Protecting Worker Safety in Alberta by Enhancing Hazard Identification and Control for Hazards Associated with Tailings Facilities, Dams, and Systems

by

Kathleen Elizabeth Nowlin Baker

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science
in
Chemical Engineering

Department of Chemical and Materials Engineering
University of Alberta

Abstract

My research was motivated by a fatality that occurred at an oil sands tailings operation on January 19, 2014, when a worker drowned in an underground cavern which formed under a leaking tailings transport system. At the time of the incident, the organization and workers did not know that ground hazards such as this could manifest. A further investigation of the regulations, best practices, and academic literature revealed a dearth of published information on worker safety specific to tailings and on the identification and control of unseen/unknown hazards. Thus, I asked the following research question: *are current hazard identification tools and processes in the oil sands tailings operations enabling workers to identify hazards and effectively control them?*

To answer this question, methods were developed to collect and analyze four datasets: a tailings safety expert hazard inventory; interviews with frontline workers, leadership, and regional contractors; multiple company incident databases related to tailings; and a ground hazard assessment. Well-known process safety Bow Tie diagrams were used to organize and analyze the tailings safety expert hazard inventory. A total of 158 people representing multiple oil sands companies and regional contractors were interviewed to determine the hazards they see in their operations and their suggestions to enhance worker safety. Over 1500 incidents from multiple oil sands companies were studied to determine the types and frequencies of incidents being reported. These four datasets were compared and corroborated the findings in the literature: worker safety in tailings is overlooked and enhancements are needed to current hazard identification tools to better equip workers to identify unseen/unknown hazards. To address these gaps, enhancements to current hazard identification tools were created using ground hazards as a case study. A ground hazard assessment was completed in summer, winter, and spring to identify how ground hazards manifest in the tailings operations.

My research provided practical, empirical, and theoretical contributions to academia, the oil sands industry, and the mining and process industries more broadly. I improved the current understanding of oil sands tailings operations and provided eight recommendations to the tailings industry to better protect workers. I also created enhanced hazard identification tools specially for ground hazards, but the methods used could be applied to other previously unseen/unknown hazards. I added to the literature on hazard identification in dynamic environments and organizational theory on wrongdoing. Finally, I created two novel case studies—application of external risk communication strategies to internal audiences to increase knowledge of ground hazards and decrease risk tolerance, and application of a well-known Process Safety Management tool, so-called Bow Tie diagrams—to holistically identify hazards. These contributions are not only applicable to oil sands tailings but to the oil sands, mining, and process industries more broadly.

Preface

The creative sentencing research project, of which this thesis forms a part, received research ethics board approval from the University of Alberta Research Ethics Board (Project Name "ASGPS Court Order 160045464P1", Project No. Pro 00075129; Original Approval: August 11, 2017; Renewal Approval: August 7, 2018; Expiration Date: August 6, 2019).

This thesis consists of four papers that I collaboratively wrote with the principal investigators of the study: Drs. Macciotta, Hendry, and Lefsrud. The design of the study was a collaborative effort, with Drs. Macciotta and Hendry leading the site visits and development of the methods for the ground hazard assessment. They also proposed the development of a ground hazard framework and photo databases that included representative facilities in the oil sands tailings operations as well as temporal factors and precursory conditions. Dr. Lefsrud provided the methods for conducting and analyzing the interviews utilizing QSR NVivo 12.0 text analysis software, and organized the collection of the company incident database. The Energy Safety Canada tailings safety task force provided the initial methods for the creation of the tailings hazard inventory. I developed the methods for the analysis of the company incident database and the tailings safety expert hazard inventory. I assisted in the collection of the majority of the data: Dr. Lefsrud and I conducted the 158 interviews; I was present on 50% of the site visits with at least one of the principal investigators and the geotechnical research assistant (Ms. Julie Zettl) (the remaining site visits were conducted by Ms. Zettl and Drs. Hendry or Macciotta); and I was provided incident data by oil sands operator companies and a hazard inventory from Energy Safety Canada. I completed the analysis of all four datasets, with assistance from Ms. Zettl and Drs. Macciotta, Hendry, and Lefsrud. I was the lead author of all four papers with comments and feedback provided by the principal investigators.

Chapter 1 of this thesis, in its entirety, is my original work.

Chapter 2 of this thesis will be submitted to The Crown on March 22, 2019. It will be made public upon its approval. The interim report, upon which the final report is based, is already in the public domain and can be found here: https://doi.org/10.7939/R3BR8MX04. I was responsible for data collection (as stated above), data analysis, and report composition. Drs. Macciotta, Hendry, and Lefsrud provided assistance with data collection (as stated above), assisted with data analysis, and contributed to report edits. Mr. Gord Winkel also contributed to report edits.

Chapter 3 of this thesis is based on an accepted peer-reviewed abstract for the Centre for Risk Integrity and Safety Engineering Workshop/Symposium (C-RISE) to be held in St. John's, Newfoundland. The paper was submitted for peer review on February 25, 2019. I was responsible for data collection (as stated above), data analysis, and manuscript composition. Drs. Macciotta, Hendry, and Lefsrud provided assistance with data collection (as stated above), assisted with data analysis, and contributed to manuscript edits.

Chapter 4 of this thesis is also based on an accepted peer-reviewed abstract for the C-RISE Workshop/Symposium to be held in St. John's, Newfoundland. The paper was submitted for peer review on February 25, 2019. Energy Safety Canada provided the original dataset. I conceived the methods and completed the data analysis and manuscript composition. Drs. Macciotta, Hendry, and Lefsrud provided assistance with data analysis and contributed to manuscript edits.

Chapter 5 of this thesis is based on an accepted peer-reviewed extended abstract for the European Group of Organizational Studies Colloquium, in Edinburgh, Scotland. The extended abstract was approved on February 9, 2019. I completed data collection with Dr. Lefsrud, data analysis with assistance from Dr. Lefsrud. I wrote a draft manuscript to which Dr. Lefsrud provided critical theoretical and intellectual content. The additions to this abstract, as seen in this thesis, are my own original work. This is a working paper and will be edited prior to full paper submission for peer review on June 15, 2019.

Dedication

This thesis represents a career pivot, where I left a full-time permanent job to return to school and pursue a Master's degree. I want to help people by using my technical engineering skills, passion for safety, and empathy; this research project combined my passions and allowed me to do just that. I will forever be thankful for this opportunity. Many people spend their lives searching for their dream job, and I am grateful that I was able to find mine early in my career.

Returning to school was not an easy decision. Without the support of my family, I never would have had the courage or freedom to pursue my goals. Thank you all for your support, guidance, and pride.

To Steve, my husband, who has supported me through the sinusoidal wave that was my degree. You challenge me to be a better person and partner. You encourage me every day, whether for my personal fitness goals, love of travel and adventure, or completing my Master's degree. You are always there, cheering me on.

To Jill and Tom, my parents, who provided me with opportunities and advice, never judgement. As I grow older, I am realizing how special it is to have their unwavering support.

To Vernice, Chuck, Max, Gail, and Rosemary, my grandparents, who never once told me that it was a bad idea to return to school. Instead, you actively encouraged me to return, providing all the support you could offer. Your presence in my life motivates me daily.

To Daniel, my brother, whose pursuit of an undergraduate degree in geology with passion and love for your chosen career inspired me to return to school and pivot my career, so I could feel the same.

To the amazing support network of women in my life who have inspired and supported me.

Acknowledgements

I have been so fortunate to have worked with three amazing supervisors over the course of this project. I am extremely grateful for the opportunities, guidance, and support that my supervisor, Dr. Lianne Lefsrud, has provided me. Through her mentorship, not only have I been able to influence sustainable change but I also improved my professional and engineering skills. Drs. Michael Hendry and Renato Macciotta were always so supportive of my research and ready to brave −45 °C to complete our fieldwork. All three mentors challenged me to be a better engineer and researcher in their own unique ways. I am so thankful to have had the opportunity to work with them.

I would like to thank Tom Baker for his editorial and proofreading assistance. I would also like to thank Julie Zettl for her assistance with the geotechnical data analysis and contributions to the interim report.

This project would not be nearly as impactful nor sustainable without the support of the oil sands tailings industry through Energy Safety Canada. Energy Safety Canada provided valuable information to this research project and the participating companies were generous with their time and resources. This research would not have been possible without the involvement and cooperation of the oil sands industry and regional contractors. The level of collaboration that I witnessed over this two-year project is unprecedented, and steps have already been taken to ensure that it continues.

I would also like to thank Gord Winkel for his guidance and feedback during the research process and on final documents. He was an absolute pleasure to work with.

Finally, I would like to thank the participating companies who also provided extensive in-kind support, from field visits to interview participants to their employees who took the time to answer any questions we had. This study would not have been completed without their participation.

Table of Contents

List of Tables

List of Figures

List of Enlarged Photos from Ground Hazard Database

Chapter 1: Introduction, Background and Overall Conclusions

Kathleen E. Baker
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
kebaker@ualberta.ca

Introduction

In the five-year period from 2011 to 2015, a total of seven fatalities occurred in the oil sands subsector in Alberta (Government of Alberta, 2017). One of these fatalities occurred at 6:00 am, January 19, 2014, at an oil sands tailings operation in the Athabasca oil sands region of Fort McMurray (OHS, 2017a). During a routine check of a leaking pipeline, a worker drowned in an underground cavern that was hidden by snow- and ice and further masked by the early morning darkness (OHS, 2017a). This cavern was created by hot tailings discharge (process water, sand, and residual bitumen) leaking from a pin-sized hole in a tailings transportation line (OHS, 2017a). The worker had followed standard operating procedures, e.g., call-in procedures and use of personal protective equipment (OHS, 2017a). Other hazard mitigations were also in place, such as leak detection; however, this particular ground hazard (the underground cavern) was previously unknown to workers (OHS, 2017a). The assumption was that a pipeline leak in the winter would be evident from the steam that would result due to the temperature differential between the hot tailings and the cold ambient air. As the tailings were draining elsewhere from the cavern, little or no steam was being emitted at the leak site and there were little to no indicators of the hazards to which the worker was being exposed (OHS, 2017a). In addition to this fatality, at least 49 other hazardous occurrences were identified in the tailings industry in British Columbia from 2000-2014 (Hoekstra, 2014). These incidents ranged in severity from the Mt. Polly tailings dam failure in 2014 to loss of containment events confined to mine sites (Hoekstra, 2014). Incidents such as these illustrate the ineffectiveness of current hazard mitigations, specifically in oil sands tailings operations. The current tools that are in place, e.g., "Life-Saving Rules" (ESC, 2018b) and Field Level Hazard Assessments, are insufficient to identify or control all the hazards that are manifesting in these operations. These tools are designed for hazards that are known to organizations and workers; they are not designed to see the unseen.

Risk mitigation strategies for tailings operations tend to focus on the prevention of catastrophic failures, such as the Mt. Polley tailings dam breach (Government of Alberta, 1999, 2000, 2015a; Mining Association of Canada, 2011). Three articles from China specifically discuss worker safety in tailings operations (Wei et al., 2003; Li et al., 2010; Tang et al., 2012). These articles discuss environmental and public safety as well as discrete aspects of worker safety in tailings such as geotechnical hazards and safety culture, but do not analyze the interactions of these various factors. Although there are minimal specific discussions of worker safety in tailings operations, there is a burgeoning field in academia analyzing worker safety and the potential for unknown/unexpected hazards in the construction and pipeline industries (Carter & Smith, 2006; Ramsay et al., 2006; Bahn, 2013; Perlman et al., 2014; Jeelani et al., 2016; Stackhouse & Stewart, 2016). The Occupational Health and Safety (OH&S) legislation provides some general guidelines for how workers should identify hazards in their work environment (i.e., using a field level hazards assessment tool), but the focus is on managing and mitigating known job-related hazards (OHS, 2009 and 2015). Discussion on unknown or unexpected hazards is lacking.

The academic literature recognizes that workers can find it difficult to identify hazards in their work environments, especially when the hazards are previously unknown or the job site is dynamic (Jeelani et al., 2016). This lack of identification is exacerbated for new workers, who are unable to identify 53% of hazards in their work environments (Bahn, 2013). Unidentified hazards are leading to hazards that are not being effectively mitigated, which can cause incidents and even fatalities in the workplace. Hazards can be further hidden as a result of safety analysis that typically featuring discrete entities, e.g., process safety managing process hazards, OH&S managing high-frequency hazards that affect workers, and behavioural safety focusing on human factors (Stranks, 2007; Khan et al., 2015). Another factor identified in the literature is the lack of identification of hazards due to normal organizational wrongdoing (Palmer, 2012) or normalization of deviance (Vaughan, 1996). These two organizational theories suggest that workers are ignoring standards and procedures that have been implemented by the company, which leads to the occurrence of incidents.

To protect workers, the level of hazard identification must be increased to better control hazards in their work environments. Increasing hazard identification and risk mitigation is done by utilizing risk communication strategies and different approaches to safety, such as process safety management, OH&S, and behavioural safety. Researchers such as Sandman (1987), Slovic (1987), and Kasperson et al. (1988) wrote some of the seminal literature regarding the communication of risk from organizations to the public; this thesis supports the application of these communication strategies between organizations and their workers. Risk communication serves to increase the knowledge of a hazard and decrease the risk tolerance.

Companies, especially in the oil sands, are allocating many resources to the safe operation of their facilities through programs such as "Life-Saving Rules" and "Get a Grip on Safety" (ESC, 2018a, b). However, the relentless occurrence of incidents in the industry and the review of the current literature show more work is clearly needed to address the potential for unknown and unseen hazards, such as the one that caused the fatality mentioned at the beginning of this section. Thus, my research asks the following question: *are the current hazard identification tools and processes in the oil sands tailings operations enabling workers to identify hazards and effectively control them?*

My thesis consists of an introduction and four thesis papers. This introduction aims to provide background and context for each paper in the larger research project and to elaborate on any literature that was not included in the papers. Each of the four papers provided as part of this thesis addresses different aspects of my research question and outcomes. All are based on the same four datasets collected as part of the larger research project: a tailings safety expert hazard inventory; interviews with 158 frontline workers, leaders, and regional contractors; company incident databases related to tailings; and a ground hazard assessment. The datasets were collected over 8 months (from August 2017 to April 2018). The case studies created are based on ground hazards as my research is motivated by the 2014 fatality. My analysis of the datasets concluded that current hazard identification tools are not adequate to identify previously unseen/unknown hazards because: worker safety is not the focus of most risk mitigation strategies; the potential for unseen hazards is not discussed in regulations; workers find it challenging to identify hazards in their workplace regardless of if they are known or unknown; unsafe acts by workers are cited as the main cause of incidents as opposed to systemic cultural problems; safety approaches are disjunct, causing hazards to be hidden in the boundaries of these approaches; and companies are creating unintentional blindness through ambiguity, uncertainty, and complexity in their operations. Risk communication strategies such as stakeholder engagement, use of visual tools, and tailings-specific training can be used to increase the awareness of hazards.

My thesis makes practical, methodological and theoretical contributions to the oil sands, mining, and process industries and academia by: providing mixed-methods to better control and communicate the risks of unseen/unknown hazards in any industry; analyzing the current literature on safety culture, tailings, and hazard identification and integrating and enhancing these individual findings to better protect worker safety; increasing the understanding of hazards in the oil sands tailings industry; offering enhanced hazard identification tools to assist in the hazard identification process and make unseen hazards seen; providing a new precedent for worker safety in tailings; proposing case studies for the uncommon use of Bow Tie diagrams to holistically identify hazards and the application of external risk communication strategies to an internal audience; and, finally, extending the literature on hazard identification and causes of wrongdoing in the dynamic work environments of heavy industry.

Following this introduction, the structure of the thesis will be presented, followed by a background. The gaps identified will be discussed and the resulting research outcomes presented. The four thesis papers will be introduced to provide context to the reader within the larger research project. My thesis concludes with a discussion of my practical, methodological and theoretical contributions to industry and academia.

Background

My research is motivated by the 2014 fatality described in the Introduction. For the full Occupational Health and Safety report, please refer to Appendix A. Traditionally, the company on whose work site the incident occurs is charged a punitive fine by The Crown (Sorensen, 2018). This is called a traditional sentence. However, another type of sentencing is being used in Alberta called a creative sentence. A creative sentence is a "form of restorative justice", where The Crown is afforded more options to address root causes of the incident through funding of research or development of health and safety training instead of monetary fines (Sorensen, 2018). In this case, the creative sentence funded research into ground hazards associated with tailings storage and transport facilities. The goal of this creative sentence is to inform current best practices to decrease the likelihood of a similar situation from occurring again. This research project represents an initiative between the oil sands industry, the Government of Alberta, and the University of Alberta. The Crown outlined three main deliverables as part of the creative sentence: (1) dissemination of information, through academic and industrial conferences, workshops, and publications; (2) an interim report, marking the halfway point of the project in March 2018; and (3) a final report, to provide a thorough review of the research conducted as part of the creative sentence and the tools developed to increase ground hazard awareness. This next section provides background information to position this thesis in relation to the existing literature. Detailed literature reviews are provided with each of the four thesis papers.

Safety and risk management of tailings storage and transport facilities and worker safety in tailings

The Mt. Polley tailings dam failure in 2014 is an example of the type of incident that Canadian tailings dam risk managers are attempting to avoid through a focus on the performance and operation of tailings structures (Morgenstern et al., 2015; Hoffman, 2015; Chambers, 2016). This incident had devastating impacts on the environment and the public (Chambers, 2016). The current regulations in Alberta and industrial best practices (e.g., Canadian International Mining guidelines) focus on the performance of these tailings structures and on future reclamation requirements (Government of Alberta, 1999, 2000, 2015a; Mining Association of Canada, 2011). This is important work, but is very different from risk management for workers and therefore does not directly extend to personal safety risks. Only one report was found that discusses worker safety and oil sands, albeit without specific mention of tailings (Government of Alberta, 2009). The Alberta Occupational Health and Safety Code provides information for the identification of hazards, but the discussion of unseen/unknown hazards is vague (OHS, 2009 and 2015). The same dearth of information is found when searching for academic articles. Three articles from Chinese research groups discuss worker safety and tailings directly but they focus on individual factors that affect worker safety, like laws and regulations, design of tailings structures, technical hazards, and human and environment factors, but not how they interact, (Wei et al., 2003; Li et al., 2010; Tang et al., 2012). Tang et al. (2012) briefly discusses the potential for hidden hazards, but does not provide actionable solutions that will help to provide clarity during the hazard identification process. Other industries such as construction and pipelines have started to enhance worker safety by discussing hazard identification and mitigation (Carter & Smith, 2006; Ramsay et al., 2006; Bahn, 2013; Perlman et al., 2014; Jeelani et al., 2016; Stackhouse & Stewart, 2016).

Hazard identification

Hazard identification is part of the risk management process where factors or conditions that could cause an incident are identified (Winkel et al., 2017). This process utilizes tools such as Field Level Hazard Assessments (FLHAs) to identify hazards and ensure the proper controls have been implemented prior to work starting. The typical hazard identification process begins with a worker identifying the hazard (Chen et al., 2013; Albert et al., 2014; Hallowell & Hansen, 2016; Jeelani et al., 2016). The next step in this process is risk perception. External and internal factors such as worker state of mind (e.g., rushing, frustration, fatigue, or complacency), inattention, and training or knowledge of hazards affect an individual worker's perception of risk (Sylvester, 2017). Once the hazard is identified and perceived, the hazard identification tool, e.g., FLHA, will direct the worker to determine if the risk level is acceptable. If the worker deems the risk level acceptable, they will begin work; if not, they will implement additional means to control the hazard prior to beginning work. Each worker will consciously or subconsciously decide if they tolerate the risk or not. Similar to risk perception, risk tolerance is also influenced by internal and external factors and is heavily influenced by a person's values and beliefs (Slovic, 1987). If the worker determines that more controls are needed, they will follow the hierarchy of controls—a systematic method where the most effective controls are implemented first, followed by the less effective options (Amyotte et al., 2009). This method is also applied during the design phase to ensure that the processes operate at a risk level that is as low as reasonably practicable. Elimination or substitution is the most effective method to manage risk, followed by engineering controls, administrative controls, and personal protective equipment.

