalties be redirected to support learning across mining and related industries.

Mining is an industry with many high-energy hazards. Thus, the overarching objective of this creative sentencing research is to understand the hazards that cause Serious Incidents and Fatalities (SIF) in mining operations, the causes, and the most effective controls to prevent fatalities. When people make mistakes, how do we ensure that there are layers of protection so that they 'fail safely', rather than 'failing lucky', or worse 'failing unsafely/unlucky'?

To answer these questions, we engaged in three complementary research activities: 1) workshops, 2) data analytics of Critical Controls Assurance (CCA) versus SIF potential + actual (SIFp+a), and 3) surveys and interviews of hazard identification and human-organizational performance.

First, through workshops with 200+ subject matter experts across 60+ companies, we repurposed a process safety management tool – bowtie diagrams – to help workers 'see' high-energy hazards and the causes, consequences, and a system of layered controls. We developed and refined eight bowties for hazards that are most likely to cause SIF in these industries:

- Confined space
- Control of hazardous energy
- Dropped objects
- Working in and around water/ice/hazardous ground
- Excavations and trenching
- Heavy vehicle – Light vehicle interaction
- Working at heights
- Lifting and hoisting

These bowties are context independent, i.e., causes, consequences and controls are general enough to be relevant for any industry with these hazards. For example, any worksite with the potential for heavy/light vehicle interactions could use Fig. 1 and an illustration of causes (left blue boxes), loss of control (center circle), consequences (right red boxes), controls (black boxes) and critical controls (in bold), and human factors that could reinforce or degrade controls (unboxed text). These bowties are now being used for pre-task planning, training, and critical control assurance. See chapter 2.

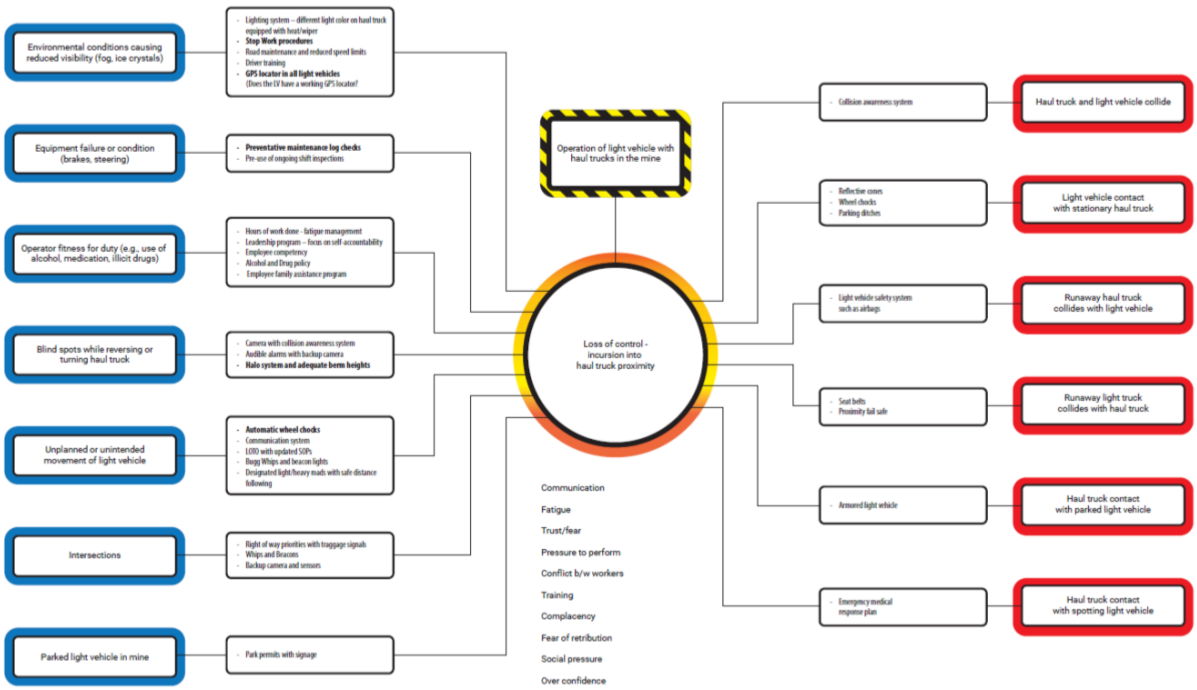

Fig. 1. *Bowtie for Heavy/Light Vehicle interaction with causes (blue boxes), loss of control (center circle), consequences (red boxes), controls and critical controls (black boxes), and human factors (floating text) that could reinforce or degrade controls*

We shared our workshop slides and a 'bowtie primer' with participants and industry safety associations (Alberta Construction Safety Association, Alberta Mine Safety Association, and Energy Safety Canada) for 'boots on the ground' workers. For companies who see safety as a cost or inconvenience, we also created a one-pager for 'The Business Case for Risk Management'. These materials are in Appendix A.

Second, we used **data analytics** (primarily machine learning and natural language processing) **across five mining operations** to analyze how inspections (specifically critical controls assurance (CCA) questions) matched with subsequent SIFp+a. This allowed us to better see the gaps and overlaps in companies' management systems and recommend enhanced CCA questions. See Fig 2 for mining and tailings (also see chapter 3), which illustrates that working with/near energized equipment (dozers, telehandler, tractors, etc. that are left running) and toxic material are hazard exposures that could cause SIFs, but have relatively less attention in CCA questions.

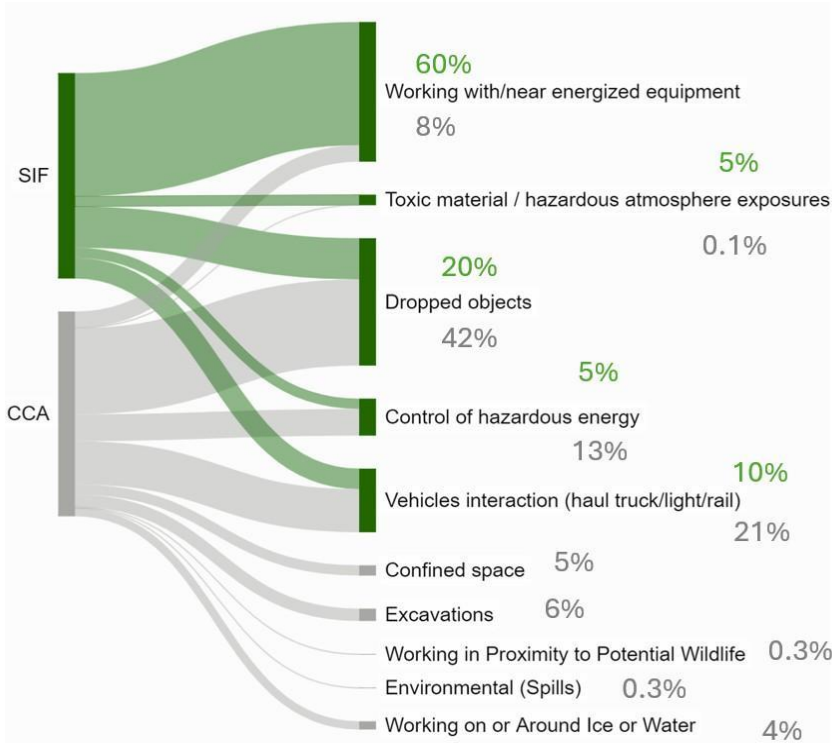

Fig 2. Most and least captured indicators in SIF incidents and CCA for Mining & Tailings.

Third, we used surveys and interviews of 4,662 employees and contractors conducted across the mining industry from August to September 2024, to understand the human and organizational factors that reinforce or degrade safety performance. See chapter 4. We have developed new survey questions for this (see Appendix B). And since mining and refining have different hazards than construction, we created and modified hazard icons for these (see Appendix C). In this report, we present descriptive and correlational statistics. And we identify safety behaviours that could contribute to (un)safe behaviours.

Respondents' attitudes generally have the strongest relationships with our proxy safety variables, further emphasizing the importance of social-psychological factors in shaping safety. See Table 14. For example, one of the strongest predictors of safety perceptions were crews who have positive safety attitudes (e.g., my crew places a great deal of emphasis on safety) and beliefs that they can conduct the work safely (e.g., collective efficacy). In contrast, factors like shift rotation satisfaction and access to personal protective equipment (PPE), while still important, were only moderately related to the safety outcomes.

Hazard identification is the first step for ensuring that workers are safe. Thus, as part of the survey, we asked respondents why hazards may not be identified or reported while on the job. In response to this question, the research team coded 2,986 reasons provided by a random subset of 1,169 workers across the mining industry that were representative of the broader sample. Of the reasons provided, the top three main areas identified as a potential reason why hazards might not be identified or reported, included:

1. Novice and Developing Workforce
2. Perceived Career Implications
3. Normalization of High Hazard Work

It is important to note that this question taps into actual and hypothetical or perceived reasons why a hazard may not be reported generally. These insights are important because they tell us about some of the beliefs employees and contractors have about hazards and hazard reporting as well as their actual reported behaviours. Thus, we also asked respondents about which hazards they are exposed to, if controls are in place, and if they fear these hazards will hurt themselves or others. These results are presented in Table 1 (top three hazards) and Appendix C (full list).

Table 1. Sample hazard icons from survey on perceptions of exposure, controls, and fear

	I am exposed to this hazard routinely	There are controls in place	I am afraid this hazard will hurt me or someone else	This hazard does not apply to me
 TRUCK COLLISIONS	42.7%	66.3%	17.8%	3.8%
 VEHICLE INCIDENT	37.1%	71.5%	12%	4.4%
 LINE OF FIRE	34.6%	72.8%	10.8%	4.2%

Comparing the general perception of "why aren't hazards identified or reported?" with the specific risk perception/exposure questions in Table 1 and Appendix C is insightful. While ~15% of respondents fear of career repercussion and 11% feared social repercussions, generally fewer (3.1% - 17.8%) feared specific hazards. Why this difference? This is partly explained by how the questions are asked: generalized perceptions of others' behaviour versus specific perceptions of one's own behaviours. It may also indicate that key hazards are being overlooked. Comparing individuals' risk perceptions versus their hazard exposures would answer this. Or is there an overreliance on existing controls, practices, experience, etc., instead of a healthy level of concern? Revisiting critical controls assurance versus SIFs, by workgroup, would answer this.

However, this also leads to a broader question: In scenarios where workers are too afraid to identify and report hazards, how do we help them to better see, understand, and control these? Conversely, for hazardous tasks where workers are over-confident in controls (i.e., not fearful enough), how can we ensure that they address this blind spot?

Our answer is to *create visualizations of the hazards and controls* with bowties, Sankey diagrams of system gaps/overlaps, and hazard icons – as shown in Fig. 1-2 and Table 1.

Visualizations enhance individuals' hazard identification and cognition, support the sharing of social knowledge, and promote mindful organizing by inscribing the big picture, temporality, and accountability. Visualizations also trigger curiosity and curiosity eliminates fear. Thus, visualizations also enable individuals to reconsider uncomfortable information, challenge preconceived assumptions, and create innovative and collaborative solutions.

In sum, here are several recommendations for mining and related industries from our work. We strongly recommend that companies consider the following:

1. Identify high-energy hazards, the stuff that kills you (STKY), develop layered controls for these hazards, and ensure that these controls are in place and functional.
2. Use visualizations to show these hazards and the associated layers of control – say with bowties, critical task infographics, start work check diagrams, etc.
3. Share these visualizations with workers so that they can better see, monitor, and manage their workplace hazards, as the work is done (versus work as planned/imagined).
4. Check the efficacy of critical controls by comparing SIFs versus the hazards/controls identified prior to work (from pre-task planning, start work checks, safeguard verification, hazard identification, etc.). Enhance your critical controls assurance questions or processes as required.
5. Compare workers' perceptions of risk versus the hazards they are exposed to. Fear of repercussions can suppress hazard reporting, while over-confidence could cause shortcutting in safeguards verification.

We will continue to share our summarized findings with companies and workers in mining, related industries, and the public more broadly by:

- Distributing this final report to all 200+ workshop participants and their 60+ companies
- Circulating this report to our partner safety associations
- Hosting additional bowtie and human factors workshops with safety associations (i.e., a workshop is already planned for ACSA's annual conference in October 2025)
- Offering to host workshops at industry conferences (i.e., Canadian Institute of Mining, Metallurgy, and Petroleum (CIM), Energy Safety Canada)
- Creating more one-pagers and short three-minute videos of our key findings
- Publishing our findings in academic journals and practitioner publications (i.e., OHS Canada, CIM Magazine)
- Responding to media and podcast requests, as required

The full report offers more specifics and insights, including the recommendations noted above and suggestions for future work.

We are deeply grateful to all who supported this project across the mining, energy, and industrial construction sectors: the thousands of survey respondents, the hundreds of subject matter experts, and the tens of companies who contributed. This project is a great example of how companies, industry safety associations, and researchers can work together when tragedies occur — to maximize learnings and develop focused improvements to SIF prevention.

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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. Despite this, Alberta's disabling injury rate and lost time claims rates have remained constant over the past 15 years (see Fig. 3). Serious injuries and fatalities are a persistent problem worldwide. For example, in the US, the total recordable incident rate has declined significantly over the past thirty years, yet worker fatalities have remained at 3.3-3.7 per 100,000 workers for the past 20 years (Bureau of Labor Statistics (BLS), 2022). For high-hazard industries, the rates for disabling injuries are 5-10 higher than average: (Statistica) for mining, quarrying, and drilling industries in Canada, there are 46.9 fatalities per 100,000 workers each year and 20.2 fatalities per 100,000 workers in construction. Canada ranks 20th among the 27 OECD countries for workplace safety (Nishikitani & Yano, 2008). 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).

This research aims to understand the precursory conditions for Serious Incidents and Fatalities (SIF) and how these can be controlled and prevented, specifically in mining operations.

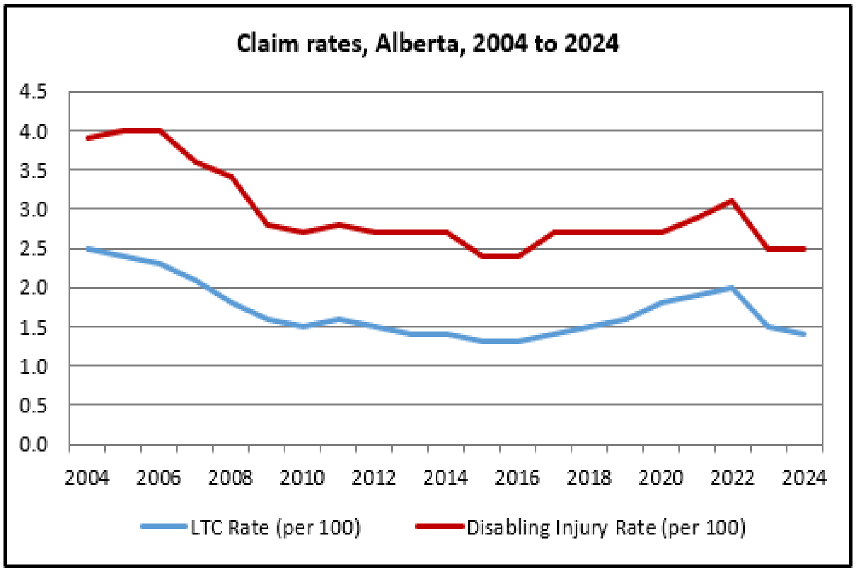

Fig 3. Lost Time Claim Rate (LTC) and Disabling Injury Rates in AB, 2004- 2024 (Wilson, 2025).

1.1 Motivation and Outcomes

Analysis shows that the causal factors for high-consequence, low-frequency incidents like SIF differ from those for more frequent, minor incidents. SIF incidents are more likely for high-energy tasks (work with heights, electrical exposures, confined spaces, struck-by and caught-between hazards), hazardous materials, and dynamic/changing work conditions (Oguz Erkal & Hallowell, 2023), as summarized in the first column of Table 2. Industries have created lifesaving rules specifically for these high-energy or high-hazard tasks, but implementation is uneven across companies (Scotti et al., 2018) and contractors (Walker et al., 2020). Research of precursors in mining (Brady, 2019; Martin & Black, 2015) and related industries like industrial construction (Bayona et al., 2022; Construction Safety Research Alliance (CSRA); Oguz Erkal et al., 2021, 2024; Salas & Hallowell, 2016) give a shortlist of factors that are most predictive of SIF at the individual/team and organizational/system levels. See Table 2.

Table 2. Precursor task, individual/organizational, and management system factors for SIF incidents.

Task / Work factors (T) (presence of)	Individual / Team Behavioural (B) Factors (absence of, or deficiencies in)	Management system / Organizational (O) Factors (absence of, or deficiencies in)
• Work with heights • Electrical exposures • Confined spaces • Struck-by and caught in/between hazards • Hazardous materials • Dynamic work	• Crew experience working together • Supervisor experience with the crew • Total number workers under the supervisors' purview • Presence of leadership development programs for frontline supervisors • Total number of high energy classes observed around the crew • Number of days the crew has been working without days off • Drug testing	• Near miss reporting • Job Safety Assessment (JSA)/Field-Level Risk/Hazard Assessment (FLRA/FLHA) development • JSA/FLRA/FLHA engagement • Contractor safety audits • Contractor Project Management engagements • Contractor safety rep engagements • Client safety engagements

Besides high-hazard tasks, some individuals, workgroups, and organizations are better able to recognize and manage these hazards; absences or deficiencies in these variables leads to higher SIF rates (second column of Table 2). Management system factors are often reported in companies' paperwork (third column of Table 2). Many of these factors are often operationalized as presence/absence or frequency of a report or an engagement. We can gain additional insights if these are operationalized as quality assurance (e.g., demonstrated competency for working on a scaffold) or quality control (e.g., audited efficacy of multi-layered, system-level controls). This would focus attention on how "work is done" in the field versus "work as planned".

These variables also interact. For example, a supervisor's work and supervisory experience affect the quality of a Field Level Hazard Analysis (FLHA) or safety audit. This experience can create positive feedback loops: if supervisors have demonstrated competency in working on scaffolds, they should recognize hazards associated with that work, ensure that controls are in place and functional, and create high- quality FLHAs. Presumably, their safety performance would also improve. However, we cannot assume positive associations between variables. Controls can be bypassed, or there can be deviation from procedures over time, whereby "work as done" diverges from "work as planned" (Martin & Black, 2015).

We identified many of these precursors in a previous creative sentence for tailings safety through several phases of data collection and analysis (Baker et al., 2019). However, other human and organizational variables - like psychological safety, learning, and team efficacy – create the capacity to ensure that hazards are recognized and controlled. While other variables – like fear and hiding – result in hazards not being identified, reported, or controlled.

Thus, in this research, we expanded our approach by collecting data via 1) workshops, 2) data analytics of Critical Controls Assurance (CCA) versus SIF potential + actual, and 3) surveys and interviews of hazard identification and human-organizational performance. This equipped us to deliver the following outcomes (see Table 3).

Table 3. Research methods and outcomes.

Research (Mar 2023 – Mar 2024) **Methods →** **Outcomes↓**	**Workshops (Calgary, Ft. McMurray, Edmonton)**	**Data analytics for CCA vs. SIFp+a**	**Surveys and interviews of HAZID, human-org performance**
1) Create a hazard inventory of 'work as done' in all mine operations (mining, extraction, treatment, and tailings) and ancillary activities.	Major incident hazard bowties	CCAs and SIF	HAZID icons
2) Identify/develop indicators for SIF precursors, controls, and assurances/audits.	Missing leading indicators	Socio- technical	Human & organizational precursors
3) Determine which activities are most likely to be completed by contractors.	-	CCAs and SIF	-
4) Examine how indicators, controls, and control/barrier assurance vary across owners/operators, contractors, and subcontractors.	-	CCAs vs SIF by site	-
5) Survey the prevailing safety culture within owners, contractors, and subcontractors.	-	-	Safety culture varies by site
6) Recommend systems-level, multi-layered, effective, and assured controls.	Develop preventative & mitigative controls	CCAs vs SIF to improve CCA questions	Recommend human and org controls
7) Promote and support the implementation of these controls into owners/operators', contractors', and subcontractors' safety management systems. Test the efficacy of these controls.	Bowties developed by and distributed to mining companies	Enhanced CCAs to be tested	Understand barriers to adoption and use

1.2 Project Team

Given the diverse nature of this project, we enlisted a multi-institutional and multidisciplinary research team, from the University of Alberta 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, Ph.D., Department of Psychology.
- Jessica Wilkins, MSc., Department of Psychology.
- Lena Le Huray, MSc., Department of Psychology.
- Madeline Springle, MSc., Department of Psychology.
- Hanna Mughal, BSc. Honors Psychology, Department of Psychology.