Current hazard identification tools assume that workers and managers have the skills and knowledge to effectively and accurately complete hazard identification to control hazards and begin work (Bahn, 2013). Multiple studies (Carter & Smith, 2006; Ramsay et al., 2006; Bahn, 2013; Perlman et al., 2014; Jeelani et al., 2016) show that most workers and managers are not equipped to adequately identify hazards, especially unknown hazards. Jeelani et al. (2016) discuss factors that make it challenging for workers to identify hazards and can lead to hazards being unseen. These 14 factors include: dynamic environments, unfamiliarity with tools, hazards unassociated with the primary task, low perceived levels of risk, premature termination of hazard recognition, unexpected hazards, visually unperceivable/obscure hazards, unknown hazards, selective attention or inattention, multiple hazards associated with a single source or task, task unfamiliarity, latent and stored energy hazards, hazard source detection failure, and hazards without immediate outcome onset (Jeelani et al., 2016).

Risk communication

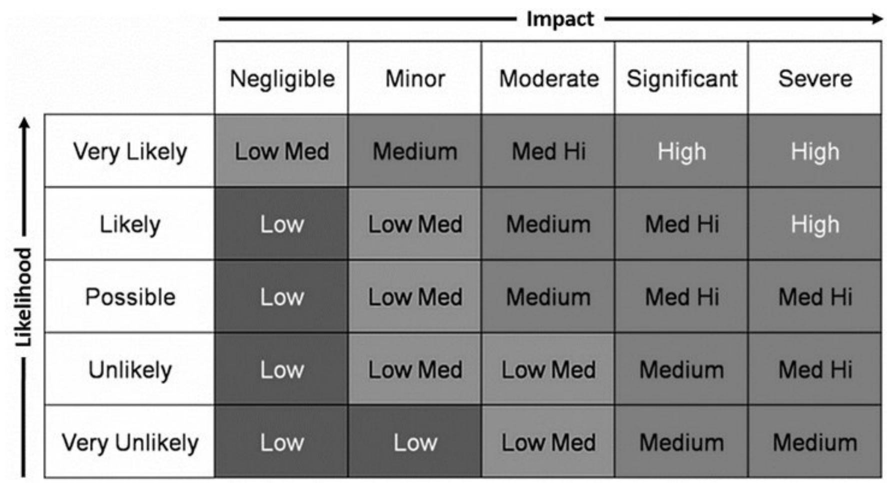
Before beginning the discussion of risk communication, stakeholders are best served by defining what is meant by risk. Every industry, company, and person has a different definition of risk, be it financial risk, occupational health and safety risk, environmental risk, or societal risk (APEGA, 2006). Typically, risk is defined as the probability of an event multiplied by consequence (ISO,

2002) that could lead to a loss related to worker well-being, assets, environment, economy, reputation, or productivity (APEGA, 2006).

As with risk, it is challenging to find a concise definition of risk communication; many industries (and individuals) have their own interpretation of risk communication and how the approach should be executed. Even within the risk communication community, consensus on a definition is difficult. Lundgren & McMakin (2013) define risk communication as "the communication of some risk" (pg. 2) and discuss the challenge of defining risk communication due to the potential for the risk, topics, communications, and audience to be diverse. In its most basic terms, risk communication is "informing people about potential hazards to their person, property or community" (EPA, 2018: https://www.epa.gov). Health Canada has a more elaborate definition: "risk communications is defined as an exchange of information concerning the existence, nature, form, severity or acceptability of health or environmental risks. Strategic risk communications can be defined as a purposeful process of skillful interaction with stakeholders supported by appropriate information" (Health Canada, 2007: https://www.canada.ca).

Traditionally, risk communication is thought of as external; from an organization to the public. Numerous publications discuss effective external communication (Sandman, 1987; Slovic, 1987; Kasperson et al., 1988; Morgan & Lave, 1990; Fischhoff, 1995; Jardine, 2008; Renn, 2010; Lundgren & McMakin, 2013; to name a few), where information is passed from an organization to the public or external stakeholders. The goals of this type of communication can be to: decrease the number of smokers (Slovic et al., 2005); get people out of harm's way as fast as possible (Morgan & Lave, 1990); or inform people about a food-borne illness such as listeria (Mikulsen & Diduck, 2013). Even with all this risk communication literature, relatively few publications address communication within a company from an organization to its workers or internal stakeholders such as workers and contractors. This is called "internal risk communication" (Schulte et al., 1993; Bahn, 2013; Jeelani et al., 2016). Most of the literature that discusses internal risk communication uses an industrial hygiene lens (Lundgren & McMakin, 2013). Much of the literature on external risk communication can be applied to internal risk communication to workers as their goals overlap. The goals of internal risk communication to workers are twofold: (1) ensure workers are aware of the risks in their working environment so they can identify the hazards and (2) decrease risk tolerance to make workers more mindful.

Visuals (e.g., photographs, videos, graphs, images, illustration), can be a useful tool to increase awareness of a hazard. Risk matrices immediately come to mind when discussing visuals in risk communication. Risk matrices are a way to visualize, quantify, and summarize the risk and communicate it to a broader audience (Hopkin, 2018). This visual tool makes information intuitively understandable and has been adopted as a way to communicate risks across the oil sands industry. An example of a typical risk matrix is shown in Figure 1.



	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

Figure 1. Example of a typical three by three risk matrix (PMBOK, 2017).

Risk matrices are also an example of a boundary object or a visual tool used to connect disciplines, communicate information, and promote interdisciplinary problem solving (Allen et al., 2018; Coslor, 2018). Boundary objects can be useful in situations where information is ambiguous, uncertain, and spans multiple disciplines (Höllerer et al., 2018). Visuals are exceptionally useful as they are not tied to the same rules as language (Halgin et al., 2018). Other examples of boundary objects in the oil sands industry are safety banners ("Get a Grip on Safety"; ESC, 2018a) and visual aid signs (e.g., "Personal Protective Equipment Required In This Area"). Successful communication can be achieved when visuals are used in thoughtful and purposeful combination with text and verbal forms of communication (Watzman, 2002). Additional literature discusses the increased retention and understanding of information when visuals are combined with other forms of communication, such as words, into multimodal messages (Albert et al., 2014; Lefsrud et al., 2016; Halgin et al., 2018; Höllerer et al., 2018). Visuals have been shown to be very effective at helping people understand the content and remember risks when processing information (Höllerer et al., 2013; Lundgren & McMakin, 2013; Boxenbaum et al., 2018; Christiansen, 2018). Another study found that retention is increased by 65% by pairing verbal information with a photo (Kouyoumdjian, 2012), illustrating the unique value of a picture when communicating.

Risk tolerance can be decreased by applying a well-known external risk communication approach: Sandman's *Hazard Plus Outrage* approach. Sandman (1987) states that risk is not merely likelihood times consequence. He believes an outrage factor can increase or decrease how people feel about a threat—a phenomenon also called risk perception. Sandman found these outrage factors could cause the public to have an elevated perceived risk level towards a hazard even if the technical risk level is low. These factors of voluntariness, control, fairness, process, morality, familiarity, memorability, dread, and diffusion in time and space can elevate but also attenuate a perceived risk level. Sandman (2012) also discusses precaution advocacy, where the goal is to arouse a healthy level of outrage and use that outrage to motivate people to take precautions. He also notes that motivating people is challenging, especially in the workplace as any safety campaign will eventually become familiar and lose effectiveness. As a solution to this problem, Sandman recommends decreasing the familiarity with a situation to make workers more cautious and communicating to workers the volatility of the operations to remind them that the hazards can change very quickly.

Combining visuals and Sandman's *Hazard Plus Outage* approach can increase hazard knowledge and decrease risk tolerance, but there is no guarantee of successful implementation of the risk communication message. Stakeholder engagement should be used to increase the likelihood of adoption of this message. Jardine (2008) discusses the importance of stakeholder collaboration when communicating risks; this is especially important with workers as they are the people who are interfacing with the hazards on a daily basis and may have solutions to mitigate risks. Unfortunately, stakeholder involvement in the development of risk communication messages is dominated by the technical professionals who are conducting risk assessments and interface with the hazards relatively infrequently (Jardine, 2008). Organizations are beginning to see the benefits of stakeholder collaboration. With increased open, two-way discussion between organizations and workers, alternative solutions to mitigate risks are being developed (Jardine, 2008). A few essential items should be remembered when soliciting feedback from stakeholders: every situation is unique and the goal of the stakeholder participation needs to be defined; stakeholder involvement must be meaningful so participants know their opinions matter and are being considered; and, above all, there should be respect and trust between all involved parties (Jardine, 2008).

Combined approaches to safety including process safety management, occupational health and safety, and behavioural safety

There are different approaches to identifying hazards in organizations based on the potential consequence or frequency. Three approaches to safety will be discussed here: process safety, occupational health and safety (OH&S), and behavioural safety. Typically, these three are discrete approaches, where hazards are assessed and managed in isolation.

Process Safety Management (PSM) is a systematic approach to identify hazards in the process industry and prevent catastrophic releases of chemicals or energy (CCPS, 2018b). PSM typically identifies and controls high consequence, low likelihood hazards, such as explosions, that have the potential to impact multiple workers, the public, environment, and organizational assets or production (Amyotte et al., 2009). PSM became a burgeoning field of engineering study with a surge in the 1970s after Flixborough (1974) and Seveso (1976) (as cited in Kerin, 2017).

OH&S focuses on protecting individual lives (i.e., preventing serious injury or death) from high frequency, relatively low consequence events and ensuring that workers are physically, mentally, and socially able to do their work (Davidson, 2018). OH&S has been evolving ever since the Industrial Revolution (Pryor, 2012). This field is well established but continues to evolve to better protect workers; this is necessary because incidents are still occurring despite all the good work and resources that have contributed to OH&S.

Behavioural safety investigates the impacts of organizational cultural on safety (Wirth, 2017; Davidson, 2018). It also looks at the behaviours of workers and leadership and their effect on safety, also known as 'human factors' (Stranks, 2007). Behavioural processes such as normalization of deviance and complacency impact the effectiveness of controls and could lead to the manifestation of a hazard (Ludwig, 2017).

All these approaches to safety have decreased the number of incidents (U.S. Department of Labor, Bureau of Labor Statistics, 2016), but fatalities are still occurring. More hazards could be identified by bridging the gaps between these approaches to safety (Kerin, 2017). To exacerbate this plateau fatality reduction, current approaches to safety are not designed to identify unknown hazards or deficiencies in safety culture (Davidson, 2018). Process safety is a process control problem, but component issues alone do not cause incidents; instead, they are caused by a myriad of factors such as human interaction, making theories such as the holistic sociotechnical approach to safety an excellent approach to increase the overall performance of the system. Such theories provide a solution to this discrete analysis and promote a holistic view of the operations, where the safety of the whole operation is analyzed together. External inputs to the system, such as the dynamic conditions in the working environment, humans interacting with the system in unique ways, and different demands of the system from various levels within the organization (regulatory compliance, safety regulations, productivity, etc.), also suggest a systems approach to process safety (Leveson & Stephanopoulos, 2014). The identification of previously unknown hazards could increase by applying a systems approach to safety and increasing the amount of interdisciplinary sharing and application of existing tools in atypical situations.

Normal organizational wrongdoing and deviance

With recent and troubling reports discussing large-scale catastrophic incidents such as the Kunshan dust explosion in 2014, Fukushima-Daiichi nuclear disaster in 2011, and BP Deepwater Macondo Blowout in 2010, organizational wrongdoing seems endemic, unmanageable, and unavoidable. However, organizational wrongdoing is often not obviously remarkable nor intentional, without clear-cut responsibilities and latent causes. Much of the current literature presumes intentionality when discussing organizational wrongdoing. Whether wrongdoing is good or evil (Brief & Smith-Crowe, 2016), involving deviance as a choice (CCPS, 2018c) or moral evaluation (Van Halderen & Kolthoff, 2016) these theories include some sort of purposeful, negative human intention when taking actions that engage in wrongful behaviour.

The phenomena described above are often referred to as the ‘normalization of deviance’. This concept first emerged after Diane Vaughan published *The Challenger Launch Decision: Risky technology, culture, and deviance at NASA* in 1996. This concept has been applied to many other industries, including financial (Nolke & May, 2018) and nuclear (Perrow, 1979), and was recently the topic of a publication from the Center for Chemical Process Safety of the American Institute for Chemical Engineers (CCPS, 2018c). Another organizational theory by Palmer (2012) is similar to normalized deviance but is called ‘organizational wrongdoing’. Palmer describes two distinct paths that lead to wrongdoing within organizations: perverse structures and processes and pervasive structures and processes. Other researchers such as Harrington (2018), Brooks and Spillane (2017), Götz et al. (2019), and Marasi et al. (2018) have begun to propose alternative frameworks for how wrongdoing and deviance manifest in organizations. Harrington (2018: pp35) proposed that "professional society, the state and globalization" influence wrongdoing whereas Brooks & Spillane (2017: pp1) discuss an unintentional communication disconnect from management to the 'quality on the ground' and this effect on wrongdoing in the workplace. Götz et al. (2019) noted that "people adjust to their own standards to external norms, suggesting they should converge over time" and, yet, this is also not illustrated in current models on workplace deviance. Marasi et al. (2018: pp25) discuss the organizational structure's effect on deviance in the workplace.

The organizational theories for wrongdoing and deviance all appear to echo each other in that humans make a choice to do right or wrong (Griffin & Lopez, 2005; Larkin & Pierce, 2015; Brief & Smith-Crowe, 2016; Assadi, 2018). They also mostly discuss 'white collar crime', such as fraud (Cooper et al., 2013; Friedrichs, 2015), tax evasion (Harrington, 2018), and insidious behaviours such as bullying (Vardi & Weitz, 2016).

Gaps Identified

Based on the analysis of the current literature, my coauthors (Drs. Macciotta, Hendry, and Lefsrud) and I identified the first two gaps: (1) even with all of the risk mitigation controls and hazard prevention programs in place, incidents still occur (Hoekstra, 2014; OHS, 2017a); and (2) the current risk management of tailings facilities tends to focus on the potential for catastrophic failures, not worker safety (Government of Alberta, 1999, 2000, 2015a; COSIA, 2012; Mining Association of Canada, 2011). This second sentiment is echoed by the limited discussion of worker safety in tailings in both academia and industrial best practices (Government of Alberta, 1999, 2000, 2015a; Wei et al., 2003; Li et al., 2010; Mining Association of Canada, 2011; COSIA, 2012; Tang et al., 2012). I conducted a further literature review and found that current hazard identification tools and OH&S regulations do not fully address the potential for unseen/unknown hazards as three of the seven fatalities that occurred in the oil sands subsector were related to unseen hazards (OHS, 2009 and 2015; Government of Alberta, 2017). Academics have shown this is because current hazard identification tools are designed for known hazards (Bahn, 2013). Thus, I ask, *are the current hazard identification tools and processes enabling workers to identify hazards and effectively control them?*

To answer this research question, I set out to determine if current hazard identification tools in oil sands tailings operations are effective. This question, the collection and analysis of preliminary datasets, and the subsequent findings provided the groundwork for further gap identification and development of research outcomes. The identified gaps, related research outcomes, and thesis papers are presented in Table 1. Following Table 1, I describe the identification of subsequent gaps, development of research outcomes, and methods to address the former and latter.

Table 1. Identifying gaps in the current hazard identification literature and resulting research outcomes.

No.	Gap identified	Research outcome	Addressed in paper(s)
I	Incidents are still occurring, despite the programs and controls that are in place	To determine if current hazard identification tools are effective	1
II	Risk management tends to focus on the potential for catastrophic failures, not worker safety	To increase discussion of worker safety in tailings	1, 2, 3, 4
III	Current hazard identification tools and OH&S regulations do not fully address the potential for unseen/unknown hazards	To develop methods for the enhancement of current hazard identification tools to better equip workers to see previously unseen/unknown hazards and effectively control them	1, 2, 3, 4
IV	The risks in the tailings operations are not being effectively communicated to workers	To create visual tools to increase the knowledge of hazards and decrease risk tolerance	1, 2, 3
V	Standard method is to analyze safety as discrete approaches	To present a case study combining approaches to safety to address hazards that were previously unidentified	3
VI	Current literature points to wrongdoing and normalized deviance as causes for hazards not being identified or reported	To determine why hazards are not being identified and/or reported (i.e., why hazard identification tools are not effective)	2, 3, 4

Gap identified and research outcome I—To determine if current hazard identification tools are effective

Based on the first identified gap (i.e., incidents still occurring in tailings), I began my research by determining if the current hazard identification tools in the oil sands tailings operations were effective. This was done by developing initial research methods with the principal investigators based on our literature review: an analysis of a tailings safety expert hazard inventory; site visits at multiple oil sands companies; interviews with frontline workers, leadership, and regional contractors; and an analysis of company incident databases.

As my analysis of the data progressed, it became clear that the hazard identification tools were not adequate to identify and control previously unseen/unknown hazards and that issues with hazard identification and control were not isolated to ground hazards. In fact, worker safety and tailings-specific hazards were being overlooked by the oil sands industry. This inattention was first identified during the literature review, which revealed a dearth of information (both academic and industrial) regarding worker safety in tailings (Government of Alberta, 1999, 2000, 2015a; Wei et al., 2003; Li et al., 2010; Mining Association of Canada, 2011; COSIA, 2012; Tang et al., 2012). The current literature focuses on individual factors, my goal was to integrate these findings with my own datasets and analyze the interactions to enhance the current literature and provide a comprehensive understanding of safety culture, tailings and hazard identification.

Energy Safety Canada (ESC) created a hazard inventory by touring multiple oil sands sites, comparing operations, and sharing best practices for worker safety in tailings. They provided us with this database in September 2017. This was the first indication that the current hazard identification tools were not effective, as the inventory identified hundreds of hazards or hazardous activities ESC felt were not adequately identified or controlled across the tailings industry. The partnership with ESC expanded our creative sentencing research as several oil sands companies saw the potential for an occurrence similar to the 2014 fatality on their work sites and the need to increase attention on worker safety in tailings.

The next indication that hazards were not always being identified was provided during our site visits. These field trips were conducted in summer, winter, and spring, at multiple oil sands operators, to familiarize ourselves with the tailings operations and identify ground hazards in all seasons. Following an action research method proposed by Zuber-Skerritt (2001), we toured tailings operations, took photographs of representative tailings storage and transport facilities, and wrote notes in a field journal. Upon returning to the University of Alberta, we reflected upon our findings and prepared for the next visit; this continued for all subsequent field tours. As mentioned previously, our focus was on ground hazards based on the 2014 fatality. We identified four types of ground hazards that were manifesting in tailings and were not guaranteed to be identified or controlled by existing safety protocols.

Interview participants provided much information regarding the effectiveness of the hazard identification tools. Research ethics board (REB) approval from the University of Alberta was obtained prior to undertaking the interviews. Seven interview questions were developed, vetted by ESC for validity, and interviews were conducted in accordance with REB standards. Interview questions were semi-structured and developed to be open-ended and facilitate discussion between the participant and interviewer. They were analyzed following grounded theory and a staged abductive approach (Suddaby, 2006; Kreiner et al., 2009; Lok & de Rond, 2013; Huy et al., 2014; Reinecke & Ansari, 2015). Participants discussed the hazard identification tools in detail and indicated they are not as effective as they could be. To ensure the reliability of our analysis, Ms. Baker and Dr. Lefsrud both analyzed the interviews and a codebook containing definitions of the themes was created. The definitions in the codebook are detailed enough so that another researcher would be able to analyze the data and be able to repeat the results.