1.3 Budget and Schedule

As this research is funded by a creative sentence, tracking expenses is paramount. As of 5 March 2025, we are on track with our expenditures. Details are given in Table 4.

Table 4. Expenditures as of 5 March 2025

Funds Available before expenditures (A):		**$370,000.00**
Expenditures		
Salaries and Benefits-BL students, research associate *	$325,615.78	
Supplies and Other-BL - printing and supplies for workshops, PPE for site visits	$10,834.50	
Travel-BL to Calgary workshop, Fort McMurray workshop/focus group, and site visits	$31,664.87	
Capital Assets-BL (computer software)	$824.76	
Total Direct Expenses (B)		**$369,939.91**
Funds Available before Indirect Costs as of 04/15//2025 (A-B):		**$60.09**

* 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.

We met our proposed project schedule. See Table 5.

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 was on schedule. Our survey was pilot-tested in May and rolled out in August-September 2024 and analyzed by December 2024.

Phase 3 – Implement best practices and Phase 4 – Industry sharing and education was planned for late 2024/2025. However, given industry demand, we initiated sharing earlier in 2024.

Table 5. Project Schedule.

Phase	2023									2024												2025			
	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																									◆

◆ = interim and final reporting

We describe each of these research activities in more detail in the following chapters.

2. Workshop Symposiums: Building Resilience to Serious Injuries and Fatalities (SIF)

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 may be insufficient, bypassed, or non-functional.

To understand the differences between 'work as intended' and 'work as done', we held three workshops, with industry subject matter experts in safety management systems and leading indicators, hazard identification and controls in mining, and hazard identification and controls in industrial construction. These workshops included:

- 35 participants (from 12 organizations) in-person at the University of Alberta – Calgary Campus on September 21, 2023, from 7:30 a.m. to 12:00 p.m.
- 115 participants (from 37 organizations) in-person at the Quality Hotel and Conference Centre in Fort McMurray, Alberta, hosted by Energy Safety Canada (ESC) on November 21, 2023, from 7:30 a.m. to 12:00 p.m. This workshop was built on the work of Suncor's process safety team: Tenny Thomas, Mike Brown, Muhammad Ehtisham, and Cory Johnson.
- 91 registered with (from 61 organizations in the oilsands, mining, construction and safety management sectors), in person at the Alberta Construction Safety Association (ACSA) in Edmonton, Alberta on November 26, 2024, from 9:00 a.m. to 1:00 p.m.

These first two SIF workshops helped us to identify, implement, and monitor critical controls for hazards with the potential for SIFs. During the November 2023 workshop in Ft. McMurray, 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. The results from the first two workshops were presented in our report (Lefsrud et al., 2024). The results of our third workshop is discussed next.

2.1 Purpose and Objectives

The overarching objective of this workshop was to examine high hazard work, human and organizational performance, and critical controls assurance using bowtie analyses.

What is a bowtie and why do we use them? Bowties are a method to visualize, communicate, and better control high-energy (stuff that can kill you – STCKY) hazards to prevent SIF incidents, causes, and consequences and strengthen controls. It helps us to understand what can go wrong (see Fig 4). And if we can see hazards and agree on how to control them, we are more likely to work safely.

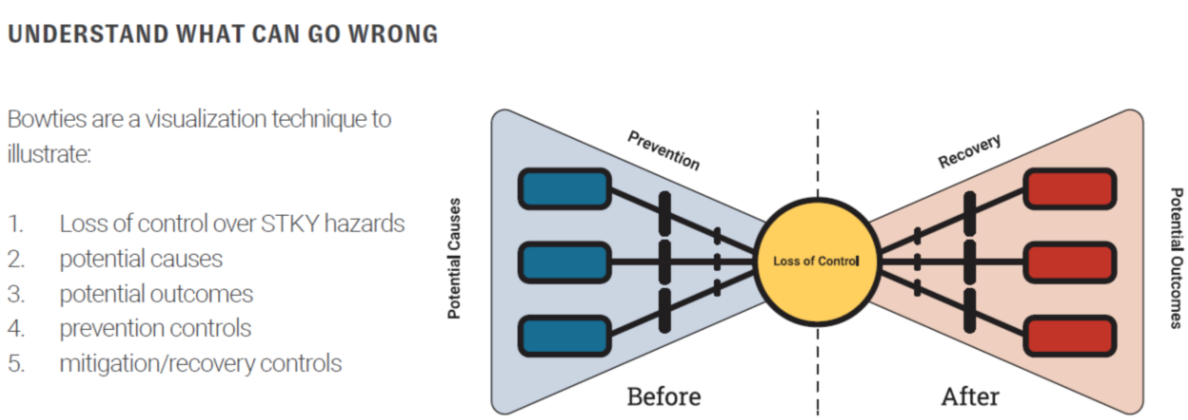

Fig 4. Elements of a Bowtie.

Bowties also illustrate that safety is the presence of layered controls rather than an absence of serious consequences. If you have more layers of controls to help you prevent and recover from an incident – a resilient safety management system - then you are more likely to fail safe than fail lucky. These layers are aligned with the hierarchy of controls (see Fig 5). Elimination, substitution, and isolation often prevent a loss of control and, thus, are most effective. If you eliminate work from heights by building modules on the ground, then you cannot fall to your death. If you substitute non-toxics for highly toxic chemicals, then a burst pipe will not harm workers. If you isolate workers from hazards, say by separating workers from moving equipment, then workers cannot get hit. Conversely, controls that are lower on the hierarchy are less effective. Administrative controls, like work permits, are easy to bypass. And Personal Protective Equipment (PPE), like hard hats or hearing protection, will not save you from being crushed by large falling equipment or objects. Relying on PPE to save workers is meager protection.

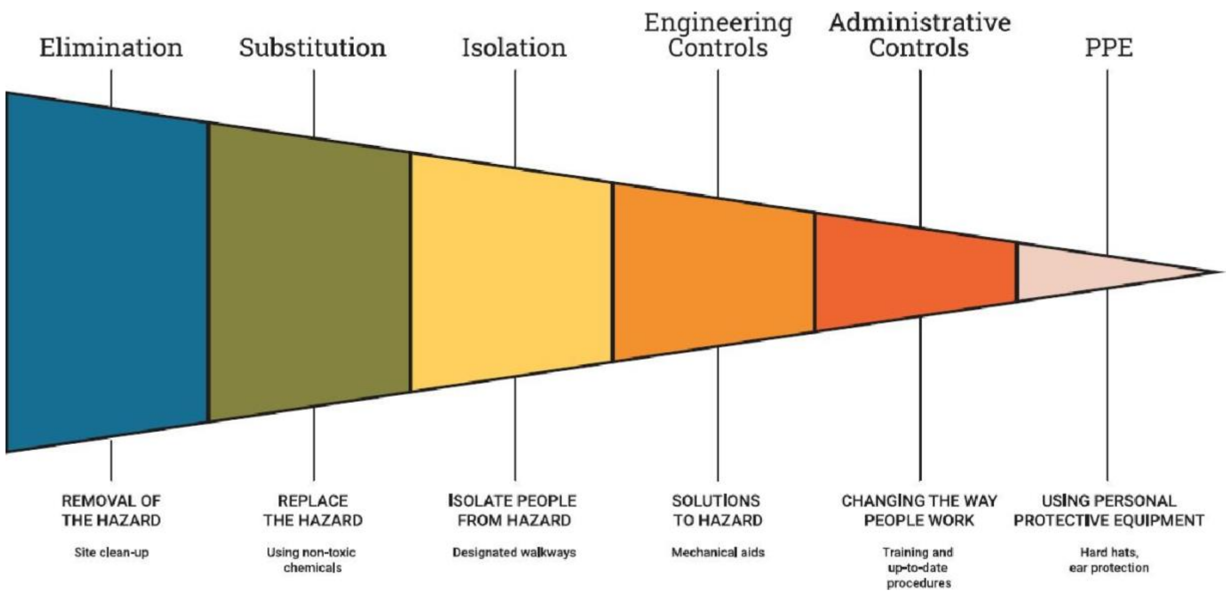

Fig 5. *The hierarchy of controls as layers of protection in a bowtie.*

Bowties are useful communication tool – to make the invisible visible and the unspeakable discussable. Engaging frontline personnel in bowtie discussions can enhance awareness, promote accountability, and provide opportunities to identify potential gaps in controls. They can be used effectively during safety meetings or toolbox talks with crews to visually communicate hazards, controls, and their roles in maintaining safety. If we understand which controls are critical, then we can assure that they are in place, functional, and non-bypassable – before work starts and as it unfolds.

Lastly, bowties show that if controls are degraded by human and organizational factors, which compromises the resilience of the system to 'fail safely'. Thus, our workshop included defining and understanding the ideas of psychological safety, trust, team learning, and safety culture. We invited participants to consider what variables should be measured and how, as well as the challenges of measuring such variables. We explored how to optimize the human and organizational factors linked to safety and how owners may support or undermine these actions.

In this workshop, we created a psychologically safe space to discuss human dynamics, leadership, and organizational factors potentially related to SIF incidents. We aimed to understand how employees experienced and understood various factors, including psychological safety, trust, motivation, appropriate training, peer-to-peer relationships, team dynamics and norms, leader and manager styles, organizational pressures, policies, (safety) cultures, and business drivers of safe and unsafe practices.

2.2 Participants

In early Fall 2024, an invitation for the symposium was circulated through Alberta Construction Safety Association (ACSA's) membership. In late Fall, this invite was also shared on social media platforms (e.g., LinkedIn) to reach a broad range of potential attendees. The invitation included an overview of the event, the topics that would be covered, and whose insights we were seeking. We focused on inviting contractors and subcontractors to encourage the expression of more open, diverse, and candid perspectives. We made it clear in the invitation that all information shared during the event would be used to develop the research program and not attributed to any one person or company. Suggestions for who should attend the symposium were included on the invite: Oilsands Contractors, Subcontractors and Suppliers: Senior Leaders, Project Managers, Project Safety Personnel, Operational Risk Management. In total, 91 guests were registered across 61 organizations in the mining, construction, and safety management sectors, and approximately 60 were able to attend in person for the session. Most attendees identified themselves as safety professionals (e.g., safety manager/coordinator/officer) or in a specialized safety role (e.g., HSEQ advisor, QA analyst), followed by management and leadership roles (e.g., manager/director).

The session included information presented and facilitated by six subject matter experts:

- Mark Hoosein (ACSA)
- Dr. Lianne Lefsrud (University of Alberta, Lynch School of Engineering Safety and Risk Management)
- Dr. Fereshteh Sattari (University of Alberta, Lynch School of Engineering Safety and Risk Management)
- Rose Marie Charuvil Elizabeth, MSc. (University of Alberta, Lynch School of Engineering Safety and Risk Management)
- Dr. Thomas O'Neill (University of Calgary, Department of Psychology)
- Jessica Wilkins, MSc. (University of Calgary, Department of Psychology)

2.3 Symposium Agenda, Process, and Content

Meeting Agenda

Part 1: Introduction and Purpose

- Describe the purpose of the workshop
- Safety Moment and industry commitment to improving workplace safety
- Introductions: Name, organization, interest in SIF

Part 2: Understanding and creating bowties as visualizations of high-energy hazards, causes, consequences, and controls

- Introduce bowties, controls, and critical controls assurance
- Group activity
    - Each table chooses one of six general loss of control scenarios (e.g., dropped objects, confined space, etc.)
    - Groups work together to identify controls for each scenario, distinguish which controls are critical controls, and what can be done for critical controls assurance
- Large Group Debriefing Discussion

Part 3: Enhancing Safety Management System to Prevent Serious Injuries and Fatalities (SIF) Using Data Analytics

- Using Machine Learning Techniques to Identify and Visualize Missing Leading Indicators
    - What are some missing leading indicators in safety inspections that lead to incidents? Knowing this, how can inspections be improved?
    - Overview of research and results
- Analyzing Incident Reports for Emotional Intelligence and Psychosocial Factors
    - What person and team variables – emotional intelligence and psycho-social factors are the most influential in causing incidents? Knowing this, how can the safety management system be improved?
    - Overview of research and results

Part 4: Social-Psychological Factors for Workplace Safety Behaviour

- Overview of social-psychological factors and how they influence safety
- Group discussion about how to promote workplace safety
- Interactive Slido questions and Group Discussion

Part 5: Call to action and concluding remarks

- Overview of projects and call for partnership/participants
- Concluding discussion and feedback

Process Overview

When registering for the symposium, participants were asked to identify their company and job title, along with any key elements they hoped to gain from the event. Participants largely indicated that they were interested in broadly gaining knowledge from the symposium (39 people mentioned this). Twenty people also mentioned wanting to learn more about the high-energy hazards that can cause SIFs, and 14 people noted interest in human and organizational performance (HOP). These interests helped guide the session and discussion topics.

The symposium was conducted in a large conference room at the ACSA headquarters. The room was filled with many large round tables, and participants were free to designate their preferred seating arrangements. They were, however, encouraged to sit close to the front to encourage active listening, participation, and engagement with others. For the hands-on activity involving bowtie analyses, participants arranged themselves into groups of approximately four to six people, each at a round table, to facilitate discussion and interaction. Presenters were situated at the front of the room and used a microphone to project their voices, and projected slideshows for visual aids of the presentation materials.

Understanding and creating bowties as visualizations of high-energy hazards, causes, consequences, and controls

To start, the participants were welcomed, oriented to the space, and a land acknowledgement was conducted. We then began with a short presentation that described what bowties are and how these tools can be used to mitigate SIF incidents. Once the purpose and process of creating a technical bowtie was explained, the floor was open to questions. Several bowtie frameworks were displayed on posters in an adjacent room that contained pre-populated critical controls and serious incidents. Serious incidents, for which controls were developed, included dropped objects, confined space, excavation and trenching, control of hazardous energy, working in or around water/ice/hazardous grounds, and lifting and hoisting.

In groups, participants chose a bowtie framework poster and gathered at their table to work on identifying controls for each hazard (Part 1), followed by identifying which controls were critical controls and what could be done to assure they were in place (i.e., critical controls assurance) (Part 2). Each part of the activity was followed by a short discussion. Markers and various sizes and colours of sticky notes were placed at each table for the participants to use to populate the bowtie poster. Facilitators circled the room to clarify questions, to ensure everyone had the opportunity to participate, and that instructions were followed correctly. Facilitation was used to ensure that the voices of all individuals were heard and accounted for, creating an inclusive environment. Feedback from this exercise was positive, with participants expressing statements such as how their combined intelligence enabled the generation of more ideas than would have been possible alone. Participants also noticed that it was beneficial to include operations personnel in the group as they provided an integral perspective. A brief group discussion on the experience of creating bowties concluded the exercise, and photographs were taken of all the bowtie posters to ensure no data was lost (see Fig 6).

Fig 6. *Bowtie exercise for Working in or around Water/Ice/Hazardous Ground.*

Enhancing Safety Management System to Prevent Serious Injuries and Fatalities (SIF) Using Data Analytics

A presentation on the work being conducted with machine learning (ML) followed. This presentation highlighted leading indicators of SIF, and which leading indicators may be missing from inspections. To determine the quality of inspection, participants expressed that more questions are not necessarily better, but rather the quality of the questions themselves is of utmost importance. Additionally, discussion was raised surrounding the inconsistency of language used in inspections and investigations. The need for common language was emphasized, presenting an opportunity to decrease complacency. Finally, the idea of the work of safety versus making the work safe was discussed, placing less of an importance on housekeeping, but rather highlighting the importance of the actual ergonomics that play an integral role required in creating safe workplaces.

Social-Psychological Factors for Workplace Safety Behaviour

Research and discussion on human and organizational performance followed, beginning with a personal anecdote related to construction safety, leading into content on workplace safety culture. Social and psychological factors that affect workplace safety behaviour were discussed, including factors such as supervisory behaviour, corporate culture, individual and group attitudes towards safety, and technology resistance. The question of how to promote safety from an organizational culture perspective was asked to the group, with responses including ensuring financial stability, creating goals over deadlines, proper leadership training, and conducting feedback and follow up on incident reports. Slido, an interactive survey software, was used to engage participants using a few questions.

Slido Question 1: What are examples of social-psychological factors influencing safety behaviour at a site you visited recently?

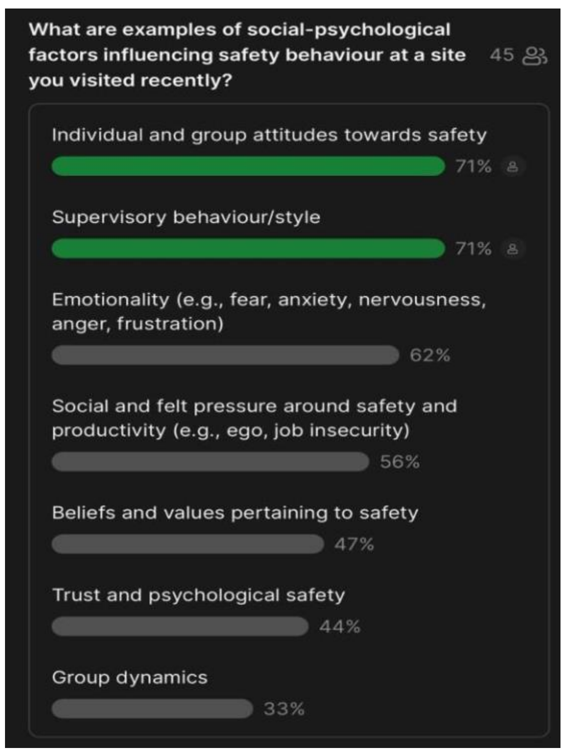

Fig 7. Responses to Slido Question 1.

When asked to identify social-psychological factors influencing safety, participants identified the two main factors as supervisory behaviour or style, and individual and group attitudes towards safety. Some examples shared included how a supervisor can role model (un)safe behaviours and demonstrate what an acceptable pace of work is (e.g., shortcuts or rushing). Group attitudes towards safety could come from differences between areas of the organization and the challenges associated with shifting safety culture over time. Individual attitudes could also be spread through the group by how people behave during safety meetings (e.g., joking instead of asking relevant questions) or how employees with different levels of experience or knowledge interact with other co-workers (e.g., behaving more or less safely).

Slido Question 2: Think of a site you visited recently. What is your perception of the level of psychological safety there?

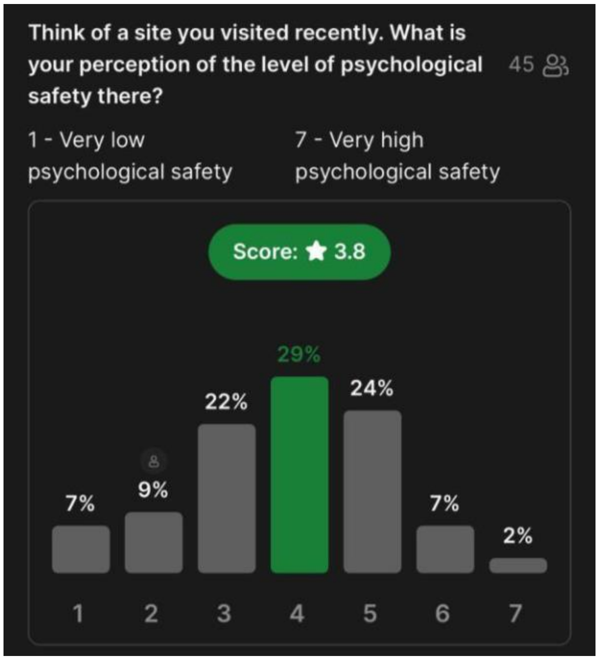

Fig 8. Responses to Slido Question 2.