The final sign that hazard identification tools could be enhanced was the analysis of the incident database, following Cohen (2017), and its comparison to the aforementioned datasets. Incident databases were collected from companies and analyzed to determine the types and frequency of incidents being reported. Database subject matter experts explained how the reporting process worked (i.e., how the data were collected) and provided us with copies of their risk matrices. The incidents were then clustered into hazard definitions according to Hallowell (2008) and Winkel et al. (2017) and classified individually by the authors and research assistant for reliability. Inconsistencies were found between the number and types of incidents reported and the information provided in the above datasets, indicating either an underreporting of incidents and hazards or that hazards are not recognized. Further analysis was required to determine the root cause.

All four of these datasets were also compared to corroborate findings and inform the development of best practices and recommendations.

Gap identified and research outcome II—To increase discussion of worker safety in tailings

Based on preliminary analysis of the four datasets, it was determined that existing hazard identification tools are not completely effective in the oil sands tailings operations, especially for unseen/unknown hazards. The interviewees also confirmed the need for increased discussion on worker safety in tailings, by saying things such as “we feel like the forgotten operation” or the “toilet bowl” or the “armpit of the operation”. With this information, and the identification of the second gap (i.e., risk management focus on preventing catastrophic failures), the next research outcome was set, namely to increase the discussion of worker safety in tailings. This outcome was met with the development and analysis of the four methods described in the previous section and the creation of the four papers that constitute this thesis. This information was also utilized to create 12 presentations for dissemination at academic conferences to diverse audiences (e.g., geotechnical, chemical, and safety professionals). ESC is continuing this dialogue by: expanding the tailings safety task force to other oil sands companies; planning to establish a monthly call to share best practices amongst operators and regional contractors; and developing tailings-specific training microlearning modules.

Gap identified and research outcome III—To develop methods for the enhancement of current hazard identification tools to better equip workers to see previously unseen/unknown hazards and effectively control them

As mentioned at the beginning of this section, information in OH&S regulations and industrial best practices is vague regarding unseen/unknown hazards (Government of Alberta, 1999, 2000, 2015a; OHS, 2009 and 2015; Mining Association of Canada, 2011). Recently, hazard identification and mitigation in the construction and pipeline industries have become a popular research area (Carter & Smith, 2006; Ramsay et al., 2006; Bahn, 2013; Perlman et al., 2014; Jeelani et al., 2016; Stackhouse & Stewart, 2016). Methods were developed to determine if similar mechanisms for the lack of hazard identification were seen in the tailings operations using ground hazards as a case study. These methods are applicable to any previously unseen/unknown hazard. The methods developed are multidisciplinary, combining fundamentals from chemical, process safety, and geotechnical engineering disciplines to better identify hazards and provide creative solutions to the problems identified.

An understanding of chemical engineering principles was needed to understand the tailings extraction process, tailings transportation and placement processes, and the failure mechanisms that resulted in the pin-hole leak in the pipeline and loss of containment event that caused the 2014 fatality. This knowledge also helped to develop the tailings hazard inventory and incident database analysis methods. The tailings hazard inventory was analyzed using well-known PSM Bow Tie diagrams to visually showcase the hazard, threat, consequence, and control data (Paltrinieri et al., 2014). PSM knowledge and chemical engineering fundamentals, such as the multiphase fluid flow and fluid-particle systems in pipelines, were used to identify pipeline failure mechanisms and interpret the tailings incident data. The tailings incident databases were also analyzed using PSM definitions for hazards. Again, an understanding of multiphase fluid flow, fluid-particle systems, and wear in pipelines was used to interpret and classify the data. Geotechnical engineering fundamentals were used to identify the ground hazards that are manifesting in oil sands tailings operations. This knowledge was also paramount in creating the ground hazard framework and ground hazard photo databases. These tools use the technocratic definitions of ground hazards, so they are understandable by anyone regardless of training or background. These methods have application in the oil sands, mining, and process industries more broadly.

Gap identified and research outcome IV—To create visual tools to increase the knowledge of hazards and decrease risk tolerance

As I continued my analysis of the four datasets, I discovered an industry-wide breakdown in the communication of hazards to frontline workers and contractors in tailings. Based on these findings, a communication approach was needed to clarify processes, decrease complexity and uncertainty, and provide workers with more information regarding tailings-specific hazards. The datasets contributed to these findings in numerous ways. The tailings safety expert hazard inventory identified hundreds of hazards and hazardous activities, indicating that hazard identification and controls are not as effective as they could be. Interview data identified cultural and organizational root causes for the breakdown in communication. Interview participants also discussed the lack of tailings-specific training and the importance of this type of training due to the dynamic and unique nature of the oil sands tailings operations. A comparison of the incident data to the interview data indicated that under-reporting was occurring with regards to ground hazards.

With these gaps in communication identified, I elected to apply well-defined risk communication strategies to increase the knowledge of risks and decrease risk tolerance amongst an internal audience. I applied a mental models approach including stakeholder engagement and Sandman's (1987) *Hazard Plus Outrage* approach. While the word "outrage" seems initially inflammatory in this particular instance, it serves to increase the concern amongst workers regarding ground hazards. To achieve this, tailings-specific safety training with a discussion of hazards and examples of their manifestations in tailings is required. Using ground hazards as a case study, I developed visual tools to enhance the training and provide examples of ground hazards to workers. These tools included a hazard identification and control flow chart, a ground hazard framework, and corresponding photo databases and Bow Tie (BT) diagrams.

The hazard identification and control flow chart combines multiple theories from the literature with a focus on the distinction between hazard identification, perception, and tolerance (CCPS, 2011; ExxonMobil, 2015; CDC, 2015; Hallowell & Hansen, 2016; Sylvester, 2017). A ground hazard assessment was completed during site visits to multiple oil sands companies in summer, winter, and spring to address the seasonality of the hazards and operations. Photos were taken during the site visits and used to create a framework and photo databases of ground hazards. The ground hazard framework and photo databases were developed to enhance current hazard identification tools by making the previously hidden seen. Lastly, using the ESC tailings hazard inventory data, BT diagrams were created by applying a well-known and defined process safety tool to an atypical work environment following the methods of Paltrinieri et al. (2014). These diagrams showcase hazards, threats, consequences, and controls. This application is appropriate due to the types of hazards manifesting in the oil sands tailings operations, as well as the pressures, temperatures, and other operating conditions in tailings transport systems.

These visual tools will be used in the tailings-specific training being designed by ESC. This training will be delivered as four micro-learning modules: general tailings hazards, summer, winter, and spring.

Gap identified and research outcome V—To present a case study combining approaches to safety to address hazards that were previously unidentified

The BT diagrams were originally a tool to make the large hazard inventory digestible and understandable. However, interesting results began to manifest by adopting a PSM tool for daily field operations. Process safety and OH&S analyses are traditionally conducted in isolation. While process safety hazards exist in tailings, there are also other hazards to worker safety that are unique to this environment. Many of the hazards and hazardous activities identified in the ESC hazard inventory fall in a "grey" area: they are not fully process safety hazards nor OH&S hazards. By combining the two, we identified hazards that were previously unidentified and not effectively managed. Other hazards were identified when the controls were added to the BT diagrams. An over-reliance on administrative controls was identified through analysis of the hazard inventory and interview data. Human behaviours and actions affect the effectiveness of administrative controls, adding behavioural safety hazards to the analysis. If this aspect of safety is not analyzed, it could lead to an unseen hazard where controls that were thought to bring the risk to a level that is as low as reasonably practicable are not effective. By combining multiple approaches to safety, hazards that were previously unidentified due to the boundaries applied to operations can be seen and effectively managed during the design phase of a project.

My research acts as a case study for combining three approaches to safety: process, OH&S, and behavioural. A more holistic analysis that does not analyze safety strictly within these discrete areas allows additional hazards that fall into the "grey" area between traditional boundaries to be identified and controlled.

Gap identified and research outcome VI—To determine why hazards are not being identified and/or reported (i.e., why hazard identification tools are not effective)

My analysis of the four datasets and relationship building with the ESC task force and workers at the oil sands companies and regional contractors evolved over this two-year project. While it was important at the inception of this research to focus on "if" the hazard identification tools were effective, it became apparent over time that determining "why" the tools were not effective was also an important question. The literature points to purposeful acts, normalized wrongdoing, and normalized deviance as the root causes for incidents and hazards not being identified or reported. These findings through the literature represent the last identified gap. I was not seeing these purposeful actions manifest in my data analysis of the interviews. On the contrary, I was seeing people with an immense amount of pride and respect for their colleagues, work, and industry actively trying to avoid incidents from occurring and, yet, they still happened.

Dr. Lefsrud and I identified normalized myopia or unintentional blindness as the root cause of the ineffectiveness of hazard identification tools and why hazards are not being identified and reported. These findings manifested in the interview data where emergent themes during my coding indicated a lack of knowledge of hazards, i.e., no tailings-specific training; psychological safety issues, i.e., fear of losing their job; and apathy, i.e., no feedback on reported hazards. Further analysis of these emergent themes resulted in the finding that organizations are unintentionally blinding themselves by creating complexity, ambiguity, and uncertainty in their workplaces. Myopia was also identified through analysis of the ESC tailings hazard inventory, as the division of safety approaches is leading to the oversight of some hazards related to worker safety in tailings.

Positioning the thesis papers

The previous sections provide background for my research, discuss gap identification, and explain the development of research outcomes and how my methods relate to these outcomes. In this section, I provide an overview of how each of my thesis papers serves to answer different aspects of my research question (*are the current hazard identification tools and processes enabling workers to identify hazards and effectively control them?*), addresses the research outcomes, and is related to the larger research project contributions. Table 2 provides a summary of each paper, the research gap, background, methods, key findings, main contribution, and research outcome addressed. Following the table, I introduce the papers in more detail.

Table 2. Overview of thesis papers.

Paper no.	Brief overview	Main research gap addressed in paper	Methods	Key findings	Contributions from papers	Outcomes addressed
1	As this research is motivated by the 2014 fatality and is part of a creative sentencing project, it was necessary to meet the deliverables set by The Crown. One of these deliverables was the creation of a final report detailing the methods, results, and recommendations from the study.	There is a dearth of information regarding worker safety in the tailings operations.	Mixed methods: this paper provides methods and results for all four of the datasets collected and analyzed.	There is a need for enhanced hazard identification tools for ground hazards.	Comprehensive review of the research; creation of visual tools for use in the oil sands tailings operations; development of methods for enhanced hazard identification in the oil sands, mining, and processing industries more broadly; eight recommendations to improve worker safety in tailings.	I, II, III, IV
2	This paper applies external risk communication strategies to an internal audience to increase awareness of hazards while decreasing risk tolerance.	A gap in the communication of risks has been identified in oil sands tailings operations.	Mixed methods: this paper uses ground hazards as a case study for communicating risks to workers based on analysis of the four datasets.	The risks of ground hazards are not being effectively communicated to workers; tailings-specific training utilizing visual tools can be used to increase awareness of hazards.	Detailed discussion regarding visual communication tools that have been developed for the tailings industry; adds to the current literature surrounding the difficulty of hazard identification in dynamic environments.	II, III, IV, VI
3	This paper applies well-known BT analysis tools to better identify hazards in the oil sands tailings operations and uses enhanced brainstorming tools to develop substitution/elimination control options.	Customary to analyze safety approaches as discrete, leading to hazards not being identified.	Mixed methods: this paper focuses on the tailings safety expert hazard inventory and enhanced brainstorming methods.	Analyzing safety in silos is leading to unidentified hazards in the boundaries between these approaches; provides a case study for applying PSM tools to tailings operations.	Provides a case study for combining PSM, OH&S, and behavioural approaches to safety to better identify and control hazards; provides an example of how PSM tools can be applied to atypical situations.	II, III, IV, V, VI
4	This paper discusses the current organizational theory regarding wrongdoing and deviance.	Current organizational literature does not adequately describe the phenomena occurring in the oil sands tailings operations that are leading to hazards not being identified or reported.	Qualitative methods: this paper focuses on analysis of the interview data using QSR NVivo 12.0 text analysis software.	Organizations are creating complexity, ambiguity, and uncertainty, which leads to unintentional blindness or myopia.	Expands current organizational literature that states normalized wrongdoing and deviance leads to incidents within organizations; provides a unique case study to the organizational research community.	II, III, VI

First thesis paper

The first thesis paper, entitled *Final Report for Creative Sentencing: Protecting Worker Safety in Alberta by Enhancing Field Level Hazard Assessments and Training for Ground Hazards Associated with Tailings Facilities, Dams, and Systems* with coauthors Drs. Macciotta, Hendry, and Lefsrud, is the report that was delivered to The Crown. This document addresses the gaps identified in academia (Wei et al., 2003; Li et al., 2010; Tang et al., 2012) and regulations regarding worker safety in tailings (Government of Alberta, 1999, 2000, 2015a; Mining Association of Canada, 2011; COSIA, 2012). It was determined that the current hazard identification tools are not effective in terms of protecting workers from unseen/unknown hazards, as the tailings workers were unaware that an underground cavern, such as the one that caused the 2014 fatality, could manifest. Three of the seven fatalities that occurred in the oil sands subsector from 2011-2015 were related to unseen/unknown hazards (Government of Alberta, 2017). This directly responds to the research question that is at the core of this work.

This first paper is paramount to my research project as it provides the background, context, and justification for the study. Research outcomes (ROs) I, II, III, and IV are discussed in this paper. As mentioned above, this report presents in detail why the current hazard identification tools are ineffective (RO I). As this is the pillar of my research, all of the other thesis papers address this research outcome as well; however, this report provides a complete overview of the analysis that was completed to answer the research question and address this research outcome. With the publication in the public domain after approval from The Crown, this report will add to the discussion and become the precedent for worker safety in tailings, thus fulfilling RO II. This paper addressed RO III by presenting a summary of the methods used to collect and analyze the four datasets. RO III is also addressed by discussing the research activities and the unprecedented level of collaboration that occurred between operating companies, regional contractors, and the University of Alberta to improve worker safety in tailings. Finally, this report meets RO IV by discussing in detail the visual tools that I created (i.e., hazard identification and control flow chart, ground hazard framework with accompanying ground hazard photo databases, and BT diagrams for the top seven hazards in the oil sands tailings operations).

This paper contributes heavily to the oil sands tailings industry and the safety and risk management of workers by providing eight recommendations as well as visual tools to better protect workers in tailings. This report is also a contribution to understanding tailings operations. While tailings ground hazards were the focus of this study, the methods are applicable to any type of hazard, especially those that were previously unknown or hidden. These methods can be applied to the oil sands, mining, and process industries more broadly. This first paper sets the stage for the continued analysis conducted in the following three thesis papers.

Second thesis paper

The second thesis paper, entitled Risk *Communication in Athabasca Oil Sands Tailings Operations* and also written with coauthors Drs. Macciotta, Hendry, and Lefsrud, addresses the difficulties workers have in identifying hazards related to their job task and work environments. Not all hazards are being seen, as incidents are still occurring in oil sands operations (Hoekstra, 2014; Government of Alberta, 2017; OHS, 2017a). This paper answers the research question by identifying breakdowns in the communication of ground hazards to workers in the oil sands tailings operations as one reason why hazards are not being recognized: workers are unaware that the hazards exist. Based on these findings, this paper provides a case study for using external risk communication approaches to communicate risks to workers.

In this paper, I address ROs II, III, IV, and VI. The first outcome (RO II) is addressed by adding to the discussion of worker safety in tailings through the publication of this paper. The second outcome (RO III) is met by presenting the detailed methods for the collection and analysis of the interview data, company incident databases, and the ground hazard assessment. A brief overview of the methods and analysis of the tailings safety expert hazard inventory is also provided for context; the third paper discusses the analysis of this dataset in more detail. I compared datasets to identify overlaps and gaps and developed action-oriented tools to bridge the communication breakdowns, effectively addressing the fourth research outcome. These tools include the hazard identification and control flow chart and the ground hazard framework with accompanying ground hazard photo databases to enhance current hazard identification tools. Finally, I set the stage for the fourth paper by identifying systemic cultural roots within organizations related to why hazards are not identified or reported (RO VI).

Through this paper, I contribute to the literature on seeing the unseen in dynamic work environments and confirm similar mechanisms for why hazards are not being identified (Haslam et al., 2005; Albert et al., 2014, 2017; Jeelani et al., 2016; Tixier et al., 2017). However, I disagree with some scholars regarding the root causes of lack of identification and reporting (Haslam et al., 2005; Carter & Smith, 2006; Hinze, 2006; Tixier et al., 2017), providing a case study for further discussion in the academic community. My case study can also be used to show the applicability of external risk communication approaches to internal audiences. The visual tools presented in this paper will be used by Energy Safety Canada in their tailings-specific training modules, opening the door for future research regarding the implementation of these tools.

Third thesis paper

The third thesis paper, also written with coauthors Drs. Macciotta, Hendry, and Lefsrud and entitled *Combining Safety Approaches to Bring Hazards into Focus: An Oil Sands Tailings Case Study*, provides a case study for combining three approaches to safety, (i.e., process safety, OH&S, and behavioural safety), to better identify hazards that are unseen when discrete analysis within these boundaries is conducted. This case study utilized BT diagrams, traditionally a PSM tool, to identify process and OH&S hazards in the tailings work environment. The BT diagrams also highlight the hazards that workers and management can introduce through behavioural safety factors. This paper answers the research question by determining that hazard identification tools are not fully effective; organizations are not looking at safety as a socio-technical system with interactions from people, technology, and culture that can manifest hazards.

ROs II, III, IV, V and VI, are addressed in this paper. I address RO II by increasing the literature on worker safety in tailings. RO III is met through the detailed presentation of methods for the collection and analysis of the ESC tailings safety expert hazard inventory. I applied well-known PSM tools such as BT diagrams to an atypical operation. This method is applicable to tailings operations as the pressures and temperatures allow for their classification as a process under PSM definitions. The frequency of the incidents we are trying to prevent is the main difference between traditional processes and the tailings operations. Methods for the enhanced brainstorming of elimination and substitution controls to manage these hazards are also discussed. Brief descriptions of the data collection and analysis methods for the other three databases are provided here for context. RO IV is addressed through the creation of BT diagrams for the top hazards in the tailings safety expert hazard inventory. These diagrams visually showcase the hazards, threats, consequences, and controls along with their level of effectiveness. The BT analysis of this inventory also contributes to RO V by providing a case study for a combined approach to safety to better holistically identify hazards in a socio-technical system. Finally, this paper relates to the fourth paper and identifies the analysis of safety approaches in silos as myopic, which can lead to unidentified hazards in the boundaries between these defined approaches (RO VI).

This paper contributes to the process safety and broader chemical engineering communities by proposing a combined approach to safety where hazards are holistically identified and managed. Discrete approaches to safety can lead to hazards being missed as some do not fit the definitions provided by PSM or OH&S. Hazards introduced from behavioural safety or human factors (i.e., worker, management and cultural interactions with the system) can also be unintentionally overlooked. The application of BT diagrams to atypical scenarios where safety approaches are combined can lead to the identification of previously unseen/unknown hazards and ensure they are effectively controlled. Chemical and process engineers should be informed of these interactions so they can use this information to incorporate more elimination and substitution controls during the design phase. This is a novel case study for the combination of these safety approaches and the use of enhanced brainstorming to develop ideas to combat behavioural safety impacts through elimination and substitution control concepts. The BT diagrams created will also be utilized by ESC in the tailings-specific training modules.