We presented a definition of psychological safety as “a belief that one will not be punished or humiliated for speaking up with ideas, questions, concerns, or mistakes, and that the team is safe for interpersonal risk-taking” (Edmondson, 2018, 1999). As this is an often used but undefined concept, providing this definition helped to ensure that all respondents had a common understanding. Then, we asked attendees to rate the level of psychological safety at a recently visited site, participants' average score was 3.8 out of 7. This is less than a 50% score, which is relatively low. For comparison, a similar poll was conducted at a workshop with members from the Alberta Mine Safety Association (January 23, 2025) and the mean score was 4.5 out of 7 with 42 participants casting a vote. Finally, when asked how to increase psychological safety, responses included pay raises (to increase financial stability), emphasis on goals rather than deadlines, proper leader training, and closing the feedback loop.

Conclusion

Final thoughts were wrapped up in a brief discussion to conclude the symposium. Participants emphasized their appreciation for the learning opportunity, and the effectiveness of the hands-on activity. ACSA noted their willingness to translate the knowledge gained to the apprenticeship program to further train young workers on the importance of safety in the workplace. Finally, guests were thanked for their participation, and a catered lunch was provided in an adjacent room for additional networking.

2.4 Symposium Outcomes

The workshop at ACSA demonstrated industry impact. The evidence for the need and interest in this session is clear. With 91 registered guests and most of these registrants in attendance, in person, there is a good opportunity to continue to offer such workshops. Moreover, scores on psychological safety perceived at sites recently visited averaged to less than 50%, suggesting a lot of room for improvement on this construct. Attendees were engaged, highly participative, and also very respectful.

The session could have easily been a one-day or even multi-day event.

Drs. Lefsrud and O'Neill are pursuing follow-up conversations for additional workshops on critical controls assurance and human and organizational factors related to serious incidents and fatalities.

After the workshop, all participants from all three workshops were sent:

- A copy of the workshop slides – for participants to take back to their organizations.
- A 'business case for risk management' – for participants whose leadership see safety as a 'cost' rather than as an investment.
- A 'bowtie primer' which describes how/when bowties could be used along with nine bowties that summarize the causes, consequences, and controls for nine major incident hazards.

These materials are in Appendix A and have been shared with industry safety associations, for sharing with their member companies and posting on their websites.

3. A Machine Learning and Natural Language Processing Approach to Analyze Socio-Technical Precursors of Serious Incidents and Fatalities (SIF) in the Mining Industry

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

3.1 Summary

Mining and energy industries are highly dynamic and hazardous (Brady, 2019). Despite advancements to reduce incidents, the rates of SIF incidents remain constant. Although regulators and companies employ a suite of tools to prevent incidents and improve health and safety at workplaces, there are still gaps in understanding how to generate industry- and company-level learning to prevent SIF. Further, there is a lack of comprehensive studies that integrate both retrospective (incident) and prospective (safety inspections) data to identify the complex precursory conditions for SIF.

To address the gaps, we use data analytics: machine learning (ML), natural language processing (NLP), and text mining techniques. To address the first gap, 822 SIFp (potential) and SIFa (actual) incidents from 2018-2023 and 86,619 critical control assurance (CCA) questions from 2022-2024 were collected. Then, the data was classified into five operational-area clusters based on subject matter experts (academia and industry): exploration & drilling, production & processing, mining & tailings, refining, and transportation & distribution. Each cluster represents the different operations in this industry, allowing a better understanding of the unique challenges associated with each. Next, several data pre-processing and cleaning steps were conducted to prepare the data for analysis. Then, we linked each SIFp and SIFa to the past month's completed CCAs to determine if there might be a mismatch between CCA efforts and SIF incidents. NLP techniques were used to compute the similarity between 142 incidents and 59,876 CCA questions from November 2022 to December 2023. Text mining was conducted on selected incidents with the least similarity with CCA descriptions. Sankey diagrams were developed to illustrate and visualize if CCAs might be missing potential hazard exposures that could lead to SIF incidents.

Results show that 'dropped objects' are a common hazard in exploration & drilling (83%), refining (55%), and transportation & distribution (50%) operational clusters but less of a focus in completed CCAs (38%, 37%, and 45%, respectively). Furthermore, for mining & tailings operations, SIF incidents related to 'working with or near energized equipment (dozers, telehandler, tractors, etc. that is left running)' and 'exposure to toxic materials or hazardous atmospheres' constitute 60% and 5% of incidents, respectively. However, CCAs focused on only 8% and 0.1% of these hazards. Similarly, in production & processing, 'working with or near energized equipment' and 'toxic exposure or hazardous atmospheres' account for 25% and 6% of SIF incidents, respectively. Yet, CCAs only focus on 1% and 0.13% of these hazards. By identifying these mismatches between SIFp+a and the attention of CCAs to prevent these, these preliminary findings help identify the potential for enhancements to the quality and attention of CCAs in this industry. Our findings were shared in Q4 2024. And, as of Q1 2025, our recommendations have been taken into consideration.

3.2 Introduction

The mining industry is highly hazardous and accounts for a substantial proportion of workplace fatalities (Nowrouzi-Kia et al., 2018; Zhang et al., 2020). In the US, the mining, quarrying, and oil & gas extraction industry reported an overall fatality rate of 14.2 per 100,000 full-time equivalent workers in 2021 (U.S. Bureau of Labor Statistics, 2022). The rates of SIF incidents have remained constant in Canada and the U.S. (Ivensky, 2016; Cooper, 2019; Bayona et al., 2024). New safety management strategies are needed to improve organizational safety performance and prevent SIF incidents.

Critical control assurance (CCA) is a promising method to prevent SIF by focusing on the high-energy, STCKY (stuff that can kill you) hazards. A 'control' is an act (an action a person must take), an object (a device that works when needed without a person's act(s)), or a system (a combination of act and object) that can independently prevent a threat or mitigate the consequences of a major incident hazard (International Council on Mining and Metals (ICMM), 2015) A 'critical control' is a control such that the absence or failure of it would significantly increase risk (probability and/or consequences) associated with loss scenarios, despite the existence of other controls (ICMM, 2015). Critical controls must be able to prevent or mitigate a threat/hazard, loss of control/containment, and/or consequence.

The criteria that should be considered when determining critical controls include the following:

- Threat/hazard to which the control applies has a high probability of causing the loss of control/containment.
- The consequence to which the control relates is very severe (i.e., fatality).
- The cause-effect pathway is of medium risk but has few controls (e.g., few layers of protection and weak defense in depth).
- The control appears on multiple cause-effect pathways (say on bowties) and thus is of cumulative importance.
- Expert judgment.

'Critical control assurance' (CCA) is an activity that confirms that critical controls are present as intended – ensuring that we can fail safely. While safety inspections, such as CCA, are crucial in lowering incidents, the results are, however, rarely analyzed more than once to serve as performance indicators or to reveal any unsafe patterns (Lin et al., 2014). Therefore, comprehensive research incorporating a wider range of datasets, such as inspections and incident reports, is needed to identify underlying factors and improve safety performance. Within the literature, several methods have been used to analyze safety, such as safety-leading indicators (Kurian et al., 2020; Naji et al., 2022). However, these methods have been studied in isolation (E. D. Oguz Erkal et al., 2021), lacking integration of other sources of data, such as safety inspections. Novel approaches using proactive and reactive data are needed to comprehensively understand and manage safety performance.

The application of machine learning (ML) and natural language processing (NLP) has been recognized as a powerful tool that provides a holistic view of safety performance. These methods can extract insights from large volumes of data to determine the importance of each contributing factor, identify patterns, and make predictions. Furthermore, they can continuously learn from new data, improving decision-making. For this reason, ML and NLP techniques are widely applied in various disciplines, such as railroads (Rana et al., 2024), construction (Ma & Chen, 2024), and the oil & gas industry (Kurian et al., 2020). ML and NLP methods are used for risk management (Sattari et al., 2021), equipment maintenance forecasting (Z. Chen et al., 2022), and incident prediction (F. Wang et al., 2023). However, these studies do not integrate prospective (inspections) and retrospective (incidents) data to analyze safety performance. As a result, the adoption of ML and NLP techniques in safety management allows us to proactively manage risks before they occur and enhance individual and organizational safety performance.

To address these limitations, this research leveraged ML and NLP techniques to reduce SIF and increase safety performance by identifying and visualizing key leading indicators that do not capture the controls to mitigate hazards in CCAs using the SIF dataset.

3.3 Research methodology

This section details the methodology employed in the research. The initial SIF dataset contained 822 SIF (SIF actual and SIF potential) incident reports (from 2018 to 2023). 47 incident records were removed from the analysis since they included only French descriptions. Therefore, overall, 775 SIF incidents (48% contractors and 52% employees) and 86,619 CCA records (based on each CCA question) were analyzed in this research.

Identification of missing leading indicators in Critical Control Assurance (CCA)

The research aimed to identify and visualize the key leading indicators that do not capture controls to mitigate hazards in CCAs that lead to SIF incidents. To achieve this, 160 SIF incidents and 86,619 CCA records were analyzed from November 2022 to December 2023 by aligning the timeline between SIF and CCA records. In the first step of the analysis, pre-processing was conducted to clean and prepare the data for analysis. After consulting with academia and industry experts, both datasets were divided into five clusters: exploration & drilling, production & processing, mining & tailings, refining, and transportation & distribution. Each cluster represents different stages in the oil sands mining industry, allowing for a more specialized analysis of risks to allocate effective resources to enhance safety performance.

After completing the data preprocessing steps, each SIF incident was linked to its corresponding past one-month CCAs. As a result, after linking, there were 142 SIF incidents and 61,558 CCA records, the distribution of which is shown in Table 6.

Table 6. Distribution of data by operational cluster after linking SIFp+a to past CCA records.

Operational Cluster	No. of SIF	Percentage	No. of CCAs	Percentage
Exploration & Drilling	6	4%	3,817	6%
Production & Processing	89	63%	42,134	68%
Mining & Tailings	20	14%	9,359	15%
Refining	20	14%	2,281	4%
Transportation & Distribution	7	5%	3,967	6%
Total	142	-	61,558	-

Sankey diagrams were developed to illustrate the missing indicators that were not captured in CCA reports. These diagrams show indicator flows, and the link's width indicates the flow's magnitude and offers a clear visualization of information (Hernandez et al., 2018). It is important to note that the study did not analyze the cause-and-effect between SIF and CCA but focused on analyzing the quality of the CCA questions and developing new questions.

3.4 Results and Discussion

This section details the findings and discusses the implications of the research. It is divided into different parts that interpret the results in the context of the research question.

The research aimed to identify and visualize the key leading indicators that do not capture controls to mitigate hazards in CCAs that lead to SIF incidents by comparing the similarities of SIF incidents and CCA descriptions. The datasets were divided into five operational clusters - Exploration & Drilling, Production & Processing, Mining & Tailings, Refining, and Transportation & Distribution. The missing leading indicators for each cluster were identified.

Exploration & Drilling

The exploration & drilling cluster includes activities to discover and assess underground natural gas or crude oil fields (offshore or onshore). It involves conducting geological surveys or seismic studies (Sahu et al., 2020) as well as drilling wells that facilitate the extraction of resources (Narayanan et al., 2023). Therefore, the activities involved in the exploration and drilling sector include using drilling rigs or elevated platforms, which can create gravitational hazards related to dropped objects, working at heights, or lifting and hoisting.

In exploration & drilling, six SIF incidents were linked to 3,817 CCA records (Table 6). All the SIF incident-CCA pairs with the least similarity (6 SIF incidents and 3,407 CCA records) were analyzed. Topics were mined for these pairs and are demonstrated in Fig. 9. It can be observed that 'dropped objects' accounted for the highest number of SIF incidents (83%); however, only 38% of CCAs focused on capturing this indicator. ‘Dropped objects’ refer to SIF precursors and CCA checklists related to gravitational hazards such as lifting or hoisting and working under a suspended load.

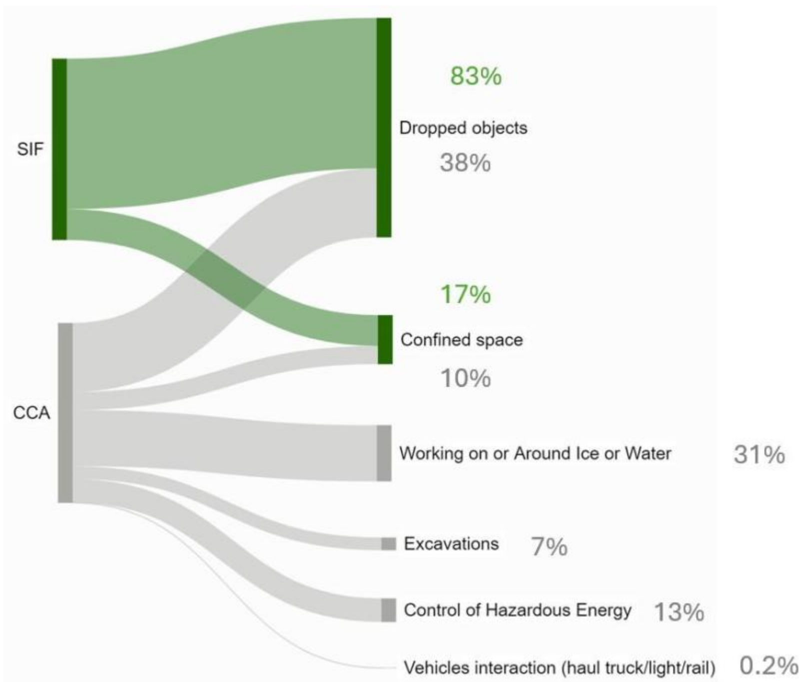

Fig 9. Most and least captured indicators in SIF incidents and CCA for Exploration & Drilling.

Previous studies have identified that dropped objects are among the top causes of SIF in the oil & gas industry (Necci et al., 2019; Narayanan et al., 2023; Xiang et al., 2023). To enhance safety performance related to ‘dropped objects’, one of the strategies discussed in the literature is improving hazard identification (Waqar et al., 2024). This is because if the hazards are unidentified, then uncontrolled exposure is increased, leading to both fatal and nonfatal incidents (Perlman et al., 2014). Different methods, such as job hazard assessments (JHAs) and field-level risk assessments that are used for hazard identification can be enhanced using artificial intelligence and large language models (Chang et al., 2024). Another proactive strategy to improve safety is to provide relevant training. By regularly holding workshops and training sessions related to dropped objects, workers are equipped with knowledge and skills that enhance safe behaviors.

A second insight from Fig 9 is that ‘confined space’ accounted for 17% of the SIF incidents; however, only 10% of this topic was captured in CCA. Confined space refers to a completely or partially enclosed space at atmospheric pressure when occupied but not intended to be a regular workspace due to restricted entry/exit points or insufficient ventilation (Narayanan et al., 2023). The conditions in these high-risk areas can be transient and change from innocuous to life- threatening (McManus, 2010) since multiple hazardous conditions are present, and several studies have reported SIF incidents in confined spaces (Chiu et al., 2020; B. Wang & Zhao, 2022). Several measures can be implemented to strengthen safety in confined spaces. For instance, a five-step risk assessment tool developed by Burlet-Vienney et al. (2015) and a

procedure for safe confined space entry rescue by Selman et al. (2019) can help in enhancing risk assessments related to confined spaces. Further, mobile applications developed by Botti et al. (2022) can help in identifying the confined spaces and the solutions recommended by Gonzalez-Cortes et al. (2022) using Inherently Safer Design (ISD) principles that can be used to improve confined space safety.
Based on the research findings, several new questions were developed to better capture these hazards during CCAs based on the SIF incidents (using incident description, SIF precursor, cause- failed and missing controls, and root causes) (Table 7). For 'dropped objects,' new questions related to the inspection of hoisting equipment and monitoring load positions are introduced. On the other hand, confined space-related questions focus on consistent check-ins, supervision, and worker training. Answering these critical questions might prevent and mitigate SIF incidents in the exploration and drilling cluster.

Table 7. Possible new CCA questions to consider including in Exploration & Drilling.

Leading indicator	New CCA question
Dropped objects	Are the positions of loads monitored to ensure they remain within safe operating limits during lifting operations? Do workers have communication devices to facilitate effective lifting? Has a function test been conducted on the runway beam end- stopper of the trolley? Has the torque value been checked and confirmed for the connection between the shock sub and Kelly pipe before initiating the lifting operation with the top drive? Is the crane cradle block inspected for integrity and secure attachment before the operation to ensure it is safe? Are all lifting and hoisting equipment components inspected, maintained, and verified before use? Training - Do the personnel conducting inspections have the required qualifications and training?
Confined space	Have all workers received confined space entry training before entering?

Production & Processing

Production and processing operations involve several activities, such as extraction and upgrading, that include working with large equipment such as compressors and processing units. Therefore, workers can be exposed to several hazards, such as unguarded machines or hazardous materials used for processing. In the production & processing cluster, 89 SIF incidents were linked to 42,134 CCA records (Table 8). Topics were mined on 89 SIF incidents and 42,079 CCA records as they had the least similarity between them (Fig. 10). The first insight from the figure is that 'working with/near energized equipment' accounted for 25% of SIF incidents; however, they were captured in only 1% of CCAs.

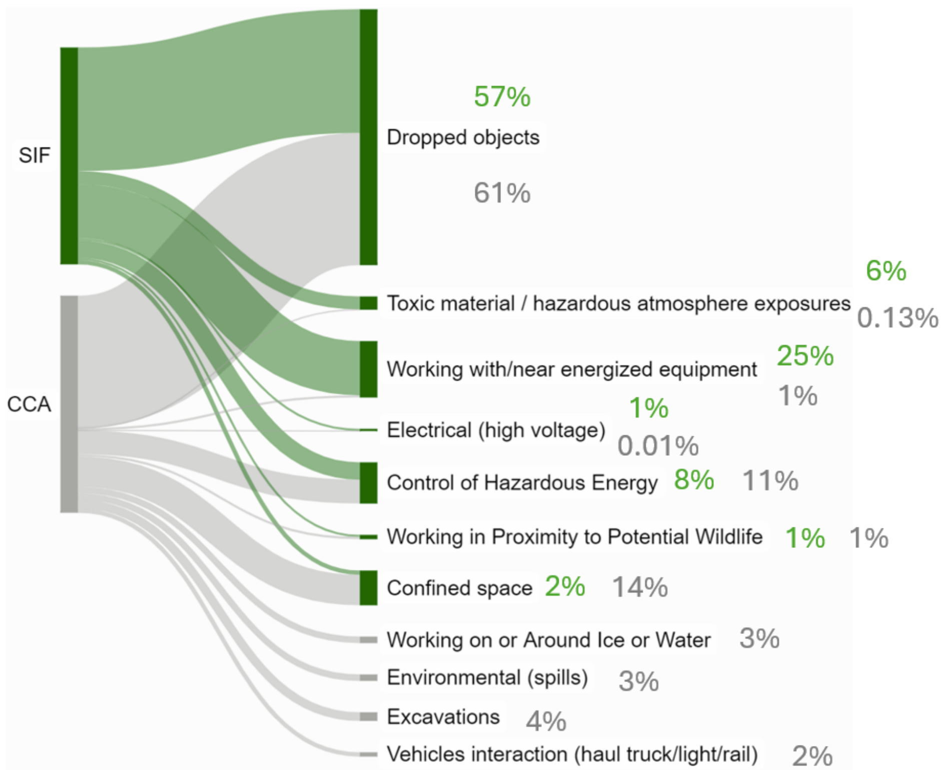

Fig 10. Most and least captured indicators in SIF incidents and CCA for Production & Processing.

The identification of many incidents involving machinery is consistent with other works. For example, equipment hazards are responsible for 3 out of 5 oil and gas industry fatalities (National Institute for Occupational Safety and Health (NIOSH), 2023). Similarly, Milch and Laumann (2019) identified that 71% of the incidents were related to equipment, such as improper equipment handling during lifting or equipment failure.

Reducing equipment downtime, increasing reliability, and availability of the equipment are considered some of the important strategies that can aid in optimizing the life cycle of equipment (Singh R, 2006). By establishing a schedule for maintenance and inspection of all energized equipment, we can identify and address potential risks before they cause failures. Predictive maintenance techniques using data analytics can help in monitoring the status of the equipment, prioritize maintenance tasks, help minimize downtime, reduce maintenance costs as well as enhance safety in production and processing operations (Babayeju et al., 2024). Another strategy to minimize incidents related to energized equipment is by implementing engineering controls. By installing insulation barriers, automatic shut-off systems, and remote monitoring and control systems, the risks can be minimized (Akhundov et al., 2023; Pearson & Martinez Fonte, 2023). 'Exposure to toxic materials and hazardous atmosphere' is the second indicator that needs attention in the production & processing cluster. While 6% of the SIF incidents are related to this cluster, only 0.13% of the CCA focuses on this indicator. Exposure to toxic materials can come from various processing methods of extracting oil from oil sands that require the use of chemicals. The source of such exposures could be from failure or rupture in pumps, valves, pipes, etc., petroleum gases like benzene or butane.

To minimize exposure to toxic materials and hazardous atmospheres, continuous monitoring and detecting systems that are regularly calibrated and maintained should be implemented (National Institute for Occupational Safety and Health (NIOSH), 2016). Remote sensing tools such as drones are emerging as highly effective for toxic exposure detection. These tools can be used to detect, track, and map any toxic exposures that complement the current conventional remote sensing techniques (Asadzadeh et al., 2022). In addition, these tools can provide solutions by providing low-cost, safer, and efficient alternatives for exposure management. A mitigative method to lower toxic exposures is by preparing robust emergency response plans. Developing and regularly updating the emergency procedures that reflect the changes in operations, equipment, and regulations can enhance preparedness in case of exposure (McNally & Minyard, 2015). Further, workers should be trained in these procedures so that all workers are familiar with the procedures and can implement them.

A third insight from Fig10 is that 'electrical (high voltage)' incidents were responsible for 1% of the SIF incidents; however, almost no CCAs (0.01%) identified this indicator. Electrocution, arc flash, and electric shocks are the common hazards identified across oil gas facilities (Narayanan et al., 2023). Several studies reported incidents related to electric exposures in the oil and gas industry (Hu et al., 2015; Brazel & Crelia, 2021). The source of such exposure could be due to damaged equipment, labeling issues, or incorrect equipment connections. A proactive measure to lower incidents related to electrical exposure is to regularly assess the performance of electrical systems so that any slight deviations can be detected and corrected. Furthermore, designing redundant systems can be crucial so that even if a component fails, backup systems can prevent any incidents such as exposures or fires (Kong et al., 2022).

Based on the findings of this research, possible new CCA questions were developed to address these missing leading indicators (Table 8). To evaluate safety protocols related to 'working with/near energized equipment', questions such as safe work areas and hazard assessments were developed. Moreover, to capture 'toxic atmosphere exposures', questions related to predictive maintenance, such as inspection of check valves and emergency isolation methods, are added. The question related to electrical indicators focuses on identifying and communicating all the cable locations to workers to prevent exposure to electrical systems.

Table 8. Possible new CCA questions to consider including in Production & Processing.

Leading indicator	New CCA question
Working with/near energized equipment	Has the air pressure fully released from the hose before disconnecting it from the hydro-truck? Has the Construction Lift Plan been completed following the Hoisting and Rigging Program to prevent misunderstandings of drawings and ensure that workers are not in the line of fire? Are skid steers being operated according to the safety guidelines mentioned in JHA without unauthorized modifications? Do dozer operators ensure that the counterweight is fully stabilized and properly positioned before starting their tasks Are park brakes set before disembarking any unit?
Toxic material/hazardous atmosphere exposures	Are the gas pressure levels monitored and coordinated with the equipment startup to prevent high-pressure spikes and unintended system shutdowns? Is the compressor discharge check valve assessed when troubleshooting governor issues? When preparing for maintenance of the Once Through Steam Generator (OTGC) system, is the drain stem fully drained without any blocks?
Electrical (high voltage)	Are all cable relocations adequately identified and communicated to the relevant personnel before work begins?

Mining & Tailings

In the mining & tailings, there were 20 SIF and 9,359 CCA records after linking each SIF incident to past CCA records (Table 10). All the least similar SIF incident-CCA pairs (20 SIF incidents and 9,216 CCA records) were analyzed. The different SIF precursors and CCA checklists were analyzed to identify the topics discussed (Fig. 11). It can be seen from the figure that 'working with/near energized equipment' accounted for 60% of SIF incidents; however, they were only identified in 8% of CCAs.

'Working with/near energized equipment' includes working in the line of fire of moving or energized equipment, driving/mobilizing equipment, and working near mobile equipment. Hazardous conditions can occur when people work with or near energized equipment such as excavators or utility tractors. Several studies have reported similar results in the mining industry. For instance, in the US mining industry, machine-related accidents accounted for 41% of all severe incidents (Ruff et al., 2011) and operating mobile equipment was the top activity resulting in fatal and non-fatal injuries (Muzaffar et al., 2013). In the Ghanaian mining industry, Stemn (2019) reported that equipment was involved in about 90% of fatal and non-fatal injuries. These results emphasize the need to capture hazards related to working with/near energized equipment in the CCAs.

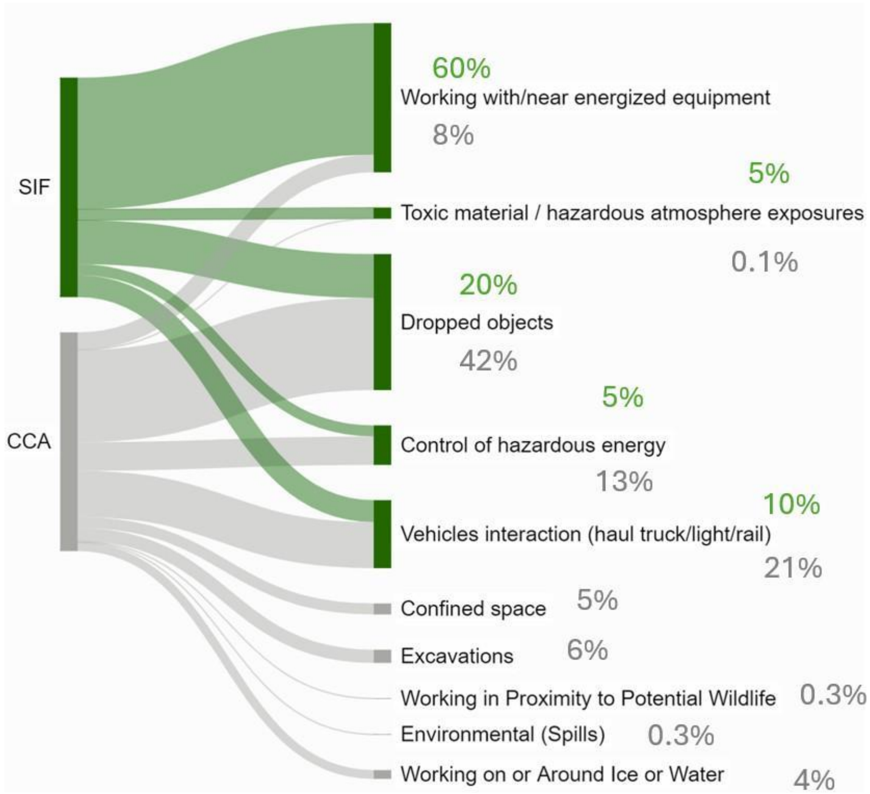

Fig 11. *Most and least captured indicators in SIF incidents and CCA for Mining & Tailings.*

A second insight from Fig 11 is that 5% of the SIF incidents were related to 'toxic materials/hazardous atmosphere exposures'. However, only 0.1% of the CCAs captured this hazard. Toxic or hazardous materials could include substances such as inorganic (e.g., hydrogen sulfide) or organic compounds (e.g., Benzene) used or produced in the mining process (Edokpolo et al., 2015; Adeniyi et al., 2020). Previous studies have reported that exposure to hazardous materials has been associated with severe incidents in oil & gas industries (Toseafa et al., 2018; Jung et al., 2020).

Possible new CCA questions were developed to facilitate better inspections that capture hazards related to 'Working with/near energized equipment' and 'toxic material/hazardous atmosphere exposure' based on the cause of SIF incidents (Table 9). The questions focus on improving the conduct of operations, communication, and training of workers for 'working with/near energized equipment' leading indicator and equipment design and asset reliability for the 'toxic material/hazardous atmosphere exposure' leading indicator. By incorporating these questions, the organization can better identify and mitigate risks.

Table 9. Possible new CCA questions to consider for Mining & Tailings.

Leading indicator	**New CCA question**
Working with/near energized equipment	When using a utility tractor to relocate cables and poles through a roller/sling system, is the correct shackle with a retaining pin used? While performing a hard bar test on equipment, is it ensured that no material or debris is left on the equipment, especially on hard-to-see spots? Are adequate barriers and administrative controls present to prevent machinery operators from entering or operating near areas where personnel, such as surveyors, are present, especially in conditions that limit visibility like steam?
Toxic material/hazardous atmosphere exposure	Is the mix point injection program conducted to prevent phosphoric acid corrosion and leaks in pipes?

Refining

In the refining stage, the crude oil is refined and purified for commercial distribution to consumers and end users (Narayanan et al., 2023). The refinement operations include distillation towers, heat exchangers, and catalytic crackers (Robinson, 2006) and involve working near large processing facilities. Several activities in the refinery include working overhead work, working at heights, and potential for dropped objects.

In refining, 20 SIF incidents were linked with 2,281 past CCA records (Table 11). All the least similar SIF incident-CCA pairs (20 SIF incidents and 1,910 CCA records) were analyzed. The different SIF precursors and CCA checklists were analyzed to identify the topics discussed (Fig 12). It can be seen from the figure that 'dropped objects' resulted in 55% of the SIF incidents; however, only 37% of the CCAs focused on this indicator. Similar results were observed in the exploration & drilling cluster, where 'dropped objects' were accountable for the highest number of incidents.

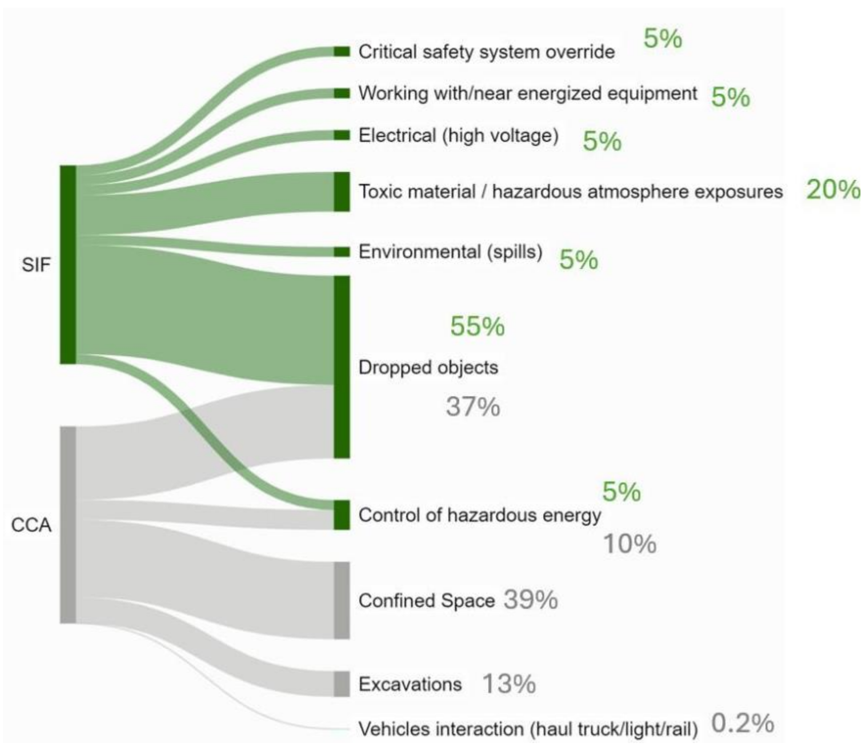

Fig 12. Most and least captured indicators in SIF incidents and CCA for Refining.

Other indicators that were found in SIF incidents include 'toxic materials/hazardous atmosphere exposures' (20%), 'critical safety system override' (5%), 'working with/near energized equipment' (5%), and 'electrical (high voltage)' (5%) (Fig. 12). Due to the chemical properties of materials such as toxicity and flammability; these chemicals are sources of exposure that lead to incidents (Cheraghi et al., 2019). Different methods such as relative risk index, consequence modeling, and computational fluid dynamics can be used to evaluate the risk related to hazardous materials and provide preventative and mitigative measures (Cheraghi et al., 2021). These hazards (critical system overrides, high voltage, toxic materials) are controlled by process safety management methods like permitting and lockout/tagout, rather than CCA. Thus, these specific gaps are not surprising. To confirm this, we could examine the complementarities, overlaps, and gaps between process safety management and CCAs for refinery operations.

Several possible new CCA questions related to dropped objects were framed based on the SIF incidents in the Refining cluster (Table 10). The questions focus on capturing gravitational hazards, such as appropriate knots and devices for lifting and hoisting operations to eliminate the risk of dropped objects. Furthermore, questions related to identifying the exclusion zones and performing regular inspections are developed so that no worker is in the line of fire. However, these questions are also applicable to other clusters, as similar risks exist across different operational contexts. Other questions address aspects related to override in critical safety systems, including lockout/tagout procedures, equipment securement, understanding job scope, preventative maintenance of equipment, and change management workflow of various activities.

Table 10. Possible new CCA questions to consider for Refining.

Leading indicator	**New CCA question**
Dropped objects	When working overhead, are tools properly tethered or equipped with a stopper on the shaft to prevent it from slipping through the grating? Are lifting ropes properly tied with appropriate knots to prevent them from becoming untied during operations?
Critical safety system override	Are all reactor valves secured with properly engaged chains and locks to prevent them from being blocked in or left in an unsecured state?
Working with/near energized equipment	Are all connections, including the pintle hitch pin and safety chains, properly secured and verified before moving equipment?
Electrical	Are proper lockout/tagout procedures followed to ensure that transformer tabs are de-energized and verified as safe before any maintenance or wiring tasks are performed?
Toxic material / hazardous atmosphere exposures	Are depressuring valves checked to ensure they operate correctly during pre-startup stroke checks?

Transportation & Distribution

In the transportation & distribution stage, oil and gas are transported to downstream industries (e.g., gas stations) through pipelines or tankers. Therefore, this stage involves a complex system of pipelines, pumps, and control mechanisms that ensure the transportation of the materials. Other sectors included in this cluster include logistics and delivery enterprises. Several activities, such as lockout/tagout and energy isolation, are performed in pipelines to isolate and secure energy sources.

In transportation & distribution, seven (7) SIF incidents were linked with 3,967 CCA records (Table 11). All the least similar SIF incident-CCA pairs (7 SIF incidents and 3,264 CCA records) were analyzed (Fig. 13). Like previous results, it can be observed from the figure that 'dropped objects' resulted in 43% of the SIF incidents. However, only 45% of the CCAs focused on this indicator. In addition, 'control of hazardous energy' accounted for 14% of the SIF incidents, and 15% of CCA records capture this indicator.

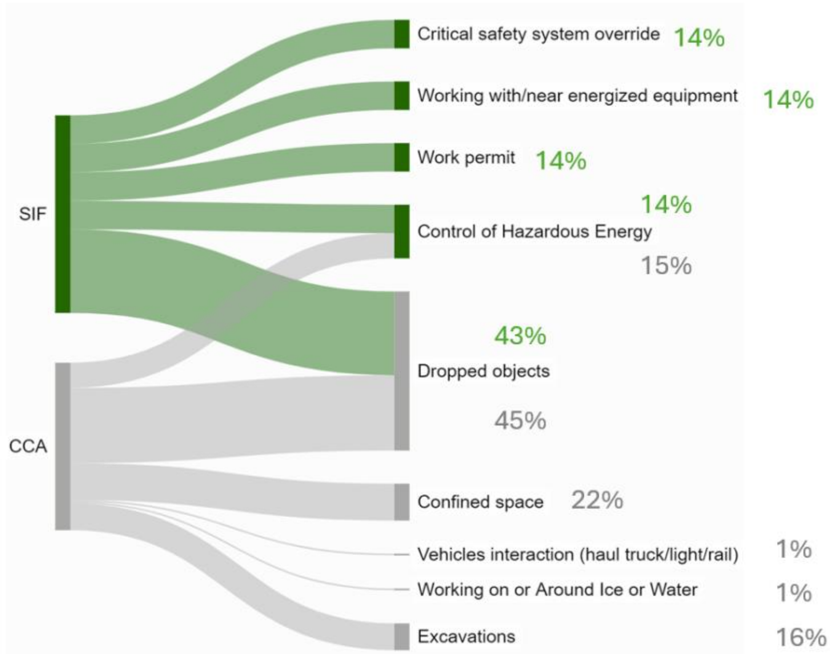

Fig 13. Most and least captured indicators in SIF incidents and CCA for Transportation & Distribution.

One way to enhance safety performance is by improving the focus on the safety programs and cultures of contractors (Salas & Hallowell 2016; Gharedaghi & Omidvari, 2019). Others have found that contractors are more prone to risks and have contributed to most accidents in industry (Muzaffar et al., 2013; Theophilus et al., 2017; Nwankwo et al., 2022, Walter, 2017). This may be because high-hazard work is outsourced to contractors given their particular expertise (i.e., marine operations), to reduce the costs of workforce and equipment (leading to higher exposure rates) and higher turnover, less training, less familiarity with the work, and less supervision (leading to a lowered organizational capacity to identify and control hazards). In addition, contractors might work across several companies/sites and, thus, 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). Given these challenges, there is a growing need for innovative solutions that support consistency and improve safety outcomes across diverse operations. One such example is to leverage digital twin technology. Since it provides continuous data acquisition, real-time monitoring, and “what-if” simulations, it can be used for asset performance management, risk assessments, and training (Wanasinghe et al., 2020; Yun et al., 2024). In addition, any design-related information can be embedded in the digital twin so that there is no information loss and seamless communication across all the stakeholders (Wanasinghe et al., 2020).

Table 11 lists possible new CCA questions to consider for addressing critical safety issues observed in the Transportation & Distribution cluster to prevent dropped objects and control hazardous energy. Questions related to hazard identification and risk assessments were developed to overcome challenges related to the override of ‘critical control systems’, ‘working with/near energized equipment’, and ‘work permit’. It ensures that safety performance can be improved through relevant checks on training, communication, and procedural adherence.

Table 11. Possible new CCA questions to consider for Transportation & Distribution.

Leading indicator	New CCA question
Dropped objects	Are smaller pallets properly secured to larger pallets to ensure load stability, and are all materials centrally positioned to prevent overhanging, especially in open aisle areas? Are drivers completing and properly securing their product loads before leaving their trailers during station checks?
Control of hazardous energy and critical safety system override	Is the current isolation status of relief lines verified, especially following maintenance before initiating flow through control valves (CV)? Are the electrical units fully de-energized before maintenance work begins?
Working with/near energized equipment	Are truck wheel chokes applied while parked to prevent rollover?
Work permit	Are Safe Work Permits obtained, and are all necessary hot work controls (e.g., fire extinguishers, gas monitors, fire blankets) in place before commencing any hot work activities?

Observing the results from Fig 9 to 13, we see that controls related to 'dropped objects' in the production and processing cluster are well identified in CCAs (61%) compared to other clusters. This suggests the potential to improve CCAs across other clusters by learning from areas where controls are better recognized. The CCA questions identified in the production and processing cluster not documented in other clusters are also included in the new possible CCA questions (Tables 7 to 11). By drawing on practices from areas with strong performance, we can improve the overall effectiveness of CCAs, leading to more consistent and reliable control measures.

3.4 Conclusions

To enhance individual and organizational safety performance, reduce SIF incidents, and improve the quality of CCA, this research used data analytics (ML and NLP) to identify missing leading indicators in CCAs. The research highlights the necessity of continuous monitoring and enhancements for high-hazard work like mining, refining, and related operations.

The research focused on improving the CCA by identifying the missing leading indicators in CCAs that lead to SIF incidents by linking each CCA to past one-month CCA records and comparing the similarity of language (NLP techniques) between incident and CCA descriptions. The dataset was divided into five clusters based on the different stages in the oil and gas industry. The findings reveal that 'dropped objects' are a prominent challenge in exploration & drilling (83%), refining (55%), and transportation & distribution (50%) clusters and are not adequately captured in CCAs (38%, 37%, and 45%, respectively) (Table 12).