Fourth thesis paper

The fourth thesis paper, entitled *Organizational Myopia: How Organizations Create Complexity, Ambiguity, and Uncertainty to Blind Their Risk Management Efforts* and written with coauthor Dr. Lefsrud, focuses on organizational theory and challenges the standard theory of wrongdoing and deviance as the causes of incidents. The current literature and theories focus on the intentional actions of workers that cause incidents. In my analysis of the interview data and while talking to participants, I did not see purposeful neglect for the standards and procedures. Instead, I saw workers who are determined to avoid incidents but are subject to competing demands and confused by the ambiguity, complexity, and uncertainty in their work environments.

This paper addresses ROs II, III, and VI. Similar to the previous three thesis papers, this document contributes to the discussion of worker safety in tailings and presents detailed methods to collect and analyze interview data with the aim of helping workers better identify previously unseen/unknown hazards (ROs II and III). To address RO VI, this work builds on the original research question. Thesis papers 1-3 determined that the current hazard identification tools are not fully effective to identify and control hazards. These papers propose methods and enhancements to current tools that better equip workers to see hazards. They also provide the data to determine the effectiveness of the current hazard identification tools. This fourth and final thesis paper begins to empirically answer why these tools are not helping workers to identify hazards.

The contributions from this paper are quite impactful. By identifying why current hazard identification tools are ineffective, it expands on organizational theories of wrongdoing by considering how organizations' well-intentioned risk management systems are unintentionally creating myopia. This paper also adds to the current organizational literature by discussing workplace fatalities in heavy industry, which is an uncommon area for this type of analysis. I hope my research represents a burgeoning field that challenges the purposeful actions of workers and analyzes the social and cultural factors that are causing incidents in heavy industry.

Discussion

I have applied fundamental chemical engineering principles to provide practical, methodological and theoretical contributions to industry and academia by answering my research question and meeting my research outcomes. My understanding of chemical engineering principles (e.g., process design, fluid dynamics) and my ability to read process flow diagrams and piping and instrumentation diagrams (P&IDs) allowed me to gain an understanding of the oil sands bitumen extraction and upgrading processes. This knowledge is important to understand the waste products that are created and transported to the tailings operations for storage and treatment. The water, sand, residual bitumen, and other chemical byproducts are transported to the tailings discharge area by pipelines and hydraulically placed. A detailed understanding of fluid mechanics is required to understand the transportation and placement processes. Additionally, a thorough understanding of fluid-particle systems allowed me to identify loss of containment hazards due to high wear areas in the tailings transport lines. It also allowed me to consider the hazards that manifest during non-steady state operations, such as start up and shut down, when there can be a drastic change of fluid velocity in the system. Fundamental process safety engineering principles were also applied to my research to further identify hazards, provide recommendations to manage hazards through effective controls, and bring the risks in the operations to a level that is as low as reasonably practicable (ALARP). I applied my chemical engineering and process safety technical knowledge as "fresh eyes" to the tailings operations, identified previously unseen/unknown hazards, and provided recommendations based on ALARP and hierarchy of controls principles. My understanding of engineering processes allowed me to combine technical and social science theories to critically evaluate the tailings process with a focus on safety. As summarized above, each of the four papers serves to show how these chemical engineering and process safety principles were applied, how the research question was answered, and how the research outcomes were met. I will discuss both my practical and theoretical contributions below. I will conclude by briefly discussing the recommendations (as they are detailed in the four thesis papers), addressing the limitations of my research and providing suggestions for future work.

Practical contributions

The practical contributions that I provide through my thesis are to the oil sands tailings industry and can be expanded to the oil sands and mining industries more broadly.

First, I contribute to an increased understanding of oil sands tailings operations. This contribution comes from the four datasets that I collected as part of this research study. They provided much insight into the tailings operations through anecdotal evidence, hazard identifications, and incident reporting systems.

Second, I created enhanced hazard identification visual tools for the oil sands tailings industry. These tools will be used by Energy Safety Canada in the development of tailings-specific training modules. These tools will increase the knowledge of ground hazards specifically in tailings with the creation of the ground hazard photo database. The BT diagrams will promote dialogue, ownership, and innovation among employees and contractors at all organizational levels. These two tools could be extended to include other hazards in tailings but also to the mining and process industries more generally. The hazard identification and control flow chart summarizes the current literature and provides a roadmap for future hazard identification activities.

Third, through the eight recommendations to improve the best practices presented in the first thesis paper, I contribute to the new precedent for worker safety in tailings.

Methodological contributions

My thesis adds to interdisciplinary literature by contributing methods and case studies

First, I contribute a mixed-methods approach (qualitative and quantitative) for the enhancement of current hazard identification tools to better equip workers to see previously unseen/unknown hazards and effectively control them. While designed for ground hazards in the tailings operations, these methods can be expanded not only to other tailings hazards but also to the mining and process industries and any operation where there is the potential for unknown hazards, such as the construction industry.

Second, I provide a case study for the uncommon use of well-known BT diagrams to holistically identify hazards that were previously missed due to discrete approaches in safety. This contribution has major applications to the chemical engineering community. During the design of a process, chemical engineers focus on the potential for low frequency, high consequence events, such as explosions (Amyotte et al., 2009). Engineers use inherently safer design principles and the hierarchy of controls to implement elimination, substitution, and engineering controls to effectively control the risk to workers. Any residual risk will be controlled using administrative controls or PPE. However, many other hazards that are identified through OH&S hazard identification will not be included in the design analysis due to the discrete approaches to safety, and may or may not be controlled with the elimination, substitution, and engineering controls selected. There are also hazards that may not fully fit either definition and be missed. The administrative controls used to manage residual risk are also subject to external factors such as company culture or worker behaviour; therefore, their effectiveness cannot be guaranteed, which potentially creates another hazard. By analyzing process, OH&S, and behavioural safety during the design phase and using tools such as hazard and operability studies (HAZOP), chemical engineers could create safer processes that protect workers from hazards related to all aspects of safety in their work environment by including elimination and substitution controls to holistically address hazards.

Third, I provide another case study for the application of external risk communication principles, such as stakeholder engagement and Sandman's (1987) outrage theory, to an internal audience. The application of these principles increases the knowledge of hazards and also decreases the risk tolerance. Again, this case study was specific to ground hazards but is applicable to the mining and process industries as well.

Theoretical contributions

My thesis also extends the current literature.

First, I contribute to the literature on hazard identification in dynamic environments by confirming the findings of Haslam et al. (2005), Albert et al. (2014, 2017), Jeelani et al. (2016), and Tixier et al. (2017) and the difficulties workers can have identifying hazards. I also found that hazards are remaining unseen because of the dynamic work environment with multiple hazards associated with a task (job hazards plus work environment hazards), hazards that are unassociated with the primary task (ground hazards in the work environment), perceived low risk hazards (high risk tolerance in tailings), unexpected/unknown hazards and visually unperceivable hazards (formation of underground caverns), selective attention (lack of mindfulness when completing tasks), and lack of experience (some parts of tailings have a seasonal workforce and there is no tailings-specific training). Jeelani et al.'s work focuses on the construction industry but my findings confirm the same difficulties with hazard identification in mining.

Second, I expand the current organizational literature that states purposeful actions cause incidents. This contribution comes from the use of an original oil sands mining case study and proposes that unintentional and well-meaning risk management systems currently in place at oil sands companies are leading to myopia. Organizations unintentionally blind themselves by creating uncertainty, ambiguity, and complexity. This finding has implications to a wide audience as very few organizational studies look at worker fatalities, and typically focus on the potential for 'white collar crime' (Perri, 2011).

Third, my thesis provides a broad overview of safety culture, hazard identification and heavy industry. The current literature only looks at certain isolated aspects of these different areas and the resulting incidents, but I draw from these different areas, integrate their findings, apply them to my tailings case study and enhance them with my own results. Through this research I begin to look at the interaction of organizational factors and how these lead to variance within organizations. I provide a comprehensive understanding of how different areas of operations interact and provide solutions to better protect workers.

Recommendations

The following recommendations for the oil sands tailings industry are based on my analysis of the four datasets and were created in consultation with the ESC tailings safety task force, which has representatives from the major oil sands tailings operators and regional contractors. Detailed recommendations are given in the first thesis paper on eight main themes: (1) increased communication within industry (e.g., interdisciplinary discussions during hazard identification activities), (2) increased communication within companies (e.g., regular safety meetings to share incidents), (3) enhancements to hazard identification tools (e.g., "fresh ink" added to hazard identification template tools, visual tools to assist with hazard identification), (4) critically evaluate current operations (e.g., spill box operation), (5) increase resources (e.g., increased workforce), (6) tailings-specific training, (7) regional standardization (e.g., line approach procedures), and (8) enhancements to incident databases (e.g., tracking potential hurts). Please refer to this paper for a discussion of these recommendations (pg. 104).

The second thesis paper builds on the above recommendations and suggests the development of tailings-specific training using visual tools such as ground hazard photo databases. ESC has already begun the process of developing this training by creating subject matter expert groups to create content.

The third thesis paper proposed a combined approach to safety using well-known BT diagrams to identify previously unseen/unknown hazards and control them through the use of elimination and substitution methods. This is an interdisciplinary method where interfaces are identified allowing for the increased identification of hazards.

The fourth thesis paper identifies systemic cultural issues within the oil sands tailings operations. Further research is required to develop concrete recommendations to combat normalized myopia. However, one suggestion to combat the apathy felt within organizations that leads to hazards not being identified or reported is providing meaningful feedback to workers. This feedback should be both on performance but also on requests for resources and identification of hazards. Another suggestion is to utilize Sandman's (2012) precaution advocacy theory and increase the level of concern amongst workers regarding their safety. This will combat feelings of apathy, complacency, and high-risk tolerance.

Limitations

As with all research, some limitations are associated with my findings. Some of the main limitations of my research stem from the heavy reliance on interview data. Dr. Lefsrud and I handwrote the original interviewee transcripts, and information could have been missed or context may not have been noted. Some of the interviews were completed with individuals whereas others were conducted as focus groups. The variation in the group size was out of our control as the companies selected when and where we could speak to workers. The "group" think mentality could have influenced the responses of participants who were not individually interviewed. Some interviews were also conducted over the phone, which could also have impacted participant responses. The interview data may also contain bias; this is human nature. Bias could originate from both the interviewees and the researchers. Personal factors could have a positive or negative influence on participant responsiveness. While coding the interviews, I could have exhibited bias. I attempted to remove this bias by creating a well-defined codebook and by having Dr. Lefsrud review my analysis.

The analysis of the incident database was qualitative. I read through all of the incidents and manually classified them into categories that I had defined. Any subjectivity was combatted by defining the incident categories prior to analyzing the data, as based on my literature review, and then by having another person review the classifications. Ms. Zettl (the geotechnical research assistant) and I both analyzed the data. Any of the classifications on which we disagreed were discussed together and we came to a concordant decision.

The ground hazard assessment was based on qualitative observations during site visits as opposed to theoretical and quantitative analysis. This assessment was further limited by the knowledge of our research team as even we are subject to unseen/unknown hazards. We were also limited in the locations that we visited, as we were provided site guides who toured us around the tailings operations. The failure mechanisms that caused the fatality are understood from a pipeline standpoint; however, the physical processes that manifested to create the cavern are not part of this thesis as we were not provided hydrogeological or other geotechnical instrumentation data.

There are also limitations to my recommendations as this analysis was conducted on an industry level. I identified many cultural issues with the effectiveness of current hazard identification tools and the identification and reporting of hazards. My dataset confirms that the tailings industry as a whole has some cultural issues. Acting on these issues and creating sustainable change is much more challenging as each company has its own corporate culture and its own tailings culture. Furthermore, some companies may already be implementing the recommendations that I have provided in this thesis, whereas others have not.

Finally, even with the methods and hazard identification tools that I created, there is still the potential for hazards to remain unseen/unknown, especially in dynamic environments. These methods and tools serve to increase the knowledge of hazards, especially ones that can be unseen/unknown, as well as prompt interdisciplinary discussions regarding hazard identification, control, and worker safety.

Recommendations for future research

"Data, I think, is one of the most powerful mechanisms for telling stories. I take a huge pile of data and I try to get it to tell stories." – Steven Levitt, Co-author of *Freakonomics* (Levitt & Dubner, 2014)

I was fortunate to obtain copious amounts of data from various sources over the course of this project. With the two-year timeline, there was a limit on how much data analysis could be completed. I took these data and told one story, but I noted many potential areas for additional future work using these same datasets. These ideas are given below.

1. Complete a similar analysis of hazard identification tools but focus on the different working groups in tailings, e.g., thickened tailings discharge area, mature fine tailings production and drying, maintenance, etc. They are very different, and each has its own unique challenges, hazards, and perceptions of risk.
2. Apply similar methods to other hazards that were previously unseen/unknown and create enhanced hazard identification tools. This could be done in the tailings operations but also the process industry, construction, or mining industry more broadly.
3. Using other hazards (not just ground hazards), further expand on Jeelani et al.'s (2016) work regarding why hazards are not seen.
4. Further analyze the interviews to include participant demographics.
5. Continue analysis of normalized myopia in tailings and provide recommendations to combat the ambiguity, complexity, and uncertainty that cause the unintentional blindness.
6. As the literature has shown that the hazard recognition skills of designers are lacking (Tixier et al., 2017), complete further work to potentially confirm this claim using our dataset to shift the focus from frontline hazard identification to hazard identification during the design phase. To complete this, more engineering and leadership interviews would be required.
7. Conduct a quantitative analysis of the incident databases to enhance my qualitative analysis, utilizing expert solicitation to develop risk values or applying "fuzzy logic" and artificial intelligence methods to the data to determine likelihood values.
8. Continue analysis and provide solutions to address normalized myopia in the oil sands operations.
9. Create risk communication tools and visual inventories for other tailings hazards. These would be valuable to create tailings-specific training and, based on recommendations from interviewees, making tailings a specialization. This could help to remove the negative stigma of tailings as simply a waste stream.
10. Apply the "Sprint" methodology to the implementation of a new tailings-specific training module to ensure success (Knapp et al., 2016). Select one of the microlearning modules to prototype.
    a. Monday: gather seven ESC tailings task force members to discuss tailings training, map out the problem, and select an important place to focus. Bring in extra experts (e.g., frontline workers and regional contractors), if needed, in the afternoon.

b. Tuesday: propose and workshop potential training module ideas.
c. Wednesday: post potential training module ideas around the room and make decisions on what to move forward with and turn into a testable hypothesis.
d. Thursday: create a realistic prototype training module.
e. Friday: test it with a group of frontline workers and regional contractors from multiple operations, get feedback that can inform the process moving forward, and enhance the training module.

11. Make the QSR NVivo training course a mandatory component for anyone conducting interviews to be completed prior to interviews commencing. This would have assisted me in how I formatted my interview questions, took notes from interviews, and had the transcriber type up the notes.
12. Present findings to design engineers and Canada's Oil Sands Innovation Alliance (COSIA). Suggest the potential for elimination, substitution and other inherently safer design principals to be incorporated during the innovation process.
13. Share findings with OH&S regarding the potential for unseen/unknown hazards to enhance The Code (2009).

Conclusion

The oil sands industry has made great strides to improve their safety record over the years, yet incidents are still occurring (Hoekstra, 2014; OHS, 2017a). My research was motivated by one such fatality that occurred on January 19, 2014, when a worker drowned in a hidden underground cavern (OHS, 2017a). Academics have identified that workers have a hard time identifying hazards, especially if they are previously unknown (Bahn, 2013; Jeelani et al., 2016). The discussion of unseen/unknown hazards in the current regulations, legislation, best practices, and hazard identification tools is vague. These findings were confirmed by my research and presented in four thesis papers. Tailings is not glamorous; it is the end of the process, is necessary to sustain the production in the mine, and, until recently, has been overlooked. I provided qualitative observations of the tailings process that add to the understanding of this industry. I also created visual tools to increase understanding of tailings-specific hazards and decrease risk tolerance. The methods for the enhancement of hazard identification tools to include ground hazards, as discussed in these papers, are applicable to the tailings, mining, and process industries more broadly. The novel case studies I discussed extend the current hazard identification and organizational wrongdoing literature.

My final thesis has become something more impactful and applicable that I ever imagined. The original goal was to prevent a similar incident to the 2014 fatality from occurring. Not only does my work contribute to preventing similar incidents but it also provides the basis for discussing previously unseen/unknown hazards not only in tailings but also in the oil sands, mining, and process industries more broadly. I provided a unique interdisciplinary look at operations and hazard identification where boundaries are broken to increase the visibility of hazards. My findings and recommendations will be challenging to implement as they target systemic cultural issues, but they are important. This is because they not only honour the fatality, but also aim to prevent future incidents due to unknown hazards from occurring.

Chapter 2: First thesis paper

Final Report for Creative Sentencing: Protecting Worker Safety in Alberta by Enhancing Field Level Hazard Assessments and Training for Ground Hazards Associated with Tailings Facilities, Dams, and Systems

Kathleen E. Baker
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
kebaker@ualberta.ca

Dr. Renato Macciotta
Industrial Professor
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
macciott@ualberta.ca

Dr. Michael T. Hendry
NSERC Industrial Research Chair in Railway Engineering
Associate Professor
University of Alberta
Civil and Environmental Engineering
Edmonton, Alberta, Canada
hendry@ualberta.ca

Dr. Lianne M. Lefsrud
Assistant Professor
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
lefsrud@ualberta.ca

Paper Status and History

<table>
<tr><th colspan="2">First thesis paper</th></tr>
<tr><td colspan="2">Final Report for Creative Sentencing: Protecting Worker Safety in Alberta by Enhancing Field Level Hazard Assessments and Training for Ground Hazards Associated with Tailings Facilities, Dams, and Systems

(Kathleen E. Baker, Renato Macciotta, Michael T. Hendry, and Lianne M. Lefsrud)</td></tr>
<tr><td>Status</td><td>Submitted for approval to The Crown, and will be published in the public domain after review and approval</td></tr>
<tr><th colspan="2">History</th></tr>
<tr><td>Interim Report submitted to The Crown</td><td>Baker, K.E., Zettl, J.D., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. 2018. Interim Report for Creative Sentencing: Protecting worker safety in Alberta by enhancing field level hazard assessments and training for ground hazards associated with tailings facilities, dams and transport systems. March 23, 2018 for Investigations, Alberta Labour. 78pp. https://doi.org/10.7939/R3BR8MX04</td></tr>
<tr><td>Peer reviewed conference papers and presentations</td><td>Baker, K.E., Zettl, J.D., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. 2018. Protecting workers exposed to ground hazards through enhanced hazard identification and management tools. GeoEdmonton. September 24, 2018, Edmonton, AB.

Baker, K.E., Zettl, J.D., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. 2018. Protecting workers exposed to ground hazards through enhanced Field Level Hazard Assessment Tools. GeoHazards 7. June 4, 2018, Canmore, AB.</td></tr>
<tr><td>Peer reviewed conference abstracts and presentations</td><td>Baker, K.E., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. 2018. Leveraging of incident databases to enable best practices in safety and risk management. 68^{th} Canadian Society for Chemical Engineering Conference. October 31, 2018, Toronto, ON.

Baker, K.E., Zettl, J., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. 2018. Leveraging of incident databases to enable best practices in safety and risk management. Canadian Institute of Mining Convention. May 8, 2018, Vancouver, BC.

Baker, K.E., Zettl, J.D., and Lefsrud, L.M. 2018. Identifying hidden hazards (Workshop). Petroleum Safety Conference. May 3, 2018, Banff, AB.