Table 12. Comparison of SIF incident prevalence and CCA across operational clusters.

Operational Cluster	SIF precursor	% SIF	% CCA
Exploration & Drilling	Dropped objects	83%	38%
Refining		55%	37%
Transportation & Distribution		50%	45%
Mining & Tailings	Working with/near energized equipment	60%	8%
Production & Processing		25%	1%
Mining & Tailings	Toxic materials/hazardous atmosphere exposure	5%	0.1%
Production & Processing		6%	0.13%

Furthermore, for mining & tailings operations, SIF incidents related to 'working with or near energized equipment' and 'exposure to toxic materials or hazardous atmospheres' constitute 60% and 5% of incidents, respectively. However, CCAs capture only 8% and 0.1% of these hazards. Similarly, in the production & processing cluster, where incidents of 'working with or near energized equipment' and 'toxic exposure or hazardous atmospheres' account for 25% and 6% of incidents, respectively, CCAs only identify 1% and 0.13% of these hazards. Overall, by focusing on 'dropped objects', 'working with or near energized equipment', and 'exposure to toxic materials or hazardous atmospheres' in the CCAs, SIF incidents can be reduced.

By applying the strategies discussed in this research, including the development of new possible CCA questions, the organization can enhance its understanding of individual and organizational factors and support improvements in safety performance. While the study did not analyze the cause-and-effect relationship between SIF and CCA, it focused on analyzing the quality of the CCA questions and developing new questions. Indeed, since we presented these findings, our recommendations have been taken into consideration in Q1 2025.

Limitations and Future Research Recommendations

There are some limitations of this research that could be addressed in future studies. For instance, the SIF incidents and CCA records were classified into five operational clusters of mining. Future work can refine this classification by analyzing specific locations, allowing for a more granular understanding of the critical controls and SIF incidents. Secondly, the current model used only SIF and CCA data. In the next phase, we can field-verify any potential enhancements to CCA questions, develop more sophisticated methods to link other precursory measures (i.e., NLP of inspection, audit, pre-task planning) with SIF incidents, examine the interactivity/additivity between these precursory variables (i.e., Bayesian Network Analysis) rather than simply presume that CCA questions apply to only one SIF, and complete causal analysis (i.e., time-series) to assess the relative predictive power of variables. Although SIF precursors like 'lifting or hoisting' and 'working under a suspended load' were grouped with 'dropped objects,' future research could examine these precursors individually, as they may involve distinct risks separate from those associated with 'dropped objects'. Lastly, our NLP analysis of CCAs and SIF incidents can be compared against survey results for these sites, especially whether workers identify hazards and why. This will help us to understand why CCAs and other inspections are not capturing the factors that cause SIF. Or how human and organizational factors degrade critical controls.

4. Surveys and Interviews to Identify and Assess the Human and Organizational Factors that Influence Safety Performance

Samantha Jones, Thomas O'Neill, Jessica Wilkins, Claire Wasel, Ian R. Gellatly, Lena Le Huray, Madeline Springle, Hanna Mughal, Lianne M. Lefsrud, Fereshteh Sattari

4.1 Summary

The mining industry has one of the highest accident rates among all sectors, with reports of a yearly average of 2.7 fatal injuries and 269 non-fatal injuries per 10,000 employees (Mining Association of Canada, 2024). 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 safety events. Despite these developments, the field remains overly fixated on technical as opposed to human factors. Presumably, these 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 and an updated approach, such as the Human and Organizational Performance movement, is needed (e.g., Conklin, 2019).

Despite all the research attention devoted to improving overall safety performance, too many accidents are still occurring (Hofmann et al., 2017), especially those resulting in SIF incidents. Alberta had a very high number in the 2024 calendar year despite tremendous efforts and good work dedicated toward improving safety in heavy construction, manufacturing, industrial, and mining environments. What is missing? In conducting this research, our aim was to go beyond an exclusive focus on technical factors to incorporate the roles played by human and social factors. A clear message coming out of recent research (e.g., Törner, 2011), the symposium results, and our conversations with subject-matter experts from the field is that work is needed to identify and measure a select set of social-psychological factors (e.g., emotions; attitudes towards safety; psychological safety, involvement, care and concern) that create both a context for safety-related decisions and behaviour, and improve our understanding of the factors that may predict SIF.
To support this objective, we conducted research utilizing a mix of social sciences research designs and data sources. This report summarizes the findings from: (1) an online quantitative survey and (2) semi-structured interviews with specific, high-hazard occupations and organizational functions to provide more robust and in-depth results (Hesse-Biber & Leavy, 2010). Leveraging complementary methodological and analytic strategies allows for a more holistic picture of the findings. The surveys provided initial insights into individual and group-level social-psychological functioning and allowed us to compare scores across individuals, groups, and sites across the organization and contractors. The surveys also provided insights into hazard recognition, understanding of critical controls, and perceptions of impact for sixteen industry-relevant hazards. The interviews provided richer insight into the perceptions of the context in which incidents are more likely to occur and how incidents can be prevented or managed safely and effectively (e.g., leadership, training). The interviews also allowed for a deeper exploration into some of our focal variables (e.g., conflict management, attitudes towards safety, safety norms) and their perceived role in SIF from the perspective of workers that navigate these hazards frequently. Integrating and interpreting a range of data sources allowed 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.

4.2 Conceptual Frame and Literature Review

To frame our exploration of how human and organizational factors may play a role in workplace safety, and more specifically, SIF, we reviewed safety and organizational literature to uncover what might influence the day-to-day safety decisions and behaviours within crews and work units (Sampson et al., 2014; Törner, 2011). Our focus here is on the social and psychological factors that influence human behaviour and organizational functioning as well as individual beliefs and perceptions about the safety environment and hazard reporting. While work rules, safety protocols, and critical controls (i.e., more technical and mechanical factors) are crucial to supporting a safe work environment, these technical factors are ultimately experienced by people and influenced by their crew, supervisor, organization, and the context of their work environment. For example, let's assume that most safety management programs tend to focus on the technical factors, and "force" safe work practices through carefully constructed systems of work rules, safe work procedures, and critical control assurance programs. In line with this assumption, many individuals and crews will see safety as in-role, non-volitional behaviour, that is a required and expected part of their job. Yet, accidents and SIF still occur. Again, what is being missed?

Notwithstanding formal job expectations and controls, organizational researchers have long known that many day-to-day work behaviours are under volitional control (Smith et al., 1983). From this perspective, safety can also be viewed as motivated, volitional behaviour that supports other members of the organization (Williams & Anderson, 1991). For instance, we see these volitional acts when individuals and crew members decide, on their own, to engage in acts that benefit the company (e.g., adhering to informal rules or procedures to maintain order), and we see this kind of behaviour when individuals and crew members act in ways to support and help one another. In short, while external control processes can effectively regulate most routine job behaviours, there are aspects of many day-to-day decisions and behaviours that are volitional in nature, at the discretion of individuals and teams. So what are the factors that shape or influence these volitional choices that influence the safety performance within teams and work units? To answer these questions, we now turn to a conceptual road map to get us started.

Conceptual Frame

A micro-theory of discretionary work behaviour that has been applied to virtually all human behaviour is the theory of planned behaviour (TPB) (Ajzen, 1991; Fogarty & Shaw, 2010; Johnson & Hall, 2005). An intuitive appeal of the TPB is the way it reconciles attitudes towards the behavioural target (e.g., following safety protocol), normative perceptions, efficacy (capability; resilience), and intentions to act. Attitudes refer to how an individual feels about a specific behaviour based on the expected outcomes and their subjective value. If they possess a positive attitude towards a behaviour, they are more likely to do it. Subjective norms come from the perception of what others expect or what they might consider normal. If they think others will approve, they are more likely to engage in a particular behaviour. Perceived behavioural control aligns with Albert Bandura's concept of perceived self-efficacy, which refers to an individual's perceptions of their ability to perform a particular behaviour (Bandura, 2001).

If individuals (or teams) believe the behaviour is difficult to perform, they are less likely to engage in it. The more favorable these three factors (i.e., positive attitude, subjective norms, and high perceived behavioural control), the more likely the behaviour. Fogarty and Shaw (2010) extended TPB and found support for the inclusion of management attitudes in the model, with perceptions of management attitudes towards the target behaviour having a direct effect on worker's own attitudes towards the behaviour and subjective norms. This finding supports the notion that the social and organizational context, such as one's work crew and organizational managers, have an impact on day-to-day safety decisions made by employees (see Fig 14). In short, whether an individual decides to act in a safe manner can be explained by examining three things: attitudes toward the behaviour, subjective norms, and perceived behavioural control.

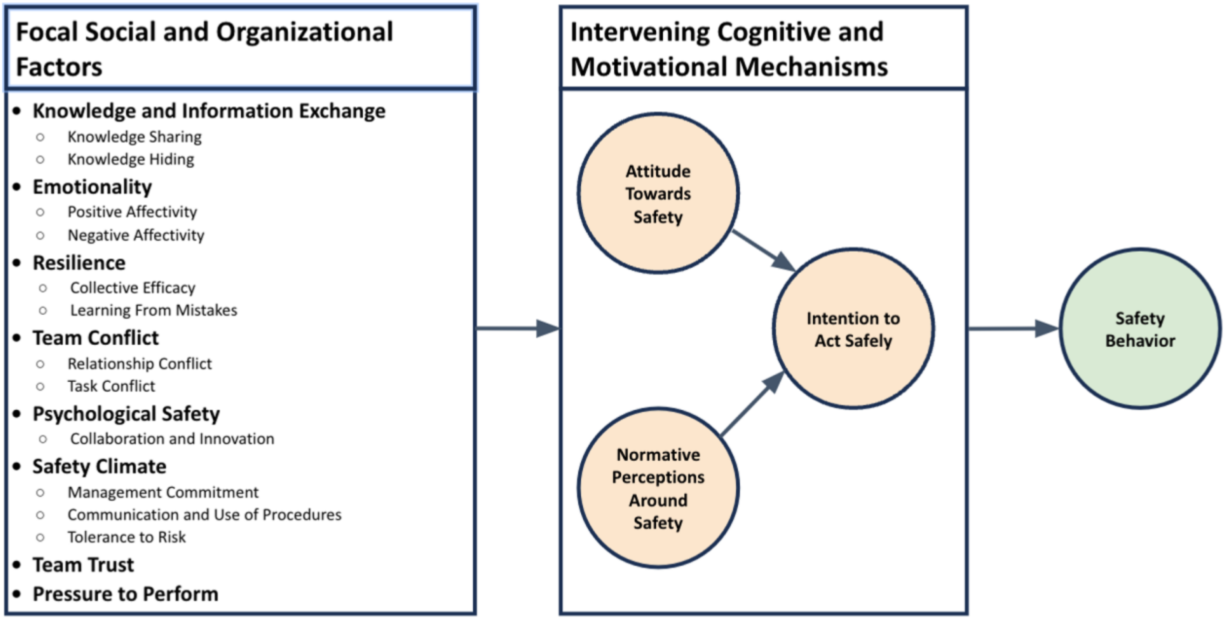

Fig 14. Summary of relationship between social and organizational factors and safety behaviour.

While an integral and helpful starting point, we recognize that TPB is, by definition, a universal model of human behaviour, including safety. However, to contextualize this model to the unique features of a particular work and (oil and gas) organizational setting, and to capture the social dynamics that occur within crews and work units, we built out and extended the logic of the TPB (Bock et al., 2005). We accomplished this objective by integrating core TPB concepts (Fig 14) with other local HOPs identified by subject-matter experts during our three symposium workshops. Thus, our contextualized framework in Fig 16 offers a high-level summary of HOPs that represents an integration of well-established motivational and behavioral principles with important local reality. Inspection of the broader, contextualized model (Fig 15) suggests nested spheres of influence, which in turn, offers an intuitive way of explaining how different types of HOPs might combine to shape the day-to-day safety-related decisions and acts of workers. We see this nesting effect occurring at different levels: the inner red sphere includes safety performance and is the target behaviour of interest, the yellow sphere includes proximal drivers of safety decisions and behaviour, while the outer green sphere includes the broader team, group, and organizational context. To explain all of this comes together, we now turn to our employee and contractor survey.

Fig 15. Nested spheres of influence: Reconciling theory with other known human and organizational precursors for safety performance in this situation.

4.3 Employee and Contractor Survey

Survey Overview

This report describes the findings from the employee safety survey conducted in August and September of 2024. The survey received 4,662 responses from employees and contractors in the mining industry. The results are organized into three main areas based on a relative ranking within the sample (we compared scores within all participants rather than between organizations or sites): Strengths, Moderates, and Developmentals. Strong areas describe areas in which organizations in mining are performing well on human and organizational factors that are related to safety, while development areas describe factors that can be leveraged for potential improvement and safety growth. Moderate areas lie between these two areas.

This report also includes an analysis of hazards indicating identified exposure, controls, fear of this hazard, as well as the option to indicate the hazard does not apply to them. Hazards that were most frequently and least frequently encountered are expanded upon in this report. Finally, this report provides an analysis of written answers regarding reasons why hazards would not be identified or reported by employees and which of these reasons they considered the most important.

Survey Methodology

Surveys were created by Drs. O'Neill, Jones (both of University of Calgary, Industrial and Organizational Psychology), Drs. Gellatly, Lefsrud, and Claire Wasel (University of Alberta, School of Business), and distributed to workers across multiple organizations in the mining industry. Data collection was completed between August and September 2024. The survey instrument, interview schedule, recruitment methods, data collection and storage processes were reviewed and approved by the University of Alberta's Research Ethics Board.1 Employees and contractors were invited to complete the survey either during a safety-related meeting or during coordination meetings at the start of their shift Employees were provided with a recruitment poster, postcards, and website (www.sif- prevention.com), outlining the purpose of the survey, how the results would be used to support the findings of a Creative Sentence and improve safety in the workplace, and how their participation was completely voluntary.

After reading the consent form at the start of the survey, if participants chose not to continue their participation, they were given the option to complete an alternative activity. If the participants were completing the survey online, the alternative activity involved reading a short safety article about the importance of stretching at work and answering a few questions about the article. If participants were completing the survey on paper, they were invited to write notes or draw on the survey copy in lieu of answering the questions. This was a step taken to help protect participants' confidentiality as others that were present at the meetings would not know if they completed the survey or the alternative activity.
The survey consisted of both multiple-choice questions and open-ended text boxes and consisted of four major sections

1. Focal Constructs: The survey first started with questions about our focal social- psychological constructs (e.g., safety norms, psychological safety) and two proxy measures for safety ("in this crew, we trust everyone to make safe decisions"; "this is a safe place to work") measured on a five-point scale (strongly disagree = 1 to strongly agree = 5).

2. Reasons for Hazard (non)Reporting: Participants were then asked an open-ended question: "In your experience, what are the top three (or more) reasons why hazards are not identified or reported?" Participants were given the option to provide three or more written reasons and identify which reason they believed was the most important or impactful.

3. Hazard Identification: Participants were then presented with sixteen industry- relevant hazards and were asked to endorse (or leave blank) the following questions:
    a. I am exposed to this hazard routinely
    b. There are controls in place for this hazard that mitigate exposure and/or impact
    c. I am afraid that this hazard will hurt me or someone else
    d. This hazard does not apply to me

4. Employee Characteristics and Demographic Information

1 *University of Alberta Research Ethics Board approved project Pro00067927, "Assessment of Partners-OHS Tools for Improving Alberta Workplace Safety," Principal Investigator: Dr. Lianne M. Lefsrud.*

To score areas of human and organizational factors, we calculated the average scores on a multi- item survey scale. Reasons for hazard (non)reporting were re-coded into overarching categories and finally frequencies were calculated for each of the hazard identification statements. A full list of all survey items can be found in Appendix D. Completing either the survey or the alternative activity took about 15 to 20 minutes. To protect participant confidentiality, this report contains summary information from key variables for the first three sections of the survey.

Survey Results: Focal Constructs

Participants responded to questions representing several variables related to workplace safety, perceptions of their work environment, and personal experiences. Most of the variables focused on how the crew handled or experienced different situations (e.g., in our crew, we…) while the remaining variables focused on individual experiences (e.g., how often do you…). The summary findings for a subset of focal constructs are presented below.

The average scores on each variable across all participants are organized into three main areas: Strong areas, Moderate areas, and Development areas. The scores were classified based on natural breaks observed in the average scores along a 5-point continuum and therefore are a relative ranking (see Fig 16). While there were some small differences between participating organizations, results all generally followed the same patterns of variables falling into Strong, Moderate, and Development areas. For a full list of survey items and their definitions, see Appendix D.

Strong areas describe areas where organizations in the mining industry are performing well on key human and organizational factors that impact safety and identify sources of strength that can be built on moving forward. It is important to reflect on these areas of strength as they capture positive employee perceptions and provide evidence that good work regarding safety is being done and recognized by workers. Developing areas describe factors that would benefit the most from focused improvement efforts as these factors may play a role in SIF prevention and overall workplace safety. Moderate areas lie between these two areas and represent factors that have a strong foundation but could benefit from developmental initiatives.

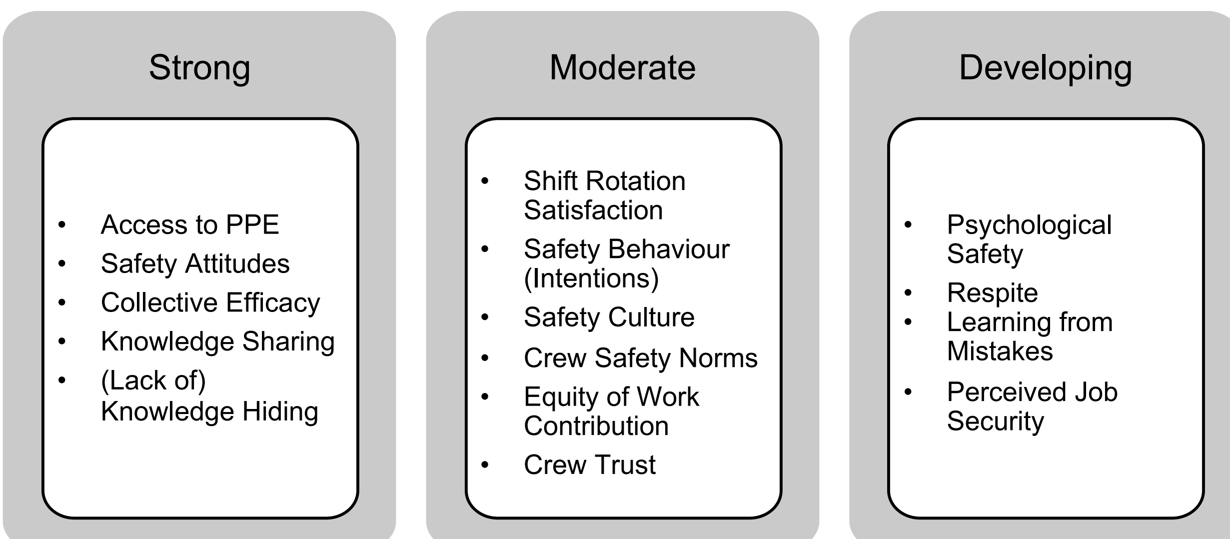

Fig 16. Overview of human and organizational safety-related variables, organized by strengths, moderate, and developing.

In addition to measuring the core focal constructs, we also examined two proxy outcome variables for safety, namely participant's trust in their crew members to behave safely and their overall perceptions of the safety of the workplace (see Appendix D for full questions). When analyzed, both safety proxy variables fell in the moderate range. To better understand how the focal human and organizational variables are related to the measured safety outcomes, we conducted a series of correlation analyses. A correlation provides information about the strength of the relationship between two variables and can range from -1 to +1. A negative correlation indicates that as the score on one variable goes up (e.g., higher job insecurity), the score on another variable goes down (e.g., lower trust in team members to behave safely). A positive correlation indicates that as the score on one variable goes up (e.g., more positive safety attitudes), the score on another variable also goes up (e.g., higher trust in team members to behave safely). Correlations can be classified as weak (value is less than ± .10, moderate (value is between ± .11 and ± .49), or strong (value is greater than ± .50) at the 0.001 significance level (less meaningful given our massive sample size). A heat map of the focal correlations is presented in Table 13. Colour coding is based on the distribution of correlation values with the strongest positive relationships being the darkest blue and the strongest negative relationships being the darkest red.

Table 13. Heatmap of correlations between focal study variables and safety proxy outcomes.

Focal Variable	Classification of Average Score	In this crew, we trust everyone to make safe decisions	Relationship Strength	This is a safe place to work	Relationship Strength
Safety Intentions	Moderate	0.66	Strong	0.60	Strong
Safety Attitudes	Strong	0.62	Strong	0.60	Strong
Collective Efficacy	Strong	0.55	Strong	0.55	Strong
Crew Safety Norms	Moderate	0.54	Strong	0.53	Strong
Equity of Work Contribution	Moderate	0.52	Strong	0.44	Moderate
Safety Culture	Moderate	0.50	Strong	0.59	Strong
Crew Trust	Moderate	--		0.53	Strong
Psychological Safety	Developing	0.49	Moderate	0.49	Moderate
Learning from Mistakes	Developing	0.25	Moderate	0.29	Moderate
Respite	Developing	0.26	Moderate	0.33	Moderate
Access to PPE	Strong	0.27	Moderate	0.33	Moderate
Job Security	Developing	0.19	Moderate	0.30	Moderate
Shift Rotation Satisfaction	Moderate	0.15	Moderate	0.29	Moderate
Knowledge Sharing	Strong	0.15	Moderate	0.16	Moderate
Knowledge Hiding	Strong	-0.12	Moderate	-0.17	Moderate

As Table 13 demonstrates, attitudes generally have the strongest relationships with our proxy safety variables, further emphasizing the importance of social-psychological factors in shaping safety. For example, one of the strongest predictors of safety perceptions were crews having positive safety attitudes (e.g., my crew places a great deal of emphasis on safety) and beliefs that they can conduct the work safely (i.e., collective efficacy). In contrast, factors like shift rotation satisfaction and access to PPE, while still important, were only moderately related to the safety outcomes.

It is also important to consider the classification of the average scores for each construct paired with the strength of the correlation to identify important areas for development. For example, most of the relationships between the focal constructs and safety outcomes that were classified as strong were also classified as a moderate area based on the average score across participants. This tells us that areas where the mining industry is performing moderately with some room for improvement, are also areas that are important predictors for safety. Recommendations and targeted interventions that impact these constructs (e.g., safety attitudes, safety culture) have the potential to have the biggest impact on safety perceptions.

Survey Results: Hazard Reporting

As part of the survey, we were interested in understanding potential reasons why hazards may not be identified or reported while on the job. In response to this question, the research team coded 2,986 reasons provided by a random subset of 1,169 participants across the mining industry (approximately 20% of the participants) that were representative of the broader sample. An overview of the content of the responses for all participants can be found in Fig 17. It is important to note that this question taps into actual and hypothetical or perceived reasons why a hazard may not be reported. For example, a participant might believe that someone might not report due to perceived normalization of hazards as a result of frequently working in hazardous environments (i.e., it does not mean that the person who answered the question failed to report hazards for these reasons and may be guessing at another worker's perceived reasoning). This does not exclusively mean that they have not or do not report for this same reason. These insights are important because they tell us about some of the beliefs employees and contractors have about hazards and hazard reporting as well as their actual reported behaviours.

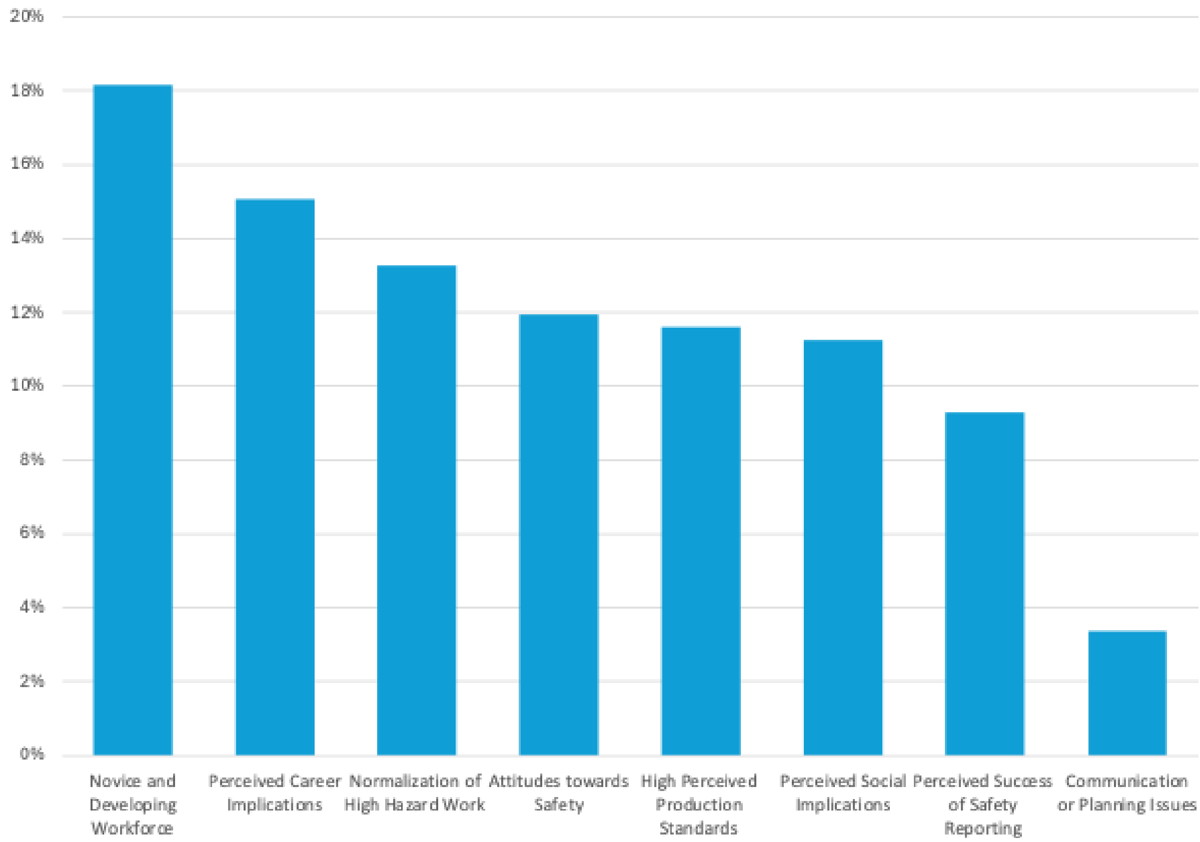

Fig 17. Percentage of respondents' answers to "In your experience, what are |the top three (or more) reasons why hazards are not identified or reported?"

Of the reasons provided, the top three main areas identified as a potential reason why hazards might not be identified or reported, say because workers are afraid, included:

1. Novice and Developing Workforce
2. Perceived Career Implications
3. Normalization of High Hazard Work

First, in relation to a **'Novice and Developing Workforce'**, individuals indicated that a potential reason why hazards may go unreported is that employees may not have enough knowledge or experience in their role to recognize features of their environment as hazards. Participants indicated this may stem from insufficient training (both amount of content and speed of training) and understanding of what relevant hazards are, as well as the large number of new and/or junior employees and high employee turnover characteristic of the industry, especially for contractors. A 'Novice and Developing Workforce' is an important observation to consider as the ability to consistently and reliably identify and report hazards in the environment is a vital first step to managing the hazard's impact. If workers believe they, or members of their crew, are unable to identify the relevant hazards in their environment, they may be at greater risk of interacting with that hazard, failing to implement available critical controls, and may have an overall higher risk of a serious injury or fatality. This challenge may be overcome through improved training (both content and length) and more standardized training and knowledge requirements across roles and contract types (i.e., permanent, temporary, contractors).

Second, relating to 'Perceived Career Implications', participants noted that people may not report hazards due to a perceived fear that reporting may have a negative consequence for their current employment or career trajectory. Some of the perceived negative consequences included changes in how their crew members or supervisors viewed their competency (e.g., someone attributing blame or fault for the hazard), losing their job or not being offered future positions or overtime (especially for temporary positions or contractors), and being moved to less desirable tasks or pieces of equipment within their crew.
It is important to note that few, if any, participants referenced any real examples of someone experiencing

prolonged career implications for reporting a hazard. However, the perception or fear of negative consequences appears to be a strong driving force for why someone might hesitate to report a hazard. Indeed, in our analysis of the focal survey constructs, we found that across the industry as perceptions of job insecurity went up, trust that crew members would make safe decisions and the overall perception that the workplace is safe, went down. Job insecurity is also related to other focal variables that relate to beliefs about the implications of reporting such as psychological safety (moderate relationship) and safety culture (moderate relationship). These perceptions may be changed over time by talking about hazards in a supportive and open way, working to come up with solutions to hazards as a crew or department, and providing positive reinforcement for hazard reporting (e.g., verbal encouragement, expressed appreciation).

Finally, participants mentioned that the 'Normalization of High Hazard Work' may influence why hazards are not identified or reported. Overall, there seems to be a perception that the very nature of mining and oil and gas work is dangerous and therefore it is 'normal' or expected to encounter hazards in the work environment. As a result, hazards may be normalized and therefore believed to be too small or not serious enough to be reported. Frequent encounters with the same hazards due to repetitive work may also contribute to a desensitization process where the hazard is accepted as a part of the normal work environment and therefore employees may assume reporting is unnecessary. Some participants also noted that hazards may be overlooked or normalized if they believe that previous reports did not result in any noticeable changes, or they did not perceive leadership to take appropriate actions in response to the report. While hazards may always be present in mining, the consistent recognition and reporting of all hazards can ensure proper controls are utilized by employees and steps are taken to ensure if an incident does occur, employees are able to "fail safely" and minimize impact. Creating meaningful messaging around hazard assessments (e.g., these are how they protect us, this is how that information is used) as well as closed-loop communication regarding what has been done to address hazards in the environment, can play an important role in ensuring routine hazards are consistently recognized.

Survey Results: Hazard Identification

To explore more about hazard identification and perceptions, a subset of the participants (approximately 95% of participants) also completed a series of questions related to 16 different hazards (see Appendix E). Given the unique combination of hazards in the mining industry, we built on the work of others on high-energy SIF hazards (Oguz Erkal et al. 2021, 2023, 2024; Hallowell & Oguz Erkal, 2024; Energy Safety Canada, 2025) and revised or created new icons (where needed) to illustrate these unique hazards like wildlife and working around water. Participants were asked to choose all that apply for each of the hazards. If the hazard was not relevant for their role or environment, participants could select "This hazard does not apply to me". Participants were included in the analysis for this question if they selected at least one of the four statements. For each statement, we share the most selected hazard, the least selected hazard, and a hazard that was selected by participants around the midpoint.

Statement 1: I am exposed to this hazard routinely.

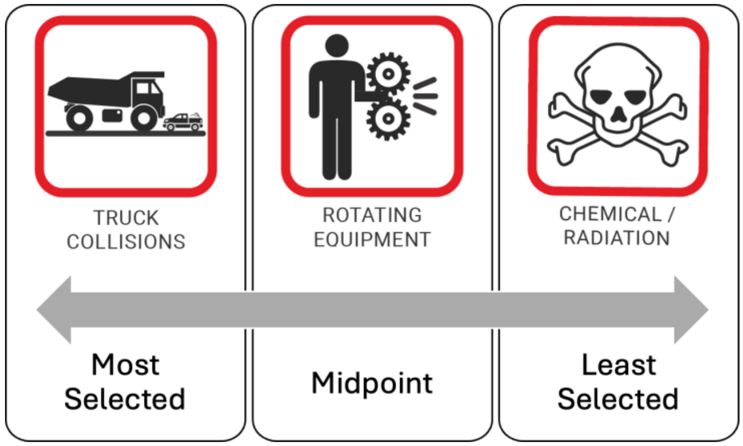

Fig 18. Summary of the Most Selected to Least Selected Hazard for Statement 1.

The first statement for each hazard sought to understand how many participants identified the hazard as being something they might encounter as part of their work on a regular basis (Fig. 18). Employees (about one in two participants) identified the most frequent hazard that they encounter as truck collisions. This hazard specifically references the interaction between large trucks (i.e., haul trucks) and smaller vehicles (compared to a vehicle incident involving only passenger or transport vehicles). On the other hand, employees identified the least frequent hazard they were routinely exposed to as chemical or radiation exposure (about one in fifteen participants). The hazard that was identified at the mid-point of the frequencies (about one in four) was encountering rotating equipment.

Overall, hazard identification frequency depended on the specific hazard which aligns with our expectations given the diversity of occupational functions and organizations that responded to the survey. The most frequently selected hazards were relevant to many different occupations and sites while the least selected hazards tended to be hazards that would only be relevant to more specialized roles.

Statement 2: There are controls in place for this hazard that mitigate exposure and/or impact.

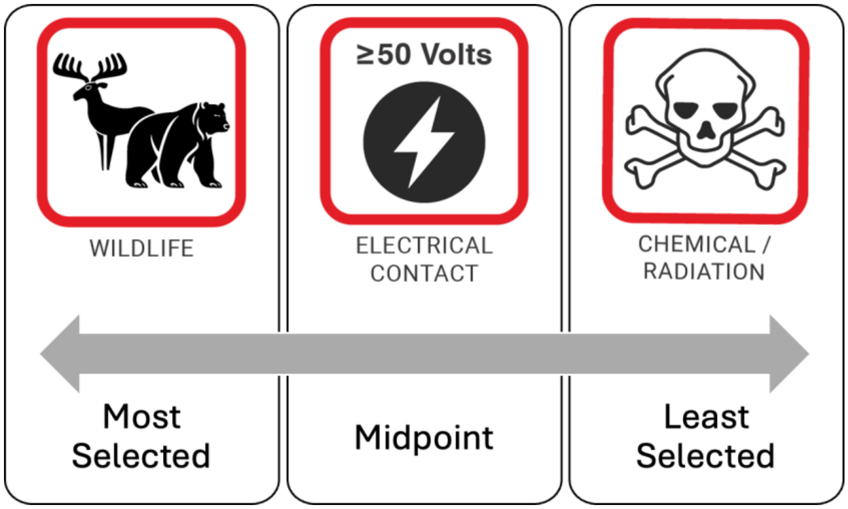

Fig 19. Summary of the Most Selected to Least Selected Hazard for Statement 2.

The second statement aimed to understand how frequently participants were aware of controls that were in place to mitigate the exposure or impact caused by the hazard (Fig. 19). Participants largely agreed that there were controls in place for wildlife (about three in four participants) as it was the hazard with the highest frequency counts. Similar to the statement about routine exposure, chemical or radiation exposure had the lowest frequency count of participants agreeing there are controls in place (about one in three participants). Lower frequencies for this statement may come from it being a less common hazard so participants are not aware of the controls in place (i.e., outside the scope of their job) or a potential belief that the controls in place could be improved (i.e., are not sufficient to mitigate exposure or impact). The hazard that was identified at the midpoint of the frequencies (about one in two participants) was controls being in place for the exposure or impact of electrical contact.

Generally, recognition and awareness of controls was relatively high, especially for the hazards that more employees reported encountering on a routine basis (e.g., truck collisions, wildlife). For hazards that employees did not encounter regularly, the recognition of controls was lower, perhaps because the hazard was not relevant to that participants' role or occupational environment.

Statement 3: I am afraid that this hazard will hurt me or someone else.

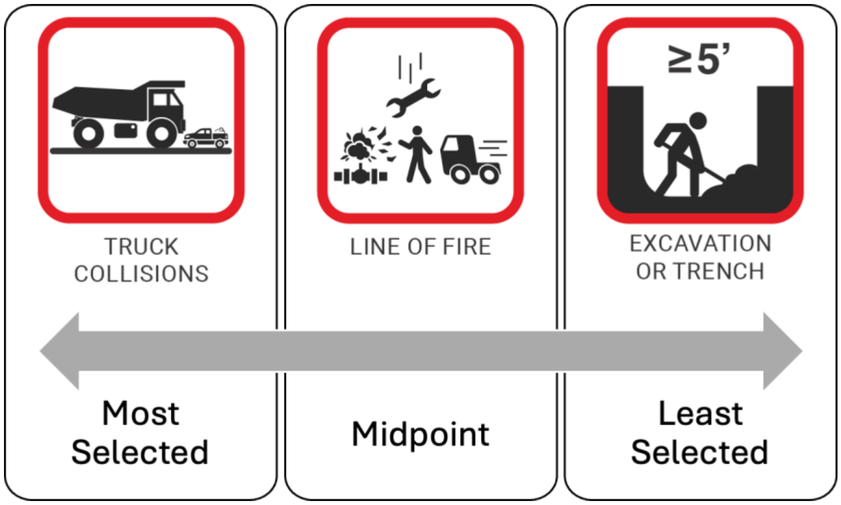

Fig 20. Summary of the Most Selected to Least Selected Hazard for Statement 3.

The third statement was interested in understanding if participants were afraid of the potential impact of different hazards they may encounter in their work environment (Fig 20). The hazard that had the highest frequency count for participants indicating fear was truck collisions (about one in six). The lowest frequency counts for fear were for the excavation or trenching hazard (about one in forty participants). The hazard that was identified at the midpoint of the frequencies (about one in ten) for fear of impact was line of fire.

Overall, expressed fear about the hazards was relatively low, which is surprising given the centrality of 'fear' and 'scared' in responds to "Why are hazards not identified or reported?". These results may reflect that participants are not afraid of the impact of the hazard because they do not encounter the depicted hazard routinely, because they believe there are appropriate controls in place so the hazard will not have a negative impact, the hazard is familiar, or that they only fear unknown hazards.

Given the specific interest in hazard identification when working around water and ice, we also explored in more detail how participants responded to each of the four statements for the hazard of water and ice (Table 14). Generally, even if participants did not select that they were routinely exposed to this hazard, approximately half of the respondents agreed that there were controls in place to mitigate the risk of working around water and ice. The number of participants that selected "I am afraid this hazard will hurt me or someone else" was generally consistent with the frequency counts for the same statement for the other fifteen hazards. Overall, the number of participants that selected each of the four statements was around the midpoint of frequencies compared to the other hazards. As these are individual workers' risk perceptions of specific hazards, comparing these to the hazard inventories of their work would determine if they are accurately identifying hazards and controlling their exposures.

Table 14. Summary responses for the hazard of working around 'Water and Ice".

WATER AND ICE

Statement	Number of participants that selected
I am exposed to this hazard routinely.	Approx. 1 in 14 participants
There are controls in place for this hazard that mitigate exposure and/or impact.	Approx. 1 in 2 participants
I am afraid that this hazard will hurt me or someone else.	Approx. 1 in 15 participants
This hazard does not apply to me.	Approx. 2 in 5 participants

Survey Successes, Challenges, and Lessons Learned

The survey findings present many strengths. The focal constructs examined in the survey are grounded in extensive organizational behaviour and safety research supporting good psychometrics for our analyses and reliable findings. We were able to collect data from many employees and contractors across the mining industry, with support from many key departments and companies, ensuring a diversity of voices and experiences were captured. Overall, feedback about the survey was positive, and the data quality of the survey responses was good. The survey provided crucial insights into the social and psychological factors that may influence the safety environment and how the mining industry is performing in several of these areas.

Despite the success of the survey, we also faced several challenges, particularly with connecting social and psychological measures collected in the survey with actual organizational measures of safety performance and SIF events. This was true across all participating organizations. While this limits our ability to test the external validity of our contextualized model, we were able to show meaningful associations among HOP concepts, including concepts with long histories of predicting actual behavior. So, despite our best efforts, we were unable to connect survey data with organizational records. That said, the historical nature of the SIF data would have precluded causal analyses. For example, the social and psychological context that surrounded a SIF event in 2021 might not reflect the current context and dynamics for the same team in the 2024 survey. To attribute the current crew dynamics to previous incidents would not provide the insights we were hoping to achieve. Moving forward, a future research project would link 2024 survey data to 2025/2026 SIF data. Given that the exploration of social and psychological factors as a precursor for SIF (as opposed to solely focusing on technical factors) is relatively new, these reporting and data matching challenges are not surprising.