Baker, K.E., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. 2017. Protecting worker safety by enhancing hazard identification and management tools. 67^{th} Canadian Chemical Engineering Conference. October 23, 2017, Edmonton, AB.</td></tr>
</table>

Industry presentations and workshops	Baker, K.E., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. 2018. Creative sentencing update and brainstorming workshop. *Tailings Safety Symposium.* November 29, 2018, Fort McMurray, AB. Baker, K., Zettl, J., Saksena, S., Macciotta, R., Lefsrud, L., and Hendry, M. 2017. Protecting workers from ground hazards by enhancing hazard identification and management tools. *Railway Ground Hazard Research Program.* December 13, 2017, Kingston, ON.
Poster presentation	Baker, K.E., and Lefsrud, L.M. 2017. Improving the sustainability of tailings operations: protecting worker safety by enhancing field level hazard assessment tools. *Faculty of Engineering Graduate Studies Research Symposium (FERGS).* June 26, 2017, Edmonton, AB.
Award	**Endowed "Sustainable Research" Award** by Faculty of Engineering Graduate Studies Research Symposium

Dedication

May we remember the importance of keeping everyone safe and managing risk in one of the most challenging working environments in Canada. We will never fully be aware of what we don't know, but we can be mindful of our limitations, aware of our surroundings, utilize tools to identify abnormal conditions and ask for help when required.

Executive Summary

Efforts related to the safety and performance of oil sands tailings storage and transportation facilities have traditionally focused on preventing catastrophic failures and are well defined by government legislation and industrial best practices. However, a recent death related to ground hazards near oil sands tailings facilities, dykes, and transport systems signals the need for improved worker safety during daily operations near these facilities. Ground hazards are known and understood by geotechnical experts, but a breakdown in communication occurs with respect to informing frontline workers. This final report serves to provide a thorough review of the research completed as part of the creative sentencing project resulting from that fatality. It represents an unprecedented collaboration and initiative between the oil sands industry, regional contractors, the Province of Alberta, and the University of Alberta.

The outcomes of this research project are increasing the discussion of worker safety in tailings by the:

(1) creation of seven tailings specific, so called, Bow Tie Diagrams that graphically provide a means to showcase hazards, threats, consequences and controls,
(2) interviews with 158 frontline workers, leaders and regional contractors to determine the viewpoint of internal stakeholders,
(3) development of a generalized framework for ground hazards in the oil sands tailings operations,
(4) creation of ground hazard photo databases for summer, winter and spring that include descriptions of the ground hazards, potential consequences, precursory conditions and temporal factors,
(5) inaugural Tailings Safety Symposium to promote collaboration between oil sands owner companies and regional contractors, and

(6) presentation of this research to 12 diverse interdisciplinary audiences across Canada.

A holistic approach to operations and worker safety that includes managing the dynamic tailings work environment, job tasks, human factor considerations, and the potential for unknown hazards so that workers are better able to control all hazards in their work environments. Of particular concern are ground hazards in oil sands tailings operations as they not always apparent and pose a threat to workers with no training relevant to ground hazards when working near tailings facilities, dykes, and transport systems.

Over the two-year research project, data were collected from four sources: the Energy Safety Canada tailings hazard inventory; incident databases related to the oil sands tailings operations; interviews with tailings workers, regional contractors, and leadership; and a ground hazard assessment conducted by the University of Alberta. These four datasets were compared to determine similarities and differences and then provide recommendations for enhancement of the current hazard identification tools and controls for ground hazards.

Process safety management tools such as the Bow Tie Risk Assessment Method were used to cluster the tailings hazard inventory and identify areas for enhanced controls. Energy Safety Canada subject matter experts reviewed the bow tie diagrams to ensure applicability to tailings operations. The final bow tie diagrams showed a heavy reliance on administrative controls (56% of the controls mentioned were administrative) such as training, permits, and hazard assessment to protect worker safety. This value was confirmed by engineers who indicated that engineering controls and elimination and substitution methods are implemented in the design phase, but administrative controls are the primary method to mitigate hazards in the field during daily operations.

Tailings incident databases from multiple companies were analyzed to determine what incidents are actually happening in the tailings operations and what is being reported. The data were categorized by hazard type, with a focus on incidents caused by or that could cause ground hazards. Incidents in the ground hazard category include slips, trips, and falls; stuck or sunk equipment; pipeline leaks; and reported ground hazards (i.e., berm breaches, washouts, and over-poured cells). It was determined that almost a quarter (23%) of the reported incidents related to ground hazards.

Interviews were also completed with 158 frontline tailings workers, safety personnel, engineers, supervisors, leadership, and regional contractors. Interviewees were asked about the hazards they see in the tailings operations, what solutions or changes they would like to see implemented, and what "words of wisdom" they would pass down to new workers. Workers are aware of the unique, dynamic environment in which they work; however, incidents still occur. One of the reasons incidents are occurring is a lack of information or training regarding tailings specific hazards.

Given the lack of training on tailings specific hazards, a framework was developed to discuss ground hazards in the oil sands tailings operations. This framework includes definitions of the four main ground hazards identified by the University of Alberta during their site visits: soft ground, surface erosion, subsurface erosion, and slope instability. To accompany this framework, three ground hazard photo databases have also been created. The photos were taken in three seasons (summer, winter, and spring) of representative tailings facilities, dykes, and transport systems. The hazards in tailings operations are seasonal, indicating the importance for multiple site visits and differentiation between times of the year. How these ground hazards manifest, potential consequences, precursory conditions, and temporal factors are discussed in the figures.

Another deliverable of this project was the dissemination of information. The results of this research were presented numerous times to the Energy Safety Canada Tailings Safety Task Force at their office in Fort McMurray. This task force has representation from all of the major oil sands operators and regional contractors. Participation from members was invaluable in terms of providing expert information for the project. Information provided at these meetings was shared with the respective organizations represented by these participants. This type of collaboration regarding tailings related safety in the oil sands is unprecedented, and is set up to continue after the conclusion of this project.

On November 29, 2018, the results of this research were also presented to the most important stakeholders—the tailings workers, contractors, and leadership—at an inaugural Tailings Safety Symposium. The 105 people in attendance represented 15 organizations. The findings from the project were presented to the group and feedback on next steps was solicited through group brainstorming methods.

In addition to the local oil sands community, this research has also been presented 12 times to diverse audiences at academic and industrial conferences and workshops, including the Canadian

Institute of Mining Convention 2018, Petroleum Safety Conference 2018, Canadian Chemical Engineering Conference 2017 and 2018, GeoEdmonton 2018, and 2018 Geohazards 7. The attendees at these presentations provided valuable feedback on the project at every stage of the research process. The full list of academic presentations can be found in Appendix G along with the accepted abstracts. This research will continue to be disseminated after submission of this report as the work has been accepted for presentation at two conferences in 2019: the Society for Risk Analysis and the Center for Risk, Integrity and Safety Engineering Symposium.

Based on the analysis of the collected data and discussions with subject matter experts at Energy Safety Canada eight recommendations were developed. The recommendations are:

(1) increased communication within industry,

(2) increased communication within companies,

(3) enhancements to hazard identification tools,

(4) critically evaluate current operations, like the operation of spill boxes,

(5) increase resources,

(6) tailings-specific training,

(7) regional standardization, and

(8) enhancements to incident databases.

Energy Safety Canada has already begun the process of implementing these recommendations with the oil sands tailings industry by taking the following actions: setting up continued meetings of the tailings safety task force, creating smaller working groups to address regional training, alignment of standards on all sites, pipeline leak best practices, spill box operation best practices, working on water and ice best practices, and engaging with emergency response teams to ensure competency for successful emergency response plans. They have also proposed a monthly call for companies (owners and contractors) to discuss lessons learned and share incidents. This type of collaboration regarding safety is unprecedented in industry, and the continued partnership will significantly improve personal safety in the tailings. Hopefully, other industries will see this project as a case study to begin their own collaborations.

Acknowledgements

We thank the following companies and organizations for their participation in this research project.

Canadian Dewatering

Canadian Natural Resources Limited

CEDA

Clear Stream Energy

ConeTec Investigations Ltd.

Energy Safety Canada

Fort McKay Group of Companies

Graham Construction

Great Excavations

Horizon Maritime Services

Imperial Oil Limited

Ketek

Ledcor

Owl Moon Environmental Inc.

Primoris Canada

Rough Rider International Limited

Suncor Energy

Syncrude Canada Limited

List of Abbreviations

AER	Alberta Energy Regulator
AICHE	American Institute of Chemical Engineers
APEGA	Association of Professional Engineers and Geoscientists of Alberta
BT	Bow Tie Analysis Method
CIM	Canadian Institute of Mining
COSIA	Canada's Oil Sands Innovation Alliance
DyPASI	Dynamic Procedure for Atypical Scenarios Identification
ESC	Energy Safety Canada
FLHA	Field Level Hazard Assessment
FLRA	Field Level Risk Assessment
HEO	Heavy Equipment Operator
IAS	Industry Accepted Standards
IRP	Industry Recommended Practices
JSA	Job Safety Analysis
LPSA	Loss Prevention Self Assessment
MOC	Management of Change
NORMs	Naturally Occurring Radioactive Materials
OHS	Occupational Health and Safety
PFD	Personal Flotation Device
PPE	Personal Protective Equipment
PSC	Petroleum Safety Conference
REB	Research Ethics Board
SIFp	Serious Injury and Fatality Prevention
TDA	Tailings Discharge Area
TSS	Tailings Safety Symposium
U of A	University of Alberta
WCB	Workers Compensation Board

Technical Glossary

Administrative Control Failure: when an administrative control fails to work, resulting in a near miss or incident.

Basic / Root Causes: the reason why substandard acts and conditions exist.

Benches: earthen structures used to stabilize the steep working faces of the mine or tailings discharge area and prevent ground from sloughing onto workers or equipment below.

Berms: sloped dividing walls between cells in the tailings discharge area, made by bulldozers pushing produced tailings into walls at approximately a 3:1 ratio.

Biological Hazard: poses a threat due to exposure to something in the environment, e.g., dust, wildlife, NORMs, etc.

Cells: the non-compacted tailings discharge containment area.

Chemical Hazard: poses a threat that is toxic, corrosive, flammable, explosive, reactive, or creates an oxygen-deficient atmosphere.

Controls: a measure (engineered, administrative, or personal protective equipment) that brings the risk of a hazard to a level that is as low as reasonably practicable.

Creative Sentence: an often unorthodox or innovative sentence as an alternative to imprisonment, especially with the aim of linking the punishment to the crime (Oxford Dictionary, 2018).

Cuts: when process water and tailings are discharged into the tailings discharge area at a high velocity, the product can erode the sand and tailings below and create an erosion feature.

Consequence: the possible impact of an unwanted event.

Differential Settlement: when the ground settles at different rates due to the varied compositions of soil, tailings, silt, and clay.

Electrical Hazard: poses a threat that could cause electrocution due to exposure to live circuits or stored energy in systems.

End of Line Device: an end-of-pipe device to help dissipate the kinetic energy from the tailings discharge pipeline and avoid the creation of cuts and other erosion features in the cell; also called a spoon.

Ergonomic Hazard: poses a threat to a moving body part or the moving body.

Erosion: being gradually worn by natural mechanisms, typically by tailings, process, or ground water in this case.

Erosion Gully: removal of ground along drainage lines.

Fine Tailings: smaller fraction (clay, silt, fine sand particles) of the by-product of the bitumen extraction process for oilsands operations. It consists of a mixture that includes water, silt, clay, residual bitumen and lighter hydrocarbons.

Ground Hazard: naturally occurring hazard, such as surface and subsurface erosion, soft ground, or slope instability, that could have an adverse effect on people, the environment, assets, or production in oil sands tailings operations

Group 1 Risk: an intolerable risk requiring immediate corrective action.

Group 2 and Group 3 Risks: medium risks requiring reduction measures.

Group 4 Risk: a risk that is currently being appropriately managed but must be monitored for continuous improvement.

Hazard: an agent that can cause harm to people, the environment, assets, or production.

Incident: an unplanned and undesired event.

Likelihood: the probability of an unwanted event occurring.

Line of Fire Hazard: direct contact between a person and a force their body cannot endure. Includes contact with stored energy, striking hazards, and crushing hazards (ESC, 2018c)

Lagging Indicators: major injuries, minor injuries, and property damage incidents; includes fatalities, serious injuries, equipment damage, or loss of containment with a consequence to people or the environment.

Leading Indicators: substandard acts and conditions observed on the site; includes unsafe acts/ conditions, auditing of structured rounds, or the culture in the workplace.

Loss of Containment: an unplanned or uncontrolled release of material from primary containment, including non-toxic and non-flammable materials (CCPS, 2018a).

Mature Fine Tailings (MFT): tailings consisting mostly of clay and water.

Mitigation Controls: after an unwanted event occurs, these measures prevent a consequence from occurring, typically via administrative or personal protective equipment.

Near Miss: an incident that could have but did not result in a loss to people, the environment, assets, or production.

Potential Gravitational Hazard: poses a threat due to a fall to the same or a lower level.

Precursory Events: indicators that could help workers to proactively identify changes in the ground prior to an incident occurring.

Sink Holes: a cavity in the ground caused by a collapse in the surface layers into an underlying void.

Soft Ground: ground that may have problems supporting the weight of a person or a piece of equipment due to saturated conditions.

Structured Rounds: daily tasks that workers in the tailings operations complete to ensure the process is operating effectively and safely.

Substandard Acts: violation of an accepted procedure that could permit the occurrence of an incident.

Subsurface Erosion: erosion of soil materials underneath the exposed, visible ground surface or snow/ice cover; typically caused by water with the potential to generate large voids or caverns.

Substandard Conditions: hazardous physical conditions or circumstances that could directly permit the occurrence of an incident.

Slope Instability: a slope on the verge of failure; the substandard condition that could lead to a failed slope when sediment, tailings, rock, ice, or snow moves downhill in response to gravity.

Sloughing: sand or soil falling off slopes in sheets in slumps due to loss of cohesion.

Surface Erosion: sand and soil on the surface being gradually worn by natural mechanisms, typically by tailings, process, or ground water in this case.

Tailings: by-product of extracting bitumen from oil sands, typically consisting of sand, silt, clay, and residual bitumen (AER, 2018).

Tailings Discharge: the waste stream from the extraction process containing silica sand, process water, residual bitumen, and other chemicals.

Tailings Discharge Area: where tailings of larger particle diameter are stored.

Tailings Pond: where mature fine tailings and process water are stored.

Temporal Factors: conditions that can influence the manifestation of ground hazards in a particular area, typically relating to season, temperature, visibility, and climate.

Thermal Hazard: poses a threat due to exposure to a hot or cold substance or enclosed environment.

Threat: activities that could lead to an unwanted event.

Threat Control: measures such as engineered and administrative controls that prevent an unwanted event from occurring.

Uneven Ground: ground with changes in grade and/or elevation due to differential settlement, freeze-thaw cycles, earth work, etc.

Unwanted Event: a potential incident that could happen on the work site.

Washout: the result of a loss of containment event, in which the sand or soil is washed away to create an erosion feature.

Worker Error / Negligence: when worker error or negligence is one of the causes of an incident.

Introduction

Ground hazards such as soft ground and slope instability can manifest in industrial settings such as oil sands, construction, or railway. Ground hazards are common and, as such, contribute to the large number of lost time incidents that occur each year in Alberta. In the five-year period from 2011 to 2015, seven fatalities occurred in the Alberta oil sands operations sub-sector, one of which was directly related to a ground hazard (Government of Alberta, 2017). Despite efforts directed towards tailings management, recent incidents have emphasized shortcomings in the identification and control of associated hazards. The Vancouver Sun reported 49 'dangerous occurrences' associated with tailings facilities occurred between 2000 and 2014 in British Columbia (Hoekstra, 2014). This article emphasized that most of these incidents were contained within the mine sites and posed no risk to the public, but worker safety was not mentioned. By enhancing the tools used to identify and control hazards, the number of incidents, fatalities, and lost time could be decreased.

The current ground hazard risk mitigation strategies for the oil sands sector focus on the performance of structures and operations for tailings storage and transport facilities. Occupational Health and Safety (OH&S) legislation is used to protect workers from job-specific hazards. A more holistic approach would incorporate multiple safety management systems and legislation to enhance the current hazard identification and controls and better inform workers about the ground hazards to which they are exposed.

The communication of ground hazard risks to frontline workers has been identified as a gap in both the literature and in practice at oil sands mines. This report aims to address this gap by providing a list of potential hazards, precursory conditions, and controls that can be integrated into training and developing hazard identification tools and training through the examination of four data sources:

1. Energy Safety Canada hazard inventories;
2. Incident databases;
3. Interviews with frontline workers, regional contractors, and leadership; and
4. A ground hazard assessment associated with tailings transport and storage facilities, conducted during field visits by the research team to oil sands operations.

The field visits had the secondary benefit of familiarizing the research team with site operations. Existing industry experience is synthesized through analysis of the inventories, interviews, and incident databases.

Scope of the Document

As per the accepted proposal for creative sentencing, Protecting Worker Safety in Alberta by Enhancing Field Level Hazard Assessments and Training for Ground Hazards Associated with Tailings Facilities, Dams and Systems (Forbes et al., 2017), a final report is required within two years of the date of the court order. This report will contain the methodologies and tools developed over the duration of the project. The submission of this document serves to communicate the findings and methodologies developed by the University of Alberta (U of A) research group to Alberta Occupational Health and Safety and Alberta Justice regarding the creative sentencing project.

Background

Description of Fatality

A worker drowned in an underground cavern, created by a pin-hole sized leak of hot tailings from a pipeline on January 19, 2014 around 6:00 am (OHS, 2017a). Protocols to ensure the safety of workers were followed, including the use of pipeline leak detection and mitigation, administrative controls such as call-in procedures, and the use of personal protective equipment (OHS, 2017a). Despite these hazard identifications and controls, none of the frontline tailings team knew that a tailings leak could create an underground cavern. Steam is typically used as an indicator of a leak in winter because of the temperature differential between the hot tailings and the ambient environment. As the tailings were draining elsewhere from the cavern, no steam was emitted at the leak site, and there was no warning of the pipeline leak. This hazard was also hidden by the snow- and ice-covered ground and early-morning darkness (OHS, 2017a).

Please see Appendix A for a copy of the full Occupational Health and Safety Report describing the fatality (OHS, 2017a).

Athabasca Oil Sands Region

The Athabasca Oil Sands Region, situated in northeastern Alberta as depicted in Figure 2, contains approximately 90,000 km^2 of active oil sands deposits, making it the largest such deposit in the world (AER, 2018). This region experiences dynamic weather changes throughout the year, with average ambient temperatures of 16.8 °C in July and −18.8 °C in January, as seen in Table 3 and Figure 3. However, the air temperature can vary much more, leading to temperatures as low as −50.6 °C in the winter months and as warm as 37 °C in the summer (Alberta Agriculture and Forestry, 2018). This fluctuation in temperature makes the Athabasca Oil Sands Region a harsh climate for work and can also affect the visibility in the tailings operations. Steam is produced when hot tailings are discharged into cooler surrounding air. The winter months tend to correspond with the most variation in the discharge and air temperatures and therefore the most steam; however, cooler summer days can also lead to steam in the tailings operations.

The precipitation in the area ranges from a peak in rainfall of 81.3 mm in July to 29 cm of snow (26.6 mm snow water equivalent) in November (Table 3 and Figure 3). Precipitation makes ground conditions more difficult for work and also reduces visibility. Precipitation events can be very damaging as the roads are constructed out of sand and tailings and can become unpassable in the rain.

Figure 2. Map of the Athabasca oil sands deposit in northeastern Alberta (AER, 2018).

Table 3. Climate normals for Fort McMurray, 1971 to 2000 (Environment Canada, 2018).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily Average (°C)	-18.8	-13.7	-6.5	3.4	10.4	14.7	16.8	15.3	9.4	2.8	-8.5	-16.5
Daily Maximum (°C)	-13.6	-7.6	0.3	10	17.4	21.4	23.2	21.9	15.4	7.8	-4.2	-11.6
Daily Minimum (°C)	-24	-19.8	-13.2	-3.3	3.3	7.9	10.2	8.6	3.3	-2.2	-12.8	-21.4
Extreme Maximum (°C)	13.1	15	18.9	30.2	34.8	36.1	35.6	**37**	32.4	28.6	18.9	10.7
Extreme Minimum (°C)	-50	**-50.6**	-44.4	-34.4	-13.3	-4.4	-3.3	-2.9	-15.6	-24.5	-37.8	-47.2
Rainfall (mm)	0.5	0.8	1.6	9.3	34.2	74.8	81.3	72.6	45	18.8	2.4	1.1
Snowfall (cm)	27	20.6	20.4	14.5	2.9	0	0	0	2.4	13.1	29	25.9
Precipitation (mm)	19.3	15	16.1	21.7	36.9	74.8	81.3	72.7	46.8	29.6	22.2	19.3
Average Snow Depth (cm)	28	31	26	6	0	0	0	0	0	1	9	20
Days with Precipitation ≥ 0.2 mm	12.3	10.3	9.2	8.1	10.9	14.1	15.8	13.5	12.6	11.1	12.2	12.4
Days with Precipitation ≥ 5 mm	0.8	0.6	0.7	1.4	2.3	4.7	5.1	4.3	2.9	1.5	1.1	0.6
Days with Visibility < 1 km	3.2	2.8	3.3	4.9	2.1	3.1	5.5	8.5	7.9	6	4.5	3
Wind Speed (km/h)	8.4	9.1	9.6	10.9	10.8	9.7	9	8.7	9.7	10.5	9	8.6
Extreme Wind Chill (°C)	-58	-60	-57	-46	-21	-6	**-3**	-6	-16	-32	-50	-53

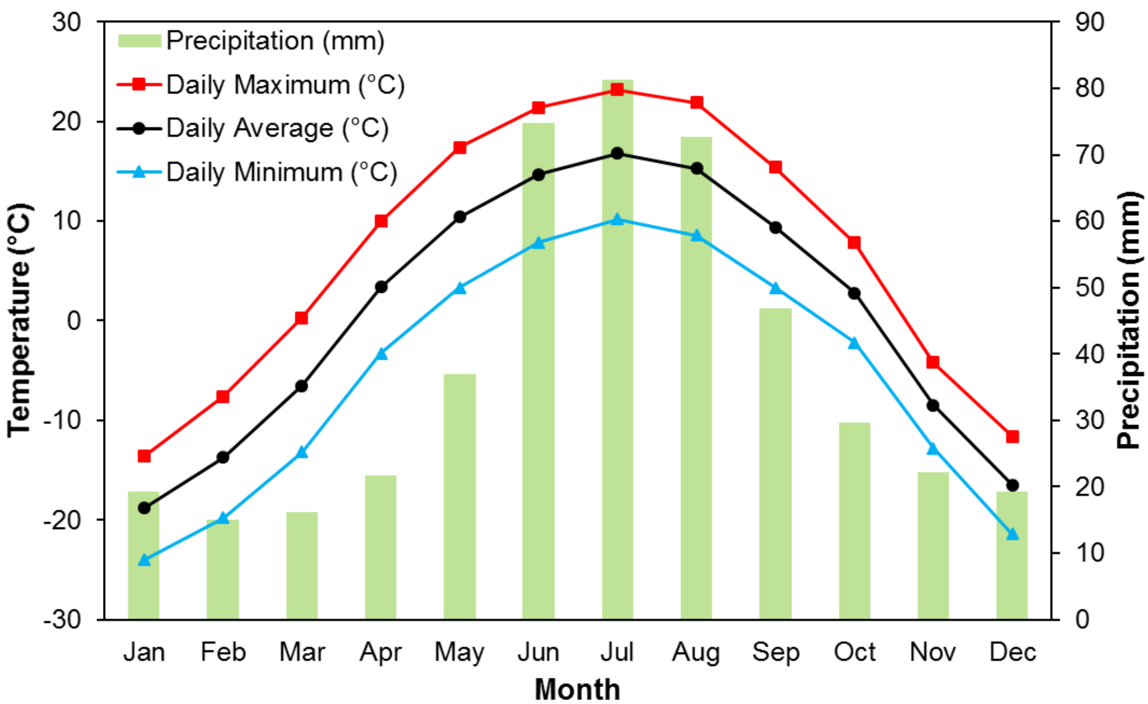


Figure 3. Temperature and precipitation graph for 1971 to 2000 Canadian climate normals, Fort McMurray (after Environment Canada, 2018).

This region has nine approved oil sands mines (AER, 2018). Each has unique operations and processing, but they all function on the same principle of mining oil sands, using open pit methods, then extracting and upgrading bitumen to produce other hydrocarbon products for use by consumers. They also all create tailings, which are a by-product of extracting the bitumen from the oil sands and consist of varying concentrations of water, silt, sand, clay, and residual bitumen (AER, 2018). Oil sands tailings are typically classified by their particle size and stored in tailings ponds on the mine site. Process water is also stored in these ponds for use in extraction and upgrading processes.

Tailings Operations Overview

The tailings operations in the Athabasca oil sands exist to manage the by-products of bitumen processing. Oil sands tailings consist of sand, process water, residual bitumen, and other chemicals used in the extraction process (Devenny, 2010). The tailings operations serve two functions: (1) capture sand for reclamation projects and (2) balance water around the facility for extraction and upgrading (Devenny, 2010).

The operations vary depending on the oil sands site. Some operations divide the tailings into coarse or fine fractions depending on particle size; other sites consider tailings discharge and process water as two separate streams and yet others use a combination of the two. For simplicity, any coarse tailings operations will be called "tailings discharge" and other tailings operations will be called "fine tailings". Both of these operations are comprised of multiple tailings facilities, dykes, and transport systems. Figure 4 is a simplified process flow diagram of the mining, extraction, and tailings production process.

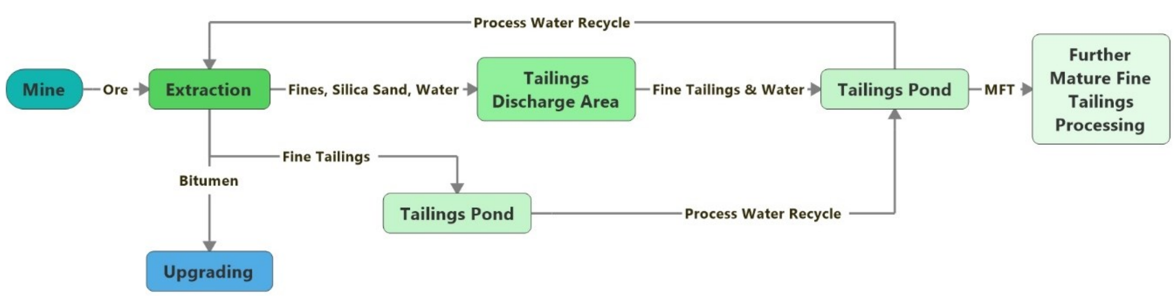


Figure 4. Simplified process flow of the mining, extraction, and tailings production process in the Athabasca oil sands.

Tailings Discharge Area

The tailings discharge area is where the larger particle size sand (>130 μm) is captured; these areas will eventually be reclaimed and must follow the Tailings Management Framework (Government of Alberta, 2015a). Planning engineers design these tailings facilities, which are comprised of dykes and benches such as those in Figure 5. Areas in the tailings discharge area known as cells are where tailings sand is stored, compacted using bulldozers to remove entrapped water, and eventually reclaimed (Devenny, 2010).

Figure 5. Cell construction in the tailings discharge area at an oil sands mine.

The tailings run down to the tailings discharge area or "cell" where sand is captured and the process water flows down to a small pond in the centre where a dredge then pumps water around the rest of the tailings operations for use in extraction or upgrading. To build these features, tailings are discharged from a pipe (hydraulically placed) that is typically equipped with an end of line device, sometimes called a spoon (Figure 6), into the cell in the tailings discharge area. The spoon is designed to dissipate kinetic energy and prevent the formation of surface erosion features, such as cuts, in the cell. The tailings discharge is a combination of silica sand, process water, residual bitumen, and other chemicals at a temperature between 45 and 50 °C.

Figure 6. End of line device (or spoon): out of service (top left), in service (top right), and inactive (bottom).

To build the dykes and benches in the tailings discharge area, bulldozers push the material and also compact, or track pack, to ensure the stability and optimal compaction of the facility for reclamation (Figure 7).

Figure 7. Bulldozer compacting sand in the tailings discharge area.

Fluid Tailings

The process water with some residual bitumen, small particle size sand (<44 µm), and chemicals is then transported via pipeline into tailings ponds around the tailings operations (Figure 8). These tailings ponds are contained by dykes and monitoring systems (e.g., piezometers) to ensure the performance of these structures and prevent releases that could affect the public or the environment. Dredges remove mature fine tailings (MFT) from the pond to manage the mudline and the water level. Water is also removed from the pond and pumped around the rest of the mine as process water. Workers obtain access to the dredges by walkway or boat.

Tailings Transport Systems

The tailings are moved from extraction to the tailings operations using tailings transport systems or pipelines (Figures 9 and 10). The transportation system is made up of permanent stainless-steel main line pipe (~28" diameter), and sometimes pipe that is lined with polymer or urethane to decrease the amount of pipe wear from the abrasive sand. There are also networks of friction fit pipe (nipple pipe, ~28" diameter) used for short-term operations in the tailings discharge area. Pipe in this area is moved quickly and frequently through pipeline advances, where more friction fit pipe is added as sand is discharged into the cell. The friction fit pipe is moved using equipment such as bulldozers or loaders.

Figure 8. Photo of a dredge and boat on a tailings pond in winter.

Figure 9. Photo of main line pipe.

Figure 10. Photo of out of service friction fit pipe.

Research Project Background

Tailings operations, specifically tailings facilities, dykes, and transport systems, are the focus of this creative sentencing project because minimal research has been conducted into worker safety at tailings operations. Energy Safety Canada (ESC) (a merger of the Oil Sands Safety Association and Enform) identified the lack of information surrounding worker safety at tailings operations (ESC, 2018d). In 2014, ESC created a tailings safety task force to tour oil sands mines and identify hazards in the tailings operations as well as share knowledge and best practices amongst operators

(ESC, 2018d). They employed the Process Hazard Analysis technique, “What If Analysis”, to identify hazards and hazardous activities in oil sands tailings operations. With this information, they developed a prioritized inventory of hazards that were similar across all operations.

ESC agreed upon the risk matrix, shown in Figure 11, to conduct the risk review and prioritize the hazard inventory. This risk matrix is based on risk being defined as likelihood multiplied by potential consequence. Using the matrix, each hazard was discussed to determine its likelihood of occurrence and the potential consequence. It was then assigned to a group: Group 1 was intolerable risk requiring immediate corrective action, Groups 2 and 3 were medium risk requiring reduction measures, and Group 4 was risks that are currently being appropriately managed but must be monitored for continuous improvement. Hazards assigned to a group were then weighted to determine the final priority.

This hazard inventory was completed prior to the U of A’s involvement in the project. In 2017, the U of A and regional contractors became involved with the project and ESC gave the hazard inventory to the U of A research group for further analysis.

The identification of ground hazards and enhanced controls was the focus of this research, as a ground hazard is what caused the fatality in 2014. Other members of the ESC task force identified the potential for a similar hazard to manifest on their sites and were keen to become involved in the project as well. This collaboration with ESC has allowed this project to become an industry-wide initiative involving multiple oil sands companies and regional contractors. This degree of collaboration is unprecedented and should serve as a model for other industries with respect to how to prioritize worker safety and implement industry best practices.

			LIKELIHOOD				
			A	B	C	D	E
			VERY LIKELY	SOMEWHAT LIKELY	UNLIKELY	VERY UNLIKELY	PRACTICALLY IMPOSSIBLE
		SAFETY / HEALTH	- Has occurred once or more in the region in the last 10 years or so - Has occurred several times in the industry in the last 10 years or so	- May occur more than once in the region in 10 - 40 years - Has occurred several times in the industry	- May occur once in the region in 10 - 40 years - Has occurred a few times in the industry	- Similar event may occur every 40 - 100 years at one of the regional sites - Have been isolated occurrences in industry	- Has not happened in the regional sites - Has happened a few times or not at all in industry
POTENTIAL CONSEQUENCE	I	Fatalities; Serious Injury to members of public	1	1	1	2	3
	II	Serious or Lost Time Injury / Illness	1	1	2	3	4
	III	Restricted Work or Medical Treatment	2	2	3	4	4
	IV	First Aid / Minor Injury	3	4	4	4	4

Group 1	Intolerable risk - immediate corrective a
Group 2	Incorporate risk-reduction measures
Group 3	Consider incorporating risk-reduction measures
Group 4	Manage for continuous improvement

Figure 11. Energy Safety Canada risk matrix (ESC, 2018d).

Regulatory

According to the Alberta Workers Compensation Board, in the 5-year period from 2011 to 2015 an average of one workplace incident fatality occurred and approximately 300 people sustained disabling injuries per year in the oil sands operations sub-sector (Government of Alberta, 2017). A concerted safety effort in the oil sands industry, spanning over three decades of continuous improvement, has significantly reduced incidents overall to the levels cited in Table 4. The industry has achieved leading safety performance when compared to other industries across the province, with a significant decrease in the disabling injury rate of 130% within the short 5-year period from 2011 to 2016. Leading firms in the oil sands contend that there is further opportunity to reduce injury frequencies. This opportunity is confirmed with the fatality statistics, which are relatively low, but do not show an apparent decrease over the last 10 years (Table 5). These firms acknowledge that further improvements may arise by equipping frontline workers with increased knowledge and understanding of hazards specific to their work environment; hence, this study aimed to characterize tailings related hazards and mitigative measures.

Table 4. WCB-reported disabling injury rate in Alberta by industry (disabling injury claims /100 person-years).

Disabling injury rate (disabling injury claims /100 person-years).							
Major Industry Sector	**2011***	**2012†**	**2013†**	**2014‡**	**2015§**	**2016§**	**Change 2011 - 2016**
Agriculture and Forestry	2.33	2.61	2.55	2.76	2.71	2.85	18%
Business, Personal and Professional Services	1.54	1.53	1.58	1.50	1.50	1.54	0%
Construction and Construction Trade Services	2.83	2.89	2.79	2.88	2.53	2.41	-17%
Manufacturing, Processing and Packing	4.54	4.48	4.10	3.97	3.30	3.10	-46%
Mining and Petroleum Development	1.86	1.44	1.30	1.46	0.90	0.81	-130%
Provincial and Municipal Government, Education and Health Services	2.81	2.83	2.89	2.88	2.87	2.91	3%
Transportation, Communication and Utilities	3.97	3.75	3.81	3.36	2.81	2.66	-49%
Wholesale and Retail	2.89	2.88	2.88	2.93	2.70	2.60	-11%

* Government of Alberta (2011b), † Government of Alberta (2013a), ‡ Government of Alberta (2015b), § Government of Alberta (2016a)

Table 5. Comparison of Province of Alberta (all sectors), mining and petroleum development sector, and oil sands operations sub-sector fatalities statistics by year.

	Fatalities by year accepted by WCB		
Year	**Province of Alberta- All Sectors**	**Mining and Petroleum Development Sector**	**Oil Sands Operations Sub-sector**
2006	124[*]	17[†]	1[†]
2007	154[‡]	10[‡]	0[†]
2008	164[‡]	13[‡]	0[†]
2009	110[‡]	13[‡]	4[†]
2010	136[‡]	15[‡]	0[†]
2011	123[§]	10[§]	1[¶]
2012	145[‖]	19[‖]	0[¶]
2013	188[‖]	18[‖]	1[¶]
2014	169[‖]	16[‖]	4[¶]
2015	125[‖]	9[‖]	1[¶]
2016	144[‖]	14[‖]	-
Total	**1582**	**153**	**12**

[*] Government of Alberta (2011a), [†] Government of Alberta (2011d), [‡] Government of Alberta (2011c), [§] Government of Alberta (2013b), [‖] Government of Alberta (2016b), [¶] Government of Alberta (2017)

The design and operation of tailings facilities tends to focus on the performance of the structures and the potential for catastrophic failures that have a large impact on the environment and the public, such as the Mount Polley tailings dam failure (Chambers, 2016). Legislation such as the Alberta Energy Regulator (AER) Tailings Management Framework, Oil Sands Conservation Act, and the Dam and Canal Safety Guidelines sets high standards for the safety management of tailings working environments (Government of Alberta, 1999, 2000, 2015a). The industry also has best practices such as those outlined in the Canadian International Mining (CIM) guidelines (1997) and the Canada's Oil Sands Innovation Alliance (COSIA) Oil Sands Tailings Technology Roadmap (COSIA, 2012). Table 6 summarizes the types of materials mentioned in each document. Only one of the documents analyzed—an Alberta government publication entitled 'Reasonable Actions: A Plan for Alberta's Oil Sands' (Government of Alberta, 2009)—mentions both worker safety and the oil sands, but not tailings safety directly. The other four documents do not mention workers operating in the tailings environment; their focus is instead on the performance and operation of the structures or reclamation of the tailings facilities. This report reviews the best practices and legislation in Alberta regarding worker safety, and specifically regarding tailings operations; importantly, it highlights the apparent lack of overlap in this regard.

Table 6. Mentions of "worker safety", "tailings safety", and "reclamation" in common regulations and best practices in the oil sands industry.

Document Title	Worker Safety	Tailings Safety	Reclamation
AER Tailings Management Framework (Government of Alberta, 2015a)	No	No	Yes
Oil Sands Conservation Act (Government of Alberta, 2000)	No	No	No
Responsible Actions: A Plan for Alberta's Oil Sands (Government of Alberta, 2009)	Yes	No	Yes
Dam and Canal Safety Guidelines (Government of Alberta, 1999)	No	Yes	No
Mining Association of Canada Guide for the Management of Tailings Facilities (Mining Association of Canada, 2011)	No	Yes	Yes
COSIA Oil Sands Tailings Technology Development Roadmap (COSIA, 2012)	No	Yes	Yes

The Occupational Health and Safety (OHS) Code (2009) provides best practices for workers to identify and control hazards before completing their specific job tasks. This includes a section on hazard assessment, elimination, and control and the importance of identifying and managing hazards both related to the job and the worksite using tools such as the Field Level Hazard Assessment (OHS, 2009 and 2015). The subsequent sections of the code focus on hazards directly related to the job task; however, some sections, such as Part 32 on excavating and tunneling, discuss the job task, potential ground hazards, and the work environment, but this is a purposeful interaction with the work environment (OHS, 2009: Part 32). The part missing from the OHS Code is unintentional interactions with hazards, the manifestation of unidentified hazards in the work environment, and the effect of human factor considerations (safety challenges introduced by human behaviours) on the risk assessment process.

Tailings Safety

There is also a dearth of academic literature on the topic of worker safety and tailings operations. In fact, only three articles from researchers in China focus directly on tailings dam operation and worker safety (Wei et al., 2003; Li et al., 2010; Tang et al., 2012). These articles discuss factors that can impact worker safety including the technical nature of the tailings structure, but they do not analyze how these various factors interact.

This gap has been confirmed in the industry after site visits to multiple oil sands mines. While workers are following OHS legislation, a breakdown in communication occurs with respect to informing frontline tailings workers about potential and localized ground hazards. For example, a worker was observed connecting pipe next to a steep berm of hydraulically placed sand. The worker was following OHS protocol for the task but seemed to be unaware of the potential ground hazards in the area based on the way he positioned himself in relation to the steep berm. Increasing the level of communication between working groups (i.e., between geotechnical consultants and frontline workers) could result in a better understanding of the hazards in the work environment.

Of particular concern is the communication of ground hazards to two groups of workers, (1) “roving contractors” and (2) contractors who work on multiple sites. The “roving contractors” group includes mechanics, pipe fitters, welders, etc. who have a particular set of skills and are deployed to work in areas around tailings facilities, dykes, and transport systems, but have no knowledge of potential localized ground hazards that may not pose a risk to the performance of the structure but could put the worker at risk of injury or death. Contractors must also learn the processes and procedures for each site, which can be challenging when they do not align.

Tailings employees and contractors view tailings operations as a dynamic environment with a high potential of exposure to various hazards; however, they still have limited knowledge of the potential for ground hazards in their working environment.

Hazard Identification

The process of identifying and controlling hazards is displayed in Figure 12. To effectively control hazards, they must first be identified (Hallowell & Hansen, 2016). It is only after hazards have been identified that steps towards mitigation and control can be implemented. There is an important distinction between the next two steps of the hazard identification process. The hazard must be understood by the worker so they can decide if they tolerate the risk or not. The perception or understanding of risk is influenced by many external and internal factors, such as state of mind, inattention, training/knowledge of hazards, etc. (Sylvester, 2017). If internal factors such as perceived pressure, frustration, fatigue, or complacency are present, a worker may not be fully engaged in the task at hand (Sylvester, 2017). The result of this inattention could be increased exposure to risk as hazards are not being identified and are not controlled, eventually leading to harm (Sylvester, 2017).

However, even if a worker is mindful while working in hazardous environments and can identify and perceive the risk, there is still one more step before the risk can be managed, namely risk tolerance. Everyone has a different risk tolerance, which is influenced by both internal and external factors. Some workers may be predisposed to a higher risk tolerance compared to others or the company itself may unintentionally influence a worker's risk tolerance (e.g., by aiming to complete a job faster). The risk tolerance factors in Figure 12 are based on Sandman's outrage factors (1987), Jeelani and colleagues (2016) and ExxonMobil (2015).

If the hazard has been identified, perceived, and not tolerated, then effective controls can be implemented using principles of a hierarchy of controls; elimination or substitution is the ideal mitigation strategy followed by engineering controls, administrative controls, and personal protective equipment (CDC, 2015). It is also important to build in redundancy and have multiple controls in place in case one or more fail, a process called the Layers of Protection approach (Baybutt, 2002; Summers, 2003).

Even with all of the processes in place to identify hazards, perceive decreased risk tolerance, and control hazards, incidents still occur, which indicates some hazards are not seen (Jeelani et al., 2016). Research has determined that all workers have difficulty identifying hazards in dynamic, complex environments (Jeelani et al., 2016; Namian et al., 2016) and novice workers are unable to recognize 53% of hazards in their work environments (Bahn, 2013). Jeelani and colleagues completed a study in the construction industry and found 14 factors that can lead to a hazard not being identified: dynamic environments, unfamiliarity with tools, hazards unassociated with the primary task, low perceived levels of risk, premature termination of hazard recognition, unexpected hazards, visually unperceivable/obscure hazards, unknown hazards, selective attention or inattention, multiple hazards associated with a single source or task, task unfamiliarity, latent and stored energy hazards, hazard source detection failure, and hazards without immediate outcome onset (Jeelani et al., 2016).

Many of the aforementioned factors can manifest in the tailings operations as well, indicating the need for increased hazard identification to mitigate risk and prevent incidents. Workers are exposed to many work environment hazards that are not associated with the primary job task, e.g., such as welding pipe at the base of a steep berm. The tailings operations are also constantly changing as the company works towards reclamation in these areas but also continues to produce tailings as a waste product. Having unknown hazards as well as working in a dynamic environment can lead to a high-risk tolerance as it is such a challenging environment. Many hazards are unexpected or cannot easily be seen because they have not been previously identified or manifest underground or in pipelines as stored energy. No tailings-specific hazard training exists, which could lead to task unfamiliarity and unexpected hazards.

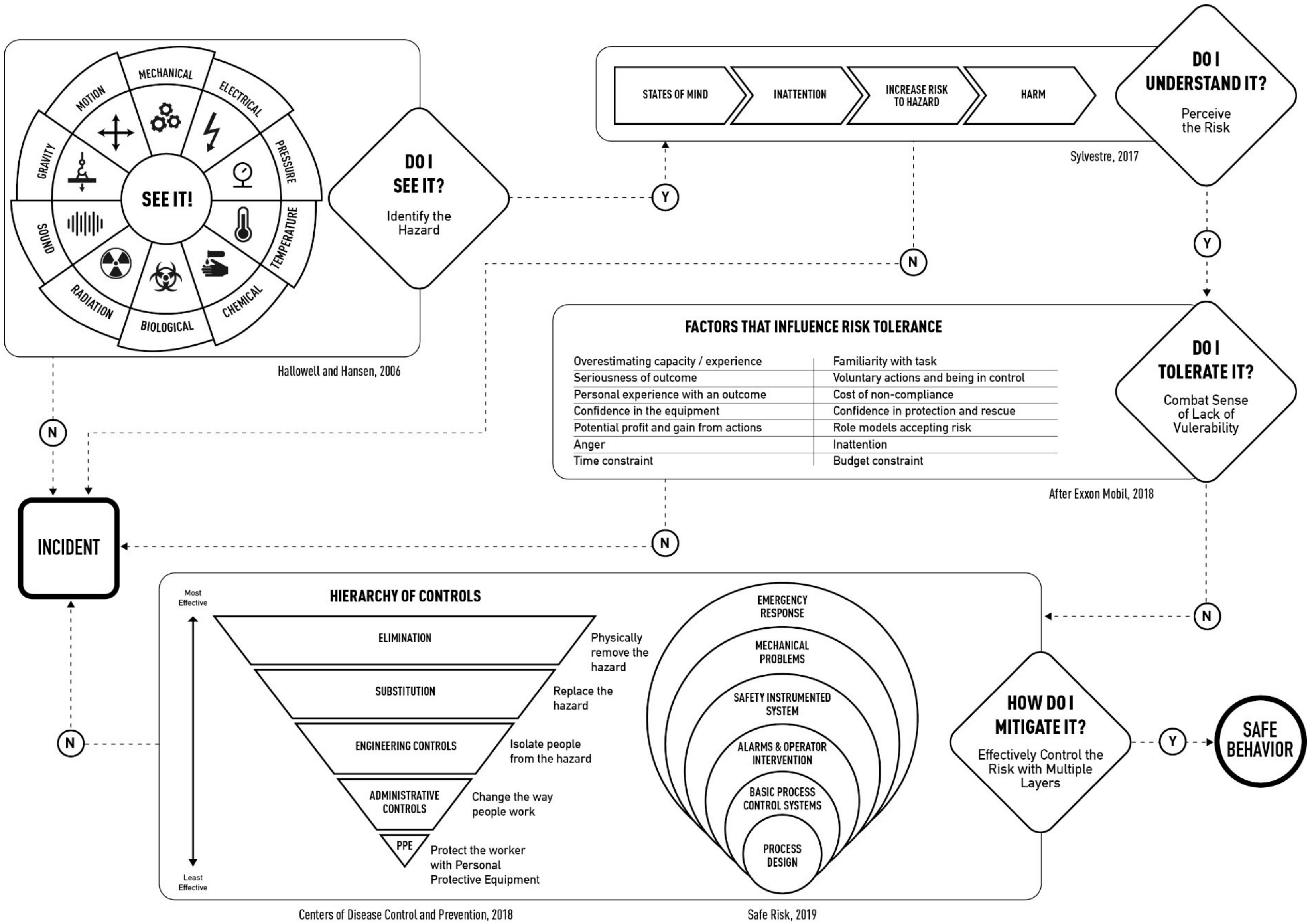


Figure 12. Hazard identification flow chart.

Methods

Energy Safety Canada Tailings Hazard Inventory

Once ESC provided the hazard inventory to the U of A research team, the Process Safety Management principle of Bow Tie Analysis (BT) was used to cluster the hazards and current controls. Analysis of the prioritized hazard list followed a method developed by Paltrinier and colleagues called the dynamic procedure for atypical scenarios identification (DyPASI), which is used to create bow ties to identify atypical scenarios (Paltrinieri et al., 2014). In this method, hazards that were previously undetected are identified. This process was conducted by ESC during site visits and resulted in the completion of the prioritized hazard inventory. The U of A classified this inventory of over 100 hazards according to process safety management definitions to ensure reliability (Table 7). Based on their expertise, site visits, and interview data, the U of A ranked the list of hazards. A facilitated discussion was held at ESC's office in Fort McMurray with the task force members to confirm the prioritized list and the current controls that are in place. Seven hazards were selected as top priority for mitigation: (1) pipeline leak, (2) soft ground, (3) working on water, (4) working on ice, (5) operating spill boxes, (6) long-term exposure, and (7) emergency response. Following Chevreau et al. (2006), local BT diagrams were created for each hazard and controls then added. Green, yellow, or red boxes were drawn around the controls to indicate the level of effectiveness (Paltrinier et al., 2014). Feedback on the BTs was solicited from the expert task force to ensure the analysis was useful and correct.

Table 7. Process safety management hazard definitions (after Winkel et al., 2017 unless otherwise stated).

Hazard	Definition
Administrative control failure	when an administrative control fails to work, resulting in a near miss or incident
Biological	poses a threat due to exposure to something in the environment, e.g., dust, wildlife, NORMs, etc.
Chemical	poses a threat that is toxic, corrosive, flammable, explosive, reactive, or creates an oxygen-deficient atmosphere
Electrical	poses a threat that could cause electrocution due to exposure to live circuits or stored energy in systems
Ergonomic	poses a threat to a moving body part or the moving body
Line of fire	direct contact between a person and a force their body cannot endure; includes contact with stored energy, striking hazards, and crushing hazards (ESC, 2018c)

Loss of containment	an unplanned or uncontrolled release of material from primary containment, including non-toxic and non-flammable materials (CCPS, 2018a)
Potential gravitational	poses a threat due to a fall to the same or a lower level
Thermal	poses a threat due to exposure to a hot or cold substance or enclosed environment
Worker error/ negligence	when worker error or negligence is one of the causes of an incident

The Bow Tie Risk Assessment Method creates diagrams, such as the one shown in Figure 13, as a visual representation of the top event (unwanted event), threats, and potential outcomes. The top event or unwanted event (orange polygon in the centre of the bow tie) is what could go wrong. On the far left-hand side is a list of all of the threats that could cause the top event or unwanted event. On the far right-hand side is a list of all of the possible consequences if the top event were to occur. Controls are then added. On the left-hand side are blue threat controls (e.g., engineering or administrative controls) put in place to avoid contact with the top event or hazard. Strong threat controls are important to avoid an occurrence of the top event. The yellow controls on the right-hand side are mitigation controls. If a threat occurs that could lead to the top event, these controls aim to prevent the undesired event from occurring.

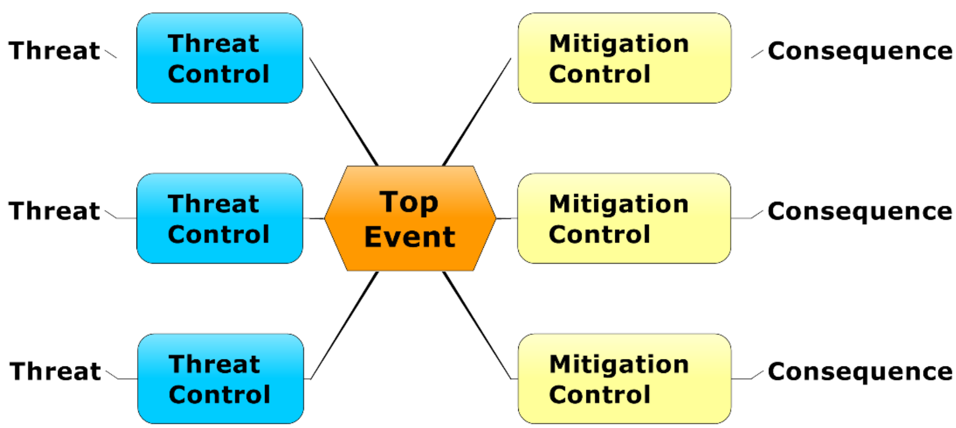


Figure 13. General bow tie analysis (after Deighton, 2016).

Different types of controls are showcased on the BT diagrams in accordance with the hierarchy of controls. The hierarchy of controls ranks the most effective controls at the top (elimination or substitution where the hazard is completely removed or substituted by something less hazardous), followed by other control types in order of decreasing effectiveness. Engineering controls are the next ideal choice to manage a hazard as they isolate the worker from the hazard; for example, a guard on a pump prevents a worker from being exposed to a pinch point. If the risk has still not been brought down to a level that is as low as reasonably practicable, administrative controls can be implemented. These are typically standard operating procedures (SOP), training, or permits. The last line of defense is personal protective equipment (PPE), which does not prevent the hazard from manifesting but mitigates the consequences to the worker, i.e., hard hat prevents injury if a worker were to be struck by an object. It is good practice to utilize multiple controls in a layer of protection approach, where if one control fails another is still in place to prevent an incident from occurring.

Tailings Incident Database

Multiple oil sands companies provided access to their incident databases related to tailings. These databases were analyzed with the aim of identifying what incidents were actually being reported and determining the likelihood of ground hazards manifesting in the tailings areas. Analysis was also completed to identify leading indicators (which measure high frequency, low consequence events) that could help to predict ground hazards before they occur.

Incident pyramids, such as the one shown in Figure 14, are used to help identify leading and lagging indicators in the data. Lagging indicators include the normalized frequencies of major and minor injuries, e.g., loss of containment with a consequence to people or the environment and/or costs associated with property damage, fatalities, serious injuries, or equipment damage. Leading indicators measure and trend substandard acts and conditions observed on the site, including unsafe acts/conditions, auditing of structured rounds, Serious Injury and Fatality Prevention (SIFp), or the culture in the workplace.

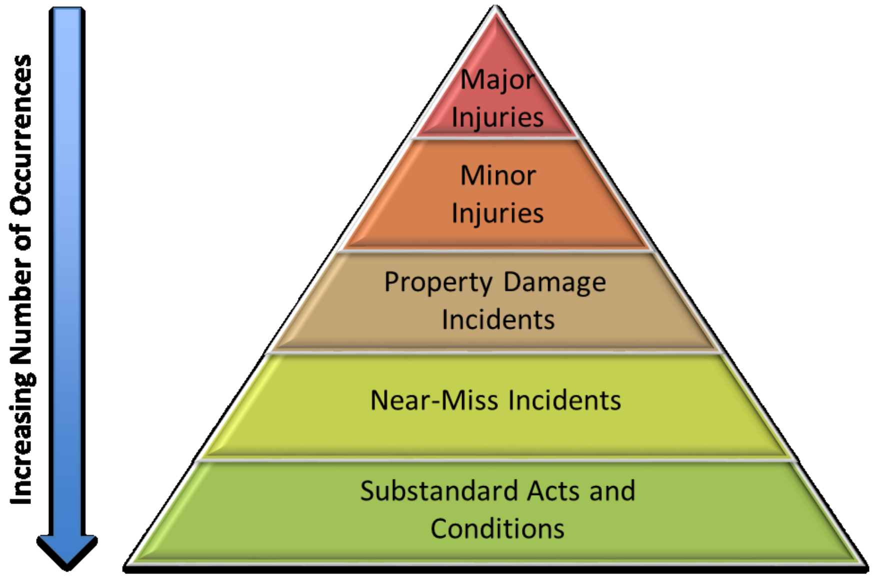


Figure 14. Incident pyramid (after Henderson, 2016).

The incident data were analyzed for keywords to ensure all tailings hazards were included and based on information from the preliminary interview analysis. The keywords used were as follows: tailings, ground, pipeline, leak, stuck, sunk, slip, trip, fall, washout, loss of containment, spool leak, steam, ice, and frozen.

The incident data were studied to determine the type of hazards to which workers would have been exposed (i.e., ground, chemical, line of fire, etc.). For reliability, these definitions were based on process safety definitions in Table 7 (from Winkel et al., 2017); these same definitions were used for the classification of the ESC tailings hazard inventory, with the addition of "ground hazard" (hazards, such as surface and subsurface erosion, soft ground, or slope instability, that could have an adverse effect on people, the environment, assets, or production in oil sands tailings operations). This method followed an approach by Cohen (2017), where incidents are read and categorized into a framework by subject matter experts. Each expert did their own analysis and any classifications that did not match, were discussed and agreed upon. All hazards were classified; however, only those relating to ground hazards were selected for further analysis.

Interviews

The purpose of interviews with frontline workers, contractors, safety advisors, leadership, and other employees was to determine which hazards in their work environment are of major concern. Recommendations to improve safety in the tailings operations were also discussed as well as "words of wisdom" that the interviewees would pass down to new workers. Prior to conducting the interviews, Research Ethics Board (REB) approval was obtained from the U of A. The REB vetted the interview questions, methodologies, and informed consent form. The consent form detailed how participant responses would be kept confidential and anonymous. Each participant was assigned a random number as an identifier, and the results reported in aggregate so no person or company could be identified. The consent form also stated that interviewees could withdraw from the study up to two weeks after the initial interview. No participants requested this; rather, many contacted the authors to add to their interview and to get more information about the status of the project.

Different questions were developed for frontline workers, leadership, and roving contractors. Please see Appendix B for a complete list of interview questions. The themes of the questions were all the same, but the questions were modified slightly to best fit the interviewee's role. Eight interview questions (seven for leadership) were developed for the semi-structured interviews. All of the interviews started with the same question, which aimed to develop a rapport with the worker, and then proceeded to questions designed to gather information about safety practices and their level of concern regarding ground hazards.

The final dataset consisted of responses from 158 participants, including 78 frontline workers (heavy equipment operators, plant operators, and maintenance staff), 33 leaders (engineers, site leaders, management, and health and safety professionals), and 47 regional contractors (dredge and boat operators, geotechnical engineers, roving contractors, and embedded contractors). Demographic data are summarized in Figure 15. Interviews lasted between 30 and 90 minutes. The majority of the interviews were conducted in person, with only 12 done over the phone. Interviews also took the worker's schedule into consideration. Most (n=129) were conducted one-on-one while others were done with larger groups (three focus-group style interviews had more than 4 participants; total n=29) to ensure the research process did not interrupt tailings operations.

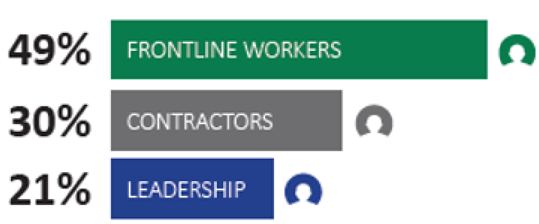


Figure 15. Demographics of the interview 158 participants.

Answers to the interview questions were hand written and transcribed for analysis (coding) using QSR NVivo 12.0. Coding is a way to analyze the interviews to identify patterns and themes in the data. These themes are organized into folders called nodes that contain supporting quotes from the interviews and group similar information. Nodes were created for each of the interview questions during the initial round of coding. Each interview was read, and supporting quotes were coded into respective folders. From this initial analysis and literature review, emergent themes became apparent and further analysis was based on abductive reasoning and completed in stages. Following grounded theory methods, Ms. Baker and Dr. Lefsrud used NVivo to develop codes and test the plausibility of our hypotheses, that ground hazards are under reported in the tailings operations, tailings specific training is lacking and there are unidentified hazards in the oil sands tailings operations (Lok & de Rond, 2013; Huy et al., 2014; Reinecke & Ansari, 2015). The coding scheme was amended as the analysis progressed (Kreiner et al., 2009). This method of abductive analysis is "most suited to efforts to understand the process by which actors construct meaning out of intersubjective experience" (Suddaby, 2006: pp. 634). After multiple cycles of analysis were completed, the codes were collapsed into subtheme categories to help develop recommendations for best practices for worker safety in the oil sands tailings operations.

The range of tailings experience level of the interviewees was broad, with some having only a week's worth of experience and others having over 40 years. Figure 16 shows the varied tailings worker experience levels. Notably, this reflects experience specific to tailings operations; many participants had more experience in other mining, oil and gas, and construction industries. This wide range in experience provided both a fresh outlook on the tailings operations as well as a more seasoned view.

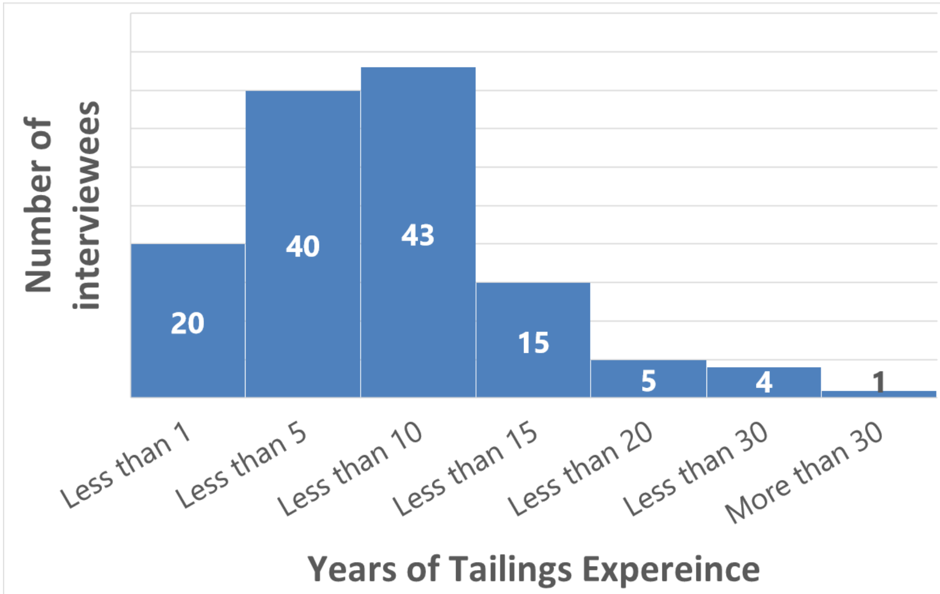


Figure 16. Tailings experience levels of the 128 interviewees (30 interviewees with unknown experience level).

University of Alberta Ground Hazard Inventory

A ground hazard inventory was compiled during field visits to oil sands companies in summer, winter, and spring utilizing the action research model, where further analysis was conducted after returning to the U of A. In this approach, ground hazards were observed in the field and then reflected upon after the site visits to determine the types of ground hazards that were manifesting (Zuber-Skerritt, 2001). This action research cycle continued after each site visit. Upon investigation of the photos from all of the sites, three main types of tailings facilities were identified: tailings storage facilities, tailings transport facilities, and dykes. Four main groups of ground hazards that manifested at these facilities: soft ground, surface erosion, subsurface erosion, and slope instability. These ground hazards do not appear in isolation, as multiple hazards can occur simultaneously. For ease of discussion and because frontline workers are not formally trained in geotechnical engineering, these four groupings were used rather than the more technocratic ground hazard classifications used by geotechnologists. This framework included the four ground hazard grouping incident descriptions of potential ground hazards and how they manifest as well as temporal factors that could adversely affect the risk (decreasing the likelihood of a worker identifying the hazard or increasing the likelihood of a ground hazard manifesting). Differential settlement was also included initially; however, it was removed as other ground hazards better identified the manifestations that were seen. For example, cavern formation is covered by subsurface erosion, uneven ground can be classified as surface erosion, and misalignment of pipelines can lead to areas of high abrasion in the line and a leak that causes soft ground, surface, or subsurface erosion features. Other manifestations of differential settlement are more of a maintenance issue or covered by slips, trips, and falls by the other ground hazards.

Based on this framework, a photo database of ground hazards at representative examples of tailings facilities, dykes, and transport systems at all participating mines was created. This database is meant to be a training tool to familiarize workers with ground hazards in their work environment. It includes descriptions of the ground hazards, potential consequences, precursory events, and temporal factors. Descriptions of the ground hazards are based on site observations noted in a field journal and documents from the oil sands operators. Precursory events are indicators that could help workers to proactively identify changes in the ground, prior to an incident occurring. Where possible, photographs of the precursory events were provided.

Due to the considerable seasonal variation, it was determined that site visits to the oil sands mines were required in summer, winter, and spring, as well as during night shifts. The research team could therefore capture the dynamic nature of the tailings operations in the oil sands mines and ensure that the database contains a comprehensive list of the ground hazards in these areas, no matter the season or time of day.

Tailings Safety Symposium

On November 29, 2018, the inaugural Tailings Safety Symposium (TSS) was held in Fort McMurray, Alberta. This was a joint initiative between ESC and the U of A to share the findings of the project with the most important stakeholders: the frontline workers. The flyer that was provided to the participating companies is provided in Appendix C. A total of 105 participants from 15 companies attended, including owners, regional contractors, and representatives from ESC and the U of A. The session was opened by Murray Elliot (CEO of ESC), Shelley Powell (Suncor Sr. VP Base Plant), and a friend and colleague of the person who died in the 2014 fatality.

In addition to listening to presentations, the participants of the symposium were asked to validate the recommendations and participate in two brainstorming sessions to answer some additional research questions: (1) why are hazards not identified or reported in the oil sands tailings operations and (2) how can elimination and substitution controls be implemented to manage the top seven hazards identified by ESC?

Sprint Brainstorming Activity

Participants were assigned to tables by ESC staff to ensure a mix of experience, job function, and company. There were 15 tables with six people per table on average. Attendees participated in a modified sprint brainstorming activity (after Knapp et al., 2016). Everyone was provided with Post-it® notes and given 5 minutes to anonymously write down as many answers as possible to the following question: "Why are hazards not identified or reported?". After the 5 minutes were up, tables randomly joined each other at a large, blank poster on the wall (six were spread out around the conference room). At these posters, facilitators began clustering the responses into emergent themes. At the end of the session, each group reported their findings back to the whole symposium.

Brain Writing or "8-1-2" Group Brainstorming

In the afternoon, the attendees were asked to address the second question: "How can elimination and substitution controls be implemented to manage the top seven hazards identified by ESC?". The brain writing or "8-1-2" ground brain storming method from John Donald (University of Guelph) and the National Initiative on Capacity Building and Knowledge Creation for Engineering Leadership (NICKEL) is an efficient way to generate and enhance solutions to common problems (Donald, 2018). Each person at the table comes up with an answer to the question, writes the solution down on a provided brainstorming sheet (Appendix D), and then passes this sheet to the person on their left. This person then has 2 minutes to enhance the original solution. The "8-1-2" moniker stems from eight people, one solution, and two-minute rotations. At the end of the session, the brainstorming sheets were provided to the U of A and typed up for analysis. The proposed elimination and substitution solutions were then added to the BT diagrams.

Results

Energy Safety Canada Tailings Hazard Inventory Results

Analysis of the ESC tailings hazard inventory indicated many of the hazards are similar across the participating oil sands operators, even though there is considerable variation in how each operator handles their tailings. The top seven hazards identified during facilitated discussions with the U of A were: (1) pipeline leak, (2) soft ground, (3) working on water, (4) working on ice, (5) operating spill boxes, (6) long-term exposure, and (7) emergency response. Local BT diagrams were created for each hazard based on the tailings operations. Qualitative analysis was completed as these diagrams are intended for use across the oil sands industry regardless of the level of experience or job function of the person using them. These diagrams will be used to visually showcase the hazardous events, potential threats, potential consequences, and mitigation techniques employed to prevent the hazardous event from occurring. They can also be used as a leading indicator tool, where management can use the bow tie to see if any controls are missing and fix these controls prior to an event occurring.

The following sections are excepts from Baker et al. (2019a) and provide detailed information about the BT diagrams as well as the visual tools. These tools should be displayed close to the job site as it is easier for workers to identify a pre-identified hazard (as per the Hazard Identification Transmission technique developed by Albert et al., 2014). The BT diagram for a pipeline leak is provided in the text below; the remaining six BT diagrams can be found in Appendix E.

Pipeline leak

Figure 17 is a BT diagram illustrating an unwanted event of a pipeline leak. The threats that could cause a pipeline leak were clustered into two main topics: (1) pipeline failures when a pipeline is struck, crushed, or splits due to internal or external corrosion or interaction with other pieces of equipment in the tailings operations and (2) process line up incorrect, which can occur when a drain is left open, a rupture disc overpressures because a valve is accidentally left closed, or when other worker errors occur.

The threat controls that prevent a pipeline leak from occurring are engineered controls such as design specifications, elevating pipeline on blocking (Figure 18), equipment strategies, or material selection. Threat controls could also include maintenance, such as quality assurance/control programs, joint integrity, and preventative maintenance programs (e.g., line rotation). The last threat control is operating procedures, such as structured rounds, predetermined operating envelopes, open-air calls to notify workers when operations are occurring, and proper housekeeping in the tailings area. All workers, including contractors, in tailings areas should have access to a radio so they can be notified when different operations are occurring.

If a pipeline leak were to occur in a tailings operation, mitigation controls would prevent a consequence from occurring. A typical pipeline leak response is implemented when a leak occurs. This procedure is designed to mitigate unwanted events such as worker injury or death. The steps in a typical pipeline leak response are as follows: (1) leak identified by worker, (2) notification procedure followed to ensure supervisors and other appropriate personnel are aware of the leak, (3) system is shut down, so there is no flow in the leaky line, and (4) a line approach procedure is followed to investigate the leak further.

Additional mitigation controls in the tailings area to prevent consequences affecting people are the permit policy, proper visibility so that leaks can be identified and managed, the area and hazards are known to workers, and there is a timely emergency response. If the area and the hazards are unknown to workers, there is an increased probability of a more severe consequence occurring because they are going into the situation blind. The permit policy attempts to mitigate this hazard by having a risk-based approach for when workers are working alone as well as a call-in procedure. During typical rounds, the worker will be alone; however, if there is anything out of the ordinary such as a known line leak or steam, they will be buddied up. Some pipes are put on blocking, and windrows are not pushed up against the side of the pipe. Elevating the pipe allows the whole pipe to be easily seen during rounds so leaks can be more easily identified. The speed at which first responders can arrive at a location will also influence the outcome of an incident.

Tailings operations are dynamic, and ESC members have identified the need for increased training in tailings operations to ensure area familiarity. Line names are unknown to people not involved in operations or planning. Some suggestions to mitigate this issue from ESC constitute maps with line names, cell names, and landmarks to be made available to workers, potentially in the permit office. There should also be increased supervision, area tours, and a permit process specific to the tailings area. There are rules and expectations for crossing pipelines on foot; training is required to ensure area personnel are aware of these expectations. People working in tailings operations also need to be aware of the soil subgrades that are more likely to erode and create underground caverns. More research should be done to determine how the different subgrades, such as clay and sand, react to a pipeline leak. There also needs to be radio training and awareness as new workers can be uncomfortable using radios.

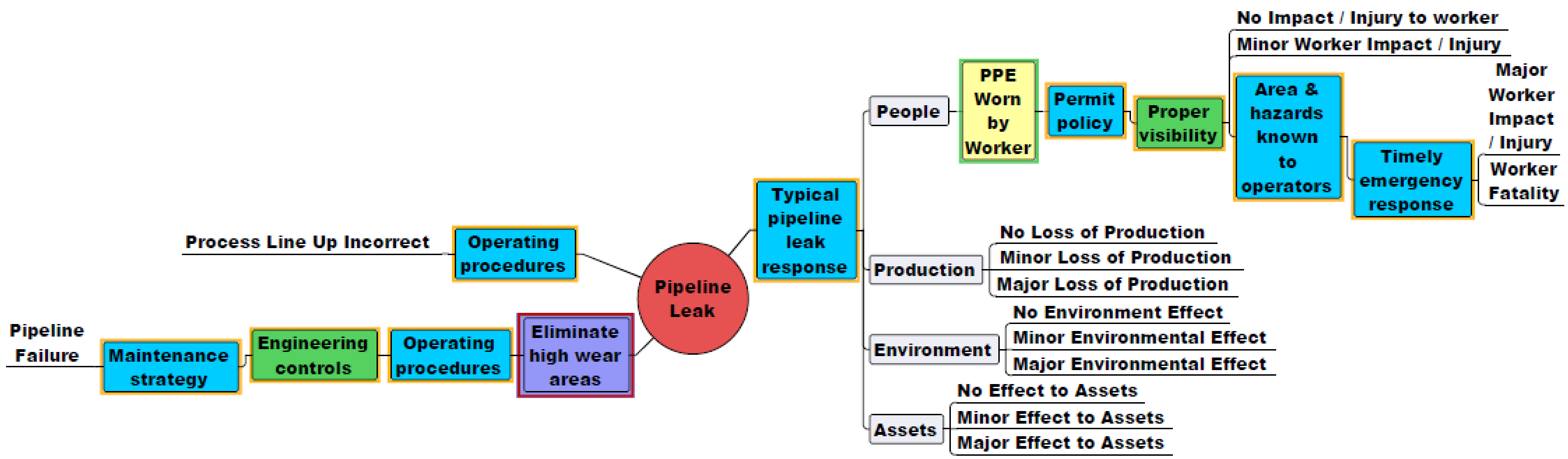


Figure 17. Pipeline leak bow tie diagram.

Figure 18. Example of a pipeline elevated on blocking for a full 360° view.

Green, yellow, and red boxes can be seen around the controls in the BT diagram (Figure 17). These coloured boxes indicate the level of effectiveness of each control (after Paltrinier at al., 2014). The effectiveness of each control was analyzed from an industry level. Some companies have more controls in place than others, but ESC felt more work could be done to mitigate these seven hazards across the oil sands tailings industry. For this reason, the majority of the controls are yellow, indicating they are in place but there is room for enhancement. Any controls in a red box are not in place or are ineffective. In this analysis, the controls are elimination and substitution suggestions from respondents who attended the TSS; this process will be discussed in more detail in the Phase II results and discussion section.

Soft ground

The four types of threats that could cause soft ground are: (1) abandoned sumps around tailings operations, (2) variations in the quality of discharge (different viscosities with higher or lower ratio of water and solids will lead to different construction ability; for example, less dense tailings (more water) have a liquid consistency that makes it difficult to build cell berms in the tailings discharge area), (3) cell construction (creation of containment areas for sand to be used for reclamation), and (4) heavy precipitation events or snowmelt leading to soft ground in the tailings areas. All of these are shown in the bow tie diagram Figure 45. The most important area of worker exposure is in the cells of the tailings discharge area, as soft ground is created daily by discharging wet tailings onto the sand. Soft ground can also be found in tailings recovery operations (TRO), in Accelerated De-Watering (ADW) operations, in cake production and storage areas, and on tailings roads, especially after heavy precipitation events or spring melt.

Threat controls to prevent soft ground from being created are engineered controls such as end of line devices (e.g., spoons) to dissipate the energy (Summer Photo (c), pp. 219) or sumps to drain the water. Maintenance strategies such as proper clean up to limit the amount of standing water in the tailings area and road maintenance are also used. The last two types of threat controls are administrative controls, including procedures where dozers are track packing or putting the discharge on overboard when the viscosity is too low and timely placement of reclamation materials to stabilize the ground.

Soft ground frequently manifests and affects people, environment, assets, and production. The consequences to people will be the focus here, the severity of which varies depending on the softness of the ground. People can become stuck in soft ground if they are surveying or monitoring pipelines on foot; they can also become stuck or sunk in a bulldozer or light vehicle depending on the softness of the sand in the cells.

The mitigation controls in place include a cell construction plan to increase the stability of the ground. Procedures are used to keep people away from the soft ground near the tailings ponds and the discharge in the tailings discharge area. The procedures differ depending on the location. For example, the low beach (area closest to the pond, with the highest fines content and lowest water table/saturation) requires more precautions to keep workers safe. Procedures state there is to be no foot traffic and no terrestrial equipment access. These procedures are taught during training. Training is an essential mitigation control as new employees may not know that an area is soft ground. For example, the top looks as dry as the desert in the TRO cells and cake areas, but this is a thin crust and a worker could very easily get stuck; for this reason, no one is allowed to walk in this area. Specialized equipment is required, and a geotechnical engineer should be involved in work planning. Restrictions also limit how close operators can get to a tailings discharge in a dozer.

On the other hand, care is still required at the high beach (area closest to the dyke, with lower fines content and the highest water table) as soft spots are possible as there is little or no compaction effort in this area. Even though the risk level is lower in this area, a trafficability assessment is still required before work can begin. Operators should watch for signs of liquefaction (boils, cracking, ground deformation, water rising to the surface). Geotechnical engineers may need to be involved in work planning.

Permit policies are used to keep track of who is in the area, determine if they are competent to work in the area, and what jobs or tasks they are doing. They also include proper PPE and whether a geotechnical engineer should be involved in the work planning. The permit department is also responsible for putting up signage and fencing to mark soft ground. This is a challenging job as tailings operations are continually changing, and therefore so is the location of soft ground. Access signs and a check-in procedure near active cells are used at some sites. Many visitors are also accompanied by a cell operator who knows the hazards of the area. Deepwater sump signs can be seen at the majority of the sites, and any area that is impassable is barricaded off. Timely emergency response to rescue workers who are stuck on foot or in a dozer includes the potential use of snow fencing for self-rescue or a rescue skid (discussed below). Snow fencing is coiled within the cabs of operating equipment and can be laid out on soft ground to permit egress from the area; the increased surface area of the path created by the laid-out fencing allowing for temporary traverse of the soft area (much like a snow shoe). Drills and simulations should be conducted to train first responders. The different ways a person could get mired in the tailings operations should be considered when creating emergency response plans (ERPs) and conducting simulations. Some possible scenarios are a person ejected from a boat in a collision with a submerged obstacle, getting stuck walking on foot in tailings operations from stuck equipment or when surveying, or falling off equipment or a boat.

Working on water

Working on water is a regular part of tailings operations (see bow tie diagram in Figure 46). The threats of concern that could cause issues while working on water are as follows: (1) fuel lines in tailings ponds, (2) live power lines in tailings ponds, (3) floating obstacles in tailings ponds, and (4) other environmental conditions.

The controls for these four threats are mostly administrative controls, such as procedures, training, and minimum distance requirements from fuel and power lines that supply the barges or dredges and from the edge of the tailings ponds, as well as flagging and signage to notify workers where water and lines could be located. Some engineering controls such as buoys are also used to keep the lines on top of the water; ground faults can mitigate any issues with live power lines. Good housekeeping is also essential to prevent boats from contacting floating obstacles in the ponds.

It is currently impossible to avoid working on water in tailings operations. Some consequences of water work could be a person ejected from a boat after a collision with a submerged obstacle, falling off walkways or boats or dredges, or becoming stuck on the pond because of intense fog or lightning.

The majority of the time, workers are aware they are working on or around water, and the risk is quite low as the hazards are well managed through the use of engineering controls such as guard rails. Administrative controls such as a rescue plan, lanes of entry for emergency evacuation, standby rescue boats or shore watch, and working alone policies are also important to keep people safe. Self-rescue, ARGO training, and proper PPE and rescue equipment such as immersion suits, personal flotation devices (PFDs), communication radios, and life rings