Reflecting on the strengths and challenges of the survey, we identified two primary lessons learned. First, to be able to appropriately connect SIF event data with social-psychological factors, changes to how safety events are reported and/or how data are stored within the reporting systems of mining companies may be required. In addition to the difficulty in matching survey data with SIF event data highlighted above, to be able to use social and psychological measures to predict SIF events, the SIF data should have good psychometrics properties. The measures that capture features of the SIF event should be reliable (the measure should produce consistent and repeatable conclusions across similar events), valid (the measure captures what it says it measures), and have sufficient variance (different groups or types of events will provide different responses to the measures). Questions with open-text boxes or few categorical choices and many questions with non-responses can make it challenging to conduct the appropriate statistical analyses to draw meaningful inferences between human and SIF factors.

Second, to better understand the connection between social-psychological factors and SIF events, the two reports need to happen in close temporal proximity. For example, crew dynamics such as psychological safety or conflict may fluctuate through seasons as the pace of work changes, as team members join or leave the crew, or as the content of the work changes. This means a measure of social-psychological factors from last year might not be the best predictor for SIF precursors and SIF this year. On-going and frequent measurement of social-psychological factors can give real-time insight into how teams are performing and allow for insights into which social and psychological factors may be leading indicators for SIF events.

To supplement our survey findings and help address some of the limitations highlighted above, we also engaged in interviews with several high-risk areas of operations within the mining industry to learn more about the role of social-psychological factors in SIF.

4.4 Semi-Structured Interviews

Interview Overview

To gain deeper insights into the human and organizational factors that may influence safety, and the risk of SIF, Drs. O'Neill, Jones and Jessica Wilkins, and other members of the research team (University of Calgary, Industrial and Organizational Psychology) conducted 170 interviews with employees, contractors, and various levels of supervision and management from organizations in the mining industry between August 2024 and February 2025. Participants represented various high-risk tasks and roles from Mining, Tailings, Maintenance, and Plant Operations. These sites and organizational functions were selected due to the high hazard nature of the work and trends observed in the survey findings.
Interview Method

A semi-structured interview guide was developed and piloted by Drs. O'Neill and Jones (University of Calgary, Industrial and Organizational Psychology) as well as other members of the research team in the Spring and Summer of 2024. A semi-structured approach includes open-ended topics and questions to guide the interview while also allowing for follow-up questions based on the stories and observations participants share. Topics in the interview guide mirrored the focal constructs from the survey and allowed us to explore notable relationships and factors that may influence SIF in more detail. Workers from different crews and departments present on site during our data collection visits were invited to participate in the interviews.

Interviews were conducted on-site in a private office space and lasted around 45-60 minutes on average. The interview protocol included seven major components:

1. Participant Introductions and Review of the Consent Form: First participants were welcomed into the interview and thanked for their time. The interviewer then gave a short introduction to the study including the purpose of the interview, what participants could expect during the interview and how their confidentiality would be ensured. Participants were reminded that their participation was voluntary, and they were free to stop the interview at any time or skip any questions they did not feel comfortable answering. Participants were then given time to review the consent form and ask any questions before proceeding.
2. Background Information: The interview began with background information about the participant (e.g., how long have you worked here) and gaining a better understanding of their role and daily tasks (e.g., what is your role? What does an average day look like for you? What are the hazards you encounter the most?).
3. Current Safety Observations: Next, the interview tapped into the participant's perception about safety at their organization (e.g., what is your company doing right when it comes to safety? What could be improved?) as well as perceived barriers and solutions to behaving safely.
4. Training and Safety Orientation: Participants were then asked about their experiences with training and safety on-boarding as well as their perceptions about the safety team and potential areas for improvement.
5. Safety Leadership: Participants then elaborated on what qualities make a good safety leader and perceptions about leadership's role in safety.
6. Contractor Coordination: Lastly, and only if it was relevant to the participant, the interviewer explored contractor coordination and what strategies crew members employ to work effectively as a contractor or with a contractor.
7. Wrap-up and Thank you

During the interview, the interviewer took notes of key themes, examples, and quotes to ensure the participants' responses were accurately captured. Participants were welcome to review the notes at any time and no identifying information was recorded during note-taking. Following the interview, the notes were analyzed by a member of the research team to identify major themes and examples. Results are summarized below.

Interview Results: Theme and Sub-theme Descriptions

The results are organized by major themes that were identified as impacting feelings of safety, safety behaviours, and were viewed as contributing to SIF if not properly managed. For each major theme, we highlight examples extracted from the data and sample recommendations. These should be further assessed to determine if these have already been implemented, are practical, and effective.

Balancing Production and Safety Goals: Aligning production goals with safety standards to ensure that employees can meet operational demands without compromising safety, ever. Although for many of the companies, their messaging clearly emphasizes safety over production, actions from all levels of the organization can encourage production competition between workers, feelings of stress and time-pressure, and implicitly or explicitly reward top production performers, regardless of safety. Balancing production and safety goals through messaging and action ensures that workers always know the safest way to do the job is the right way to do the job.

- Example from data: Decrease motivation to rush due to fears related to maintaining employment, being excluded by crew/leaders, and receiving perceived punishments (e.g., different work assignments)
- Example from data: Support from management trickles down to support from supervisors to do the work safely no matter what
- Example from data: Effective and resilient work planning ensures production goals can be met without rushing or compromising safety

Standardized, High Quality Training Programs: Providing accessible and comprehensive training resources ensures employees have consistent and accurate knowledge of safety protocols and appropriate procedures for doing the work. Training programs should include continuous, real- time feedback, have instructors and mentors who are engaged and dedicated, and have clear guidelines for ensuring competency when signing off on qualifications/certifications. Coaching, mentorship, and peer to peer learning should continue in the field. Certifications should be kept current.

- Example from data: Web-based training provides a useful foundation of knowledge but needs to be augmented with field training
- Example from data: Field training should be done by skilled trainers with a degree of standardization, recognizing varying field conditions call for different approaches
- Example from data: Trainers should create a psychologically safe environment, and trained behaviours should be promoted in regular work
- On the Job Development of Experience and Knowledge: Learning and skill development should extend beyond initial certifications to maintain an experienced, competent, and safe workforce. Field-based opportunities for employees to gain sufficient competency and continually update their experience and knowledge in critical roles helps to put the right people in the right positions and to enhance safety awareness across roles on-site. Field-based training is supported by mentoring and practical exposure to different work conditions, hazards, and levels of responsibility.
- Example from data: Training for mentors to be effective in developing others
- Example from data: Dedicating sufficient time to cross-training, mentorship, and field experience before moving workers to new positions
- Example from data: Hiring individuals with a growth and learning orientation and building a culture that rewards such behaviours

Supervisory Presence and Support: Supervisors play a vital role in maintaining safety by dedicating time to safety checks and safety-related communications, being visible on-site, providing guidance to employees, and acting as an intermediary between front-line workers and management. Supervisors should have experience with the job and equipment although it might be possible to mitigate with high curiosity and learning orientation. Consistent application and adherence to procedures across supervisors.

-
- Example from data: Supervisors build rapport and trust with direct reports
- Example from data: Supervisors do not shortcut procedures and hold others accountable
- for performing the work safely
- Example from data: Supervisors provide support and safe solutions for workers who feel unsafe with a given job

Fostering Positive Interpersonal Dynamics and Safety Norms: Promoting healthy interpersonal relationships within work crews and managing conflicts effectively sets the foundation for positive safety norms where workers trust their crew to do the work safely and have their back. Knowing when a team member is having an “off” day and needs support or even a “fit for duty” conversation is facilitated by strong interpersonal bonds and supportive crew dynamics.

- Example from data: Respect and inclusion for everyone; no ostracizing
- Example from data: Build a team spirit and team dynamic that promotes safety, learning, peer support, and a proactive approach to safety in the crew
- Example from data: Encourage supervisors who deal with team members that undermine the crew and bring the collective mood down

Addressing Employee-Specific Factors: Supporting individual safety mindsets and attitudes, accounting for varying risk tolerances and motivational levels, and providing resources for managing personal challenges (e.g., home life stressors) and emotional regulation fosters a workforce better equipped to focus on safe work practices. This is particularly important from a leadership skill perspective. Tailored initiatives, such as mental health support and training on emotional control, can further enhance safety behaviours and overall well-being.

- Example from data: Active mental health supports in the workplace
- Example from data: Education on physical, mental, and financial well-being
- Example from data: Training on self-management and interpersonal skills, such as emotional self-regulation, communication, stress-management, and personal care.

Aligning Union Policies with Safety and Performance Goals: Reviewing and adjusting union rules and policies that may inadvertently interfere with safety and organizational performance, such as role bidding systems that prioritize seniority over experience and competence, ensure that employees in critical positions have the necessary skills and training. Collaboration between management and union representatives should create policies and practices that support both employee rights and workplace safety.

- Example from data: Avoid union policies that interfere with competency-based work assignments
- Example from data: Avoid union policies that prevent strong performance management practices
- Example from data: Avoid union policies that create a culture of complacency

Improving Contractor Coordination and Relations: Establishing clear guidelines and communication channels between employees and contractors ensures alignment on safety protocols and performance expectations. Building positive relationships and fostering mutual respect between contractors and employees can reduce conflicts, improve teamwork, encourage hazard reporting and communication, and ensure consistent adherence to safety standards and procedures across all work groups.

- Example from data: Contractors are treated as equals and with respect
- Example from data: Contractors have the appropriate communication channels to coordinate with other workers on-site
- Example from data: Contractors are appropriately trained and competency assurance mechanisms are in place

Cultivating a Proactive Safety Culture: Encouraging open dialogue and fostering perceptions of inclusion and consultation related to safety concerns sets the foundation for a proactive (versus reactive) safety culture. When workers feel cared for, appreciated, trusted, listened to, and valued they are more likely to take on safety initiatives, feel empowered to speak up, and be less resistant to new safety practices. Running regular and effective (e.g., relevant, interactive) safety meetings and crew meetings also supports a proactive safety culture.

- Example from data: A culture of being forward-looking with respect to work processes, planning, organization, and advances in safety science
- Example from data: A culture that does not bend the rules when it comes to safety and procedure and is responsive to employee concerns
- Example from data: A culture of safety meeting engagement and attendance

Interview Successes, Challenges, and Lessons Learned

The interview methodology and analytical approach provided several strengths. We were able to interview a wide diversity of workers covering characteristics such as years of experience with their company and in related industries, gender, age, job positions and departments, and hazards encountered. The interview length and smooth on-site coordination by partner organization staff ensured that we were able to spend as much time with participants as possible and hear their perspectives on a wide variety of safety topics.

To maximize the number of workers we could interview, during some interviews we opted to conduct interviews independently, having each member of the research team interview and take their own notes. While this increased the research team's capacity, more details may have been captured using other data recording methods. However, given the topics of discussion and the importance of gaining multiple perspectives, we believe this method best balances diversity of participants with participant's confidentiality and security.

The findings from the semi-structured interviews largely confirmed the key human and organizational factors and social-psychological factors that were evident in the themes identified in the symposium workshops and survey results. Interviewees consistently emphasized the tension between production pressures and safety priorities, noting that while their organization's formal messaging prioritizes safety, implicit incentives and time constraints sometimes encourage risk-taking behaviors. This theme was apparent across the mining industry, appearing in interviews from all of the participating organizations and sites. Psychological safety emerged as a critical factor that warrants continued focus by organizations, with workers highlighting that the ability to speak up about safety concerns without fear of reprisal was unevenly distributed across teams, sites, and organizations. The interviews reinforced previous survey results that suggested crew dynamics, leadership support, and training can significantly impact safety behaviours. Furthermore, interviewees provided detailed examples of how these dynamics play out in day-to-day operations, which once again identify the need for strong leadership and proactive communication in fostering a strong safety culture.

Additionally, the interviews offered unique insights beyond those captured in the survey and symposium discussions. While the survey and symposium identified safety leadership, psychological safety, and training as key factors, the interviews highlighted variability in training effectiveness, with some workers reporting that field training is not always standardized and depended heavily on the trainer's expertise. Contractors, in particular, voiced concerns about communication gaps and differences in safety expectations between permanent employees and contract workers, emphasizing the need for stronger integration and socialization strategies. The interviews also shed light on the role of individual and group attitudes in shaping safety behaviors, with some workers describing a reluctance to report hazards due to fear of social exclusion or perceived inefficacy of reporting mechanisms. These qualitative insights provide a deeper and richer understanding of the organizational and psychological barriers to safety – and the industry as a whole can benefit from continuous improvement in these areas.

Future work may seek to interview more contractors from smaller organizations to gain more insights into the challenges of contractor coordination and contractor dynamics. While we were able to speak to some contractors, they generally had significant experience working on their specific sites and therefore might have been more integrated into the contracting organization's policies and procedures than other contractors.

4.5 Conclusions and Recommendations

The findings from this report are consistent with the broader trend toward Human and Organizational Performance principles (Conklin, 2019) that are now widely recognized as valid:

- People make mistakes
- Blame fixes nothing
- Context drives behaviour
- Learning is vital
- Response matters

Therefore, impactful efforts to reduce SIF will require a holistic and integrative approach. Any one-size-fits-all or isolated initiative will have limited impact. A coordinated approach is what's needed. In this spirit, considering both the machine learning and natural language processing analyses as well as the human factors perspective of this creative sentence clearly signals that both technical engineering controls (such as hazard identification, controls, and critical control assurance) and human and organizational factors (such as organizational culture, psychological safety, and leadership) need to be addressed in a multi-pronged approach in all organizations working in high risk environments.

The symposium and research findings highlighted the importance of psychological safety, trust, and leadership in shaping safety-related behaviors and decision-making. Participants acknowledged that while procedural and technological interventions remain essential, fostering a strong safety culture, improving communication between leadership and workers, and addressing social-psychological factors are equally critical in preventing SIF. The 170 interviews with front-line employees confirmed this. Moving forward, organizations must focus on implementing structured interventions that enhance workplace psychological safety, improve the transfer of these behaviours to the work environment, increase leader accountability for safety behaviors (not putting them in the position of having to choose production over safety procedures), and ensure workers feel empowered to report hazards without fear of reprisal.

Limitations and Future Directions

Despite the strengths of this research, several limitations exist that should guide future efforts. First, linking social-psychological factors with actual SIF events remains a challenge due to the limitations in historical safety data and reporting databases, as well as managing confidentiality, anonymity, and privacy. This is very important to overcome in the future because linking actual social-psychological data to SIF occurrence and rates will mathematically connect the two sets of variables and show the strength of association. It could also be used to narrow down the most impactful social psychological variables for future targeted interventions. With respect to interventions, scientific testing is needed in pilot programs. There are significant barriers to implementing training on such variables, ensuring learning occurs, and seeing this learning transfer into behaviour change on the job. This is a critical avenue for future research and practice. It will take collaborations involving industry, safety associations, universities, and other relevant bodies.

Future research should also explore real-time measurement of human dynamics and incident precursors (if not incidents themselves) to help establish clearer relationships between these variables. Again, this will require collaboration among parties involved and an openness to try new methods. Fortunately, some companies are making progress in this area and it should be possible to build on their good work. Second, while the survey and interviews provided valuable insights, additional workshops with corporate and site leadership are recommended. These strategy sessions can be used to integrate the findings in company training processes and identify levers for culture change improvement, for example. It is strongly believed by the research team that continued investment in things like leadership training, improved communication channels, and a shift from a reactive to a proactive safety culture will be crucial. Third, organizations should also explore policy changes, such as restructuring incentive systems to reward safety-conscious behaviors rather than productivity-based performance alone. Finally, integrating psychological safety metrics into routine safety audits and incident investigations could further support the long-term sustainability of these initiatives. Ultimately, reducing the likelihood of SIF in high-hazard industries is a wicked problem, and continued research and collaboration is needed to advance knowledge and identify the best options for diagnosing and solving the problem.

5. Conclusions

This research was motivated and funded by a creative sentence for the death of Patrick Poitras. A workplace fatality is a great tragedy and failing to learn from it only adds to the tragedy. It is therefore imperative that industry learns and takes steps to prevent future events. Specifically, how do we ensure that there are layers of protection so that workers are more likely to 'fail safely'?

Thus, our objective is to understand the hazards that cause SIF in mining and related operations, the causes, and the most effective controls to prevent fatalities (Outcomes 1-7):

1. Create a hazard inventory of 'work as done' in all mine operations (mining, extraction, treatment, and tailings) and ancillary activities.
2. Identify/develop indicators for SIF precursors, controls, and assurances/audits.
3. Determine which activities are most likely to be completed by contractors.
4. Examine how indicators, controls, and control/barrier assurance vary across owners/operators, contractors, and subcontractors.
5. Survey the prevailing safety culture within owners, contractors, and subcontractors.
6. Recommend systems-level, multi-layered, effective, and assured controls.
7. Promote and support the implementation of these controls into owners/operators', contractors', and subcontractors' safety management systems.

To answer these, we engaged in three complementary research activities: 1) workshops, 2) data analytics of Critical Controls Assurance (CCA) versus SIF potential + actual, and 3) surveys and interviews of hazard identification and human-organizational performance.

First, through workshops with 200+ subject matter experts, we repurposed a process safety management tool – bowtie diagrams – to help workers 'see' high-energy hazards and the causes, consequences, and a system of layered controls. We developed and refined eight bowties for hazards that are most likely to cause SIF in mining operations and other heavy industries:

- Confined space
- Control of hazardous energy
- Dropped objects
- Working in and around water/ice/hazardous ground
- Excavations and trenching
- Heavy vehicle – Light vehicle interaction
- Working at heights
- Lifting and hoisting

We shared our workshop slides and a 'bowtie primer' with participants and industry safety associations (Alberta Construction Safety Association, Alberta Mine Safety Association, and Energy Safety Canada), to make this information available to 'boots on the ground' workers. For companies who see safety as a cost or inconvenience, we also created a one-pager for 'The Business Case for Risk Management'. These materials are in Appendix A.

Second, we used data analytics (primarily machine learning and natural language processing) to analyze how inspections (specifically critical controls assurance CCA questions) matched with subsequent SIFp+a. This allowed us to better see the gaps and overlaps in companies' management systems and recommend enhanced CCA questions, which they have already incorporated. We could use NLP for gap analysis to compare SIFp+a to other data sources like risk registers, process safety management (permits, lockout/tagout), technical competency assurance, leadership training, etc., to identify gaps and overlaps. It could also identify inconsistencies or redundancies (i.e., safety clutter').

Third, we used surveys and interviews to understand the human and organizational factors that reinforce or degrade safety performance. We developed new survey questions for this (see Appendix D). And since mining, refining, and industrial construction are particularly hazardous work, we created new hazard icons (see Appendix E). In this report, we present descriptive and correlational statistics. And we identify safety behaviours that could contribute to SIF which addresses project objectives 2 and 5.

Lastly, in this report, we recommend future work to leverage across these research activities. Workshops and survey/interviews would help us determine we need other one-pagers, like:

- How can you know if your workers are afraid or hiding information?
- 7 things frontline supervisors can do to ensure workers feel safe to speak up
- 5 things owner companies can do to better integrate contract workers
    - Data analytics and survey interviews will help identify what other high-energy hazards are more likely to cause SIF, so that we can develop bowties for these.
    - Data analytics and surveys/interviews will help us identify which controls are critical controls and how these controls could become degraded. This would help us to develop CCA questions for human and organizational factors. And it would supplement our bowtie visualizations, so that everyone is aware of how critical controls could be unwittingly undermined.
    - Data analytics like Bayesian Network Analysis and/or time series would help determine if enhanced CCA is reducing SIFp+a
    - Connecting CCA/SIF and survey data will determine which sites/teams are safer and why and, conversely, which are vulnerable. These learnings would help vulnerable teams learn from more resilient/safer teams.
    - Data analytics can also be applied to additional data sets to determine broader gaps and overlaps in competencies, training, task planning, etc.

We are deeply grateful to all who supported this project across the mining, energy, and industrial construction sectors: the thousands of survey respondents, the hundreds of subject matter experts, and the tens of companies who contributed. This project is a great example of how companies, industry safety associations, and researchers can work together when tragedies occur — to maximize learnings and develop focused improvements.

Our hope is that these findings, recommendations, and future work can help mining and other high-hazard industries in Canada and abroad to reduce serious incidents and fatalities.

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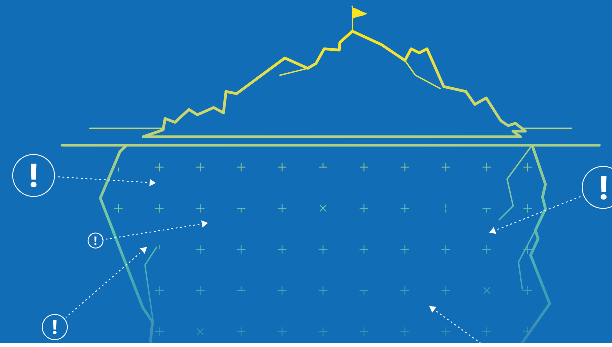
Appendix A – Industry learning materials produced from the workshops

- 'Business case for risk management'
- Bowtie primer

Risk Management is Good Business

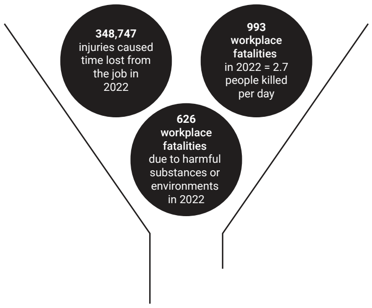


AS A PROFESSOR AND RISK, INNOVATION, AND SUSTAINABILITY CHAIR (RISC), FACULTY OF ENGINEERING, UNIVERSITY OF ALBERTA, I AM OFTEN ASKED ABOUT THE BUSINESS CASE FOR SAFETY: **DOES RISK MANAGEMENT 'PAY OFF'?**

MY ANSWER IS A RESOUNDING **'YES!'**

FIRST, RISK MANAGEMENT HELPS TO AVOID LOSS.

Every year, thousands of workers in Canada are injured or killed on the job. According to the Association of Workers' Compensation Boards of Canada (AWCBC), in 2022, there were 348,747 lost time injuries, 626 workplace fatalities from harmful substances, and 993 workplace fatalities of which 33 were young workers aged 15-24.

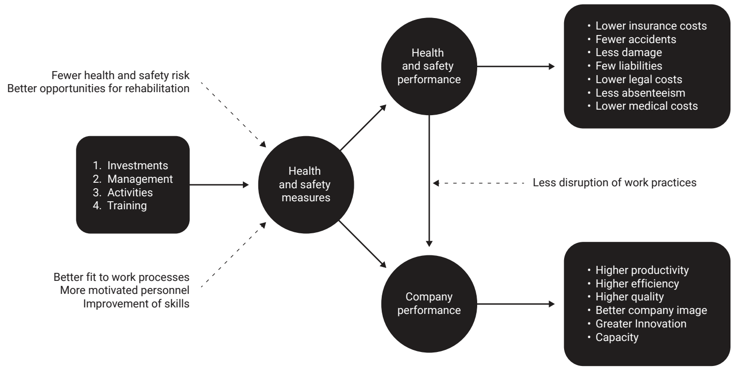


The cost of injuries in Canada was estimated to $29.4 billion in 2018. This includes direct costs of $20.4 billion arising from health care expenditures and indirect costs of $9 billion associated with reduced productivity from hospitalization, disability and premature death.[1] Workplace incidents are expensive: the associated losses of production loss, absenteeism, medical cases and compensation equate to 4–5% of the annual global gross domestic product (GDP);[2] more than twice Canada's 1–2% annual GDP growth rate.

SECOND, RISK MANAGEMENT ENABLES BETTER FIT TO WORK PROCESSES AND SUSTAINED, OPTIMIZED PERFORMANCE.[3]

Research on 18 case studies of workplace safety initiatives show an average increase of 82% in safety performance, 66% in productivity, 44% in quality, and 71% in cost benefits.[4]

Companies with mature risk management systems are valued as much as 25% higher.[5] Despite this, only 3.4% of organizations have mature processes to actively identify, evaluate, and manage their risks.[2]



For more information on how you can analyse the gaps in your company's risk management system, contact me:

Dr. Lianne Lefsrud, P.Eng.
Risk, Innovation and Sustainability Chair (RISC) 780.951.3455 | lefsrud@ualberta.ca

Lynch School of Engineering
Safety and Risk Management

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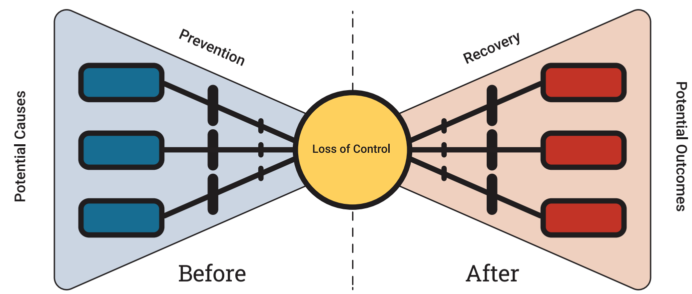
Using Bowties to Visualize, Communicate, and Control High Energy STKY Hazards to Prevent Serious Incidents and Fatalities

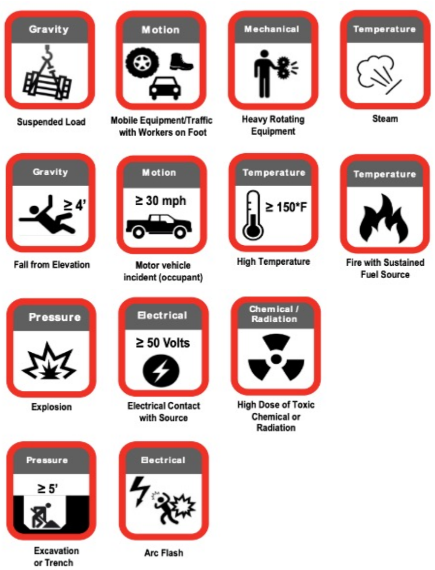
UNDERSTAND WHAT CAN GO WRONG

Bowties are a visualization technique to illustrate:

1. Loss of control over STKY hazards
2. potential causes
3. potential outcomes
4. prevention controls
5. mitigation/recovery controls



THE S**T THAT KILLS YOU (STKY), HIGH ENERGY HAZARDS ARE OFTEN REPRESENTED AS LIFE SAVING RULES.

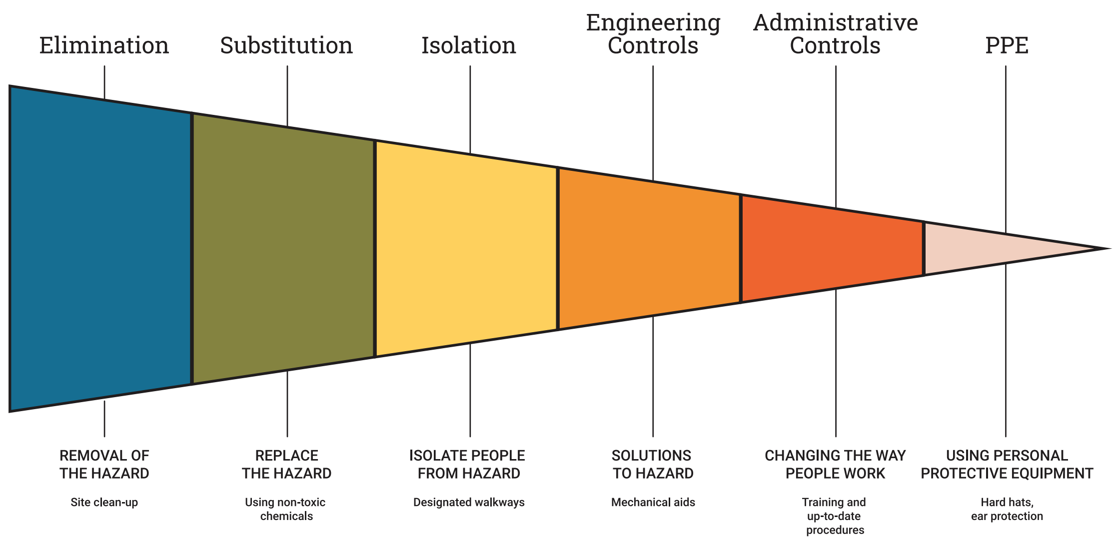


Workers' recognition of and respect for these hazards is the key first step in keeping everyone safe.

UNDERSTAND THE ROLE OF CONTROLS IN SAFETY

Bowties show that safety is a presence of layers of controls, rather than an absence of serious consequences. If you have more layers of controls to help prevent and recover, you are more likely to fail safe than fail lucky.

These layers are also aligned with the hierarchy of controls. Elimination, substitution, and isolation often prevent the loss of control and, thus, are most effective. While administrative controls (training, permits) and PPE often only minimize consequences and are less effective.



Bowties communicate risks and help organizational learning - between senior executives and frontline workers, operations and safety, internal employees and external contractors.

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WHEN TO USE A BOWTIE

Bowties can be used effectively during safety meetings or toolbox talks with crews to visually communicate hazards, controls, and their roles in maintaining safety. Engaging frontline personnel in Bowtie discussions can enhance awareness, promote accountability, and provide opportunities to identify potential gaps in controls or barriers.

While a Bowtie is inherently qualitative, it can be quantified by assigning failure probabilities to model their impact on incident likelihoods. This approach combines the intuitive Bowtie framework with robust probabilistic analysis, offering the best qualitative and quantitative methods.

EROSION OF CONTROLS

Controls can be degraded by human and organizational factors that can compromise efficacy. Degradation Factors are often included where there is a particular concern about a control or where *historically* the degradation factor has been a cause of control failure – the holes in the Swiss cheese – active or latent.

Examples:

- **Preventative control:** Operator action with critical in-hand procedure
- **Degradation Factor:** Erosion of skill/accountability

- **Mitigation control:** Evacuation Alarms
- **Degradation Factor:** System bypassed or malfunctioned

CRITICAL CONTROLS

Critical controls have the capability on their own to prevent or mitigate a loss of control or consequence. The absence or failure of a critical control would significantly increase the risk despite the presence of other controls.

Criteria that should be considered when determining critical controls include:

- Cause to which the control contributes has a ***high probability of causing*** *a loss of control*
- The consequence to which the control relates is ***very severe***
- The pathway is of medium risk but has ***very few controls*** (e.g., few layers / weak defense)
- The control appears on multiple pathways or bowties and thus is of cumulative importance
- Expert judgment

* **IN THE FOLLOWING BOWTIES, THE MEASURES HIGHLIGHTED IN BOLD ARE CRITICAL CONTROLS.**

Bowtie sample

Confined Space

Control of Hazardous Energy

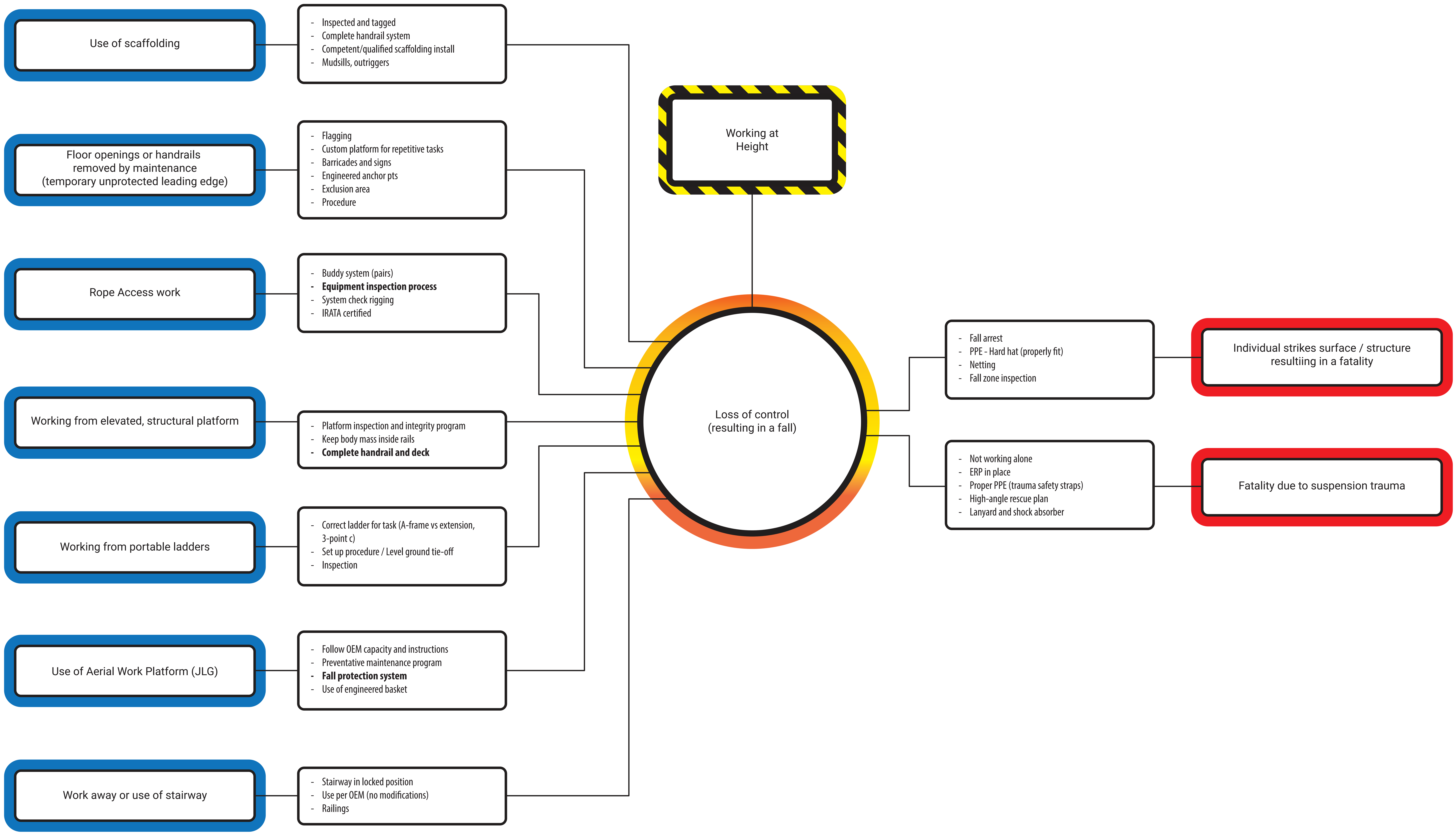
Dropped Object

Excavation and Trenching

Working in or around water/ice/hazardous grounds

Heavy Vehicle – Light Vehicle interaction

Working at heights



Lifting and Hoisting

Appendix B - Survey Materials for Presented Results

Variable	Source	Definition	Items in Survey
Access to PPE	(Lefsrud et al., 2021)	An individual's perceived adequacy of workers' access to personal protective equipment.	All workers are supplied with excellent gear/PPE for the job
Safety Attitudes	(Bock et al., 2005)	How positive crew members' perceptions are toward safety.	My crew places a great deal of emphasis on safety The crew I work with has a positive attitude towards safety rules and procedures Most people on my crew care a lot about working safely
Collective Efficacy	(Chen et al., 2001)	Extent to which an individual believes their crew can perform safety and at a high level.	When facing difficult tasks, I am certain my crew will be successful My crew is able to overcome any safety-related challenges it faces I am confident my crew can perform safely on many different tasks
Knowledge Sharing	(Connelly et al., 2011)	An individual's willingness to share information with others in their crew.	I answered all their questions immediately I told my crew member exactly what they needed to know
Knowledge Hiding	(Connelly et al., 2011)	An individual's attempts to keep information from others.	I agreed to help them but never really intended to I pretended that I did not know the information

			I explained that I would like to tell them, but was not supposed to
Shift Rotation Satisfaction	Developed for study	How satisfied an individual is with their shift rotation.	I am able to get sufficient rest and stress relief during my non- working hours
Safety Culture	(Lefsrud et al., 2021)	An individual's perception of the extent to which supervisors address unsafe acts in a helpful way, good safety behaviour is recognized and rewarded, up-to- date safety policies and procedures, clear understanding of stop work authority, and playing it safely if there is a risk of an incident.	When supervisors see an unsafe act or situation they intervene in a helpful way. Good safety behaviour is consistently recognized and reinforced in a positive manner by supervisors We all clearly understand conditions in which work should stop due to safety concerns The majority of safety procedures are up-to-date In our crew, we don't take chances when we think an incident may happen
Crew Safety Norms	(Bock et al., 2005)	The extent to which crew members hold each other accountable for safety and the supervisor has strong expectations for everyone in the crew to behave safely.	My crew members hold each other accountable for following safety protocol My supervisor expects that everyone within my crew makes good decisions with respect to safety I feel a lot of social pressure within my crew to put safety first
Equity of Work Contributions	(O'Neill et al., 2020)	A measure of how appropriate crew members' contributions are to the crew's work.	Crew members put in the appropriate amount of effort for their assigned tasks Crew members uphold their commitments to the crew

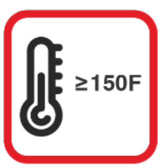
Crew Trust	(O'Neill et al., 2020)	Level of trust among members of a crew in terms of making safe decisions and behaving safely.	In this crew we have a high degree of trust in each other's safety behaviours In this crew, we trust everyone to make safe decisions Crew members keep their word with each other
Respite	Developed for study	Individual's perception of getting sufficient rest and relief during their non-working hours.	I am satisfied with my shift rotation
Psychological Safety	(Edmondson, 1999)	The extent to which an individual feels it is safe to speak up, surface concerns, and disagree openly without fear of negative repercussions or pressure to conform.	If you make a mistake on this crew, it is often held against you My supervisor doesn't hold it against me if I make a mistake Members of this crew are able to bring up problems and tough issues No one on this crew would deliberately act in a way that undermines my efforts
Learning from Mistakes	Developed from (Frese & Keith, 2015)	The extent to which crews learn, generate new insights, and make adjustments after mistakes are made.	In our crew, we find that errors are very helpful ways to learn how to improve In our crew, we will often get our best ideas after making mistakes and learning from them In our crew, we use errors and mistakes as ways of evaluating our new ideas or procedures
Perceived Job	(De Witte,	How confident an individual is	I feel insecure about the future of my job

Insecurity	2000)	that they will keep their job in the future.	I think I might lose my job in the near future
Safety Behaviour (Intentions)	Developed for study	The crew's prioritization of, and attention to, safety behaviour in the workplace.	My crew is committed to following all safety rules and regulations, even if it takes extra time. My crew would report any unsafe conditions or practices that we notice, regardless of the consequences to myself or my crew My crew prioritizes the safety of myself and my crew members over productivity

Appendix C - Hazard Icons, exposures, and risk perceptions

Individual workers' risk perceptions of specific hazards for all companies and sites. Comparing these to the hazard inventories of their work would determine if they are accurately identifying hazards and controlling their exposures.

	I am exposed to this hazard routinely	There are controls in place	I am afraid this hazard will hurt me or someone else	This hazard does not apply to me
 ARC FLASH	8.3%	38.2%	3.6%	56.3%
 CHEMICAL / RADIATION	5.8%	35.5%	3.1%	60.0%
 COMPRESSED GAS AND STEAM	7.3%	43.0%	3.5%	51.0%
 ELECTRICAL CONTACT	11.9%	56.6%	3.9%	34.6%
 EXCAVATION OR TRENCH	7.9%	37.9%	2.6%	56.8%

	I am exposed to this hazard routinely	There are controls in place	I am afraid this hazard will hurt me or someone else	This hazard does not apply to me
 EXPLOSION	7.8%	45.5%	5.9%	47.3%
 FALL FROM ELEVATION	20.5%	70.1%	4.7%	16.3%
 FIRE	16.0%	78.1%	8.9%	9.4%
 HIGH TEMPERATURE	13.9%	54.3%	4.0%	36.1%
 LINE OF FIRE	34.6%	72.8%	10.8%	4.2%
 ROTATING EQUIPMENT	21.8%	62.6%	5.1%	24.7%

	I am exposed to this hazard routinely	There are controls in place	I am afraid this hazard will hurt me or someone else	This hazard does not apply to me
 SUSPENDED LOAD	13.5%	47.4%	4.4%	46.5%
 VEHICLE INCIDENT	37.1%	71.5%	12%	4.4%
 TRUCK COLLISIONS	42.7%	66.3%	17.8%	3.8%
 WATER AND ICE	13.5%	52.6%	6.3%	39.7%
 WILDLIFE	31.1%	77.7%	8.7%	4.2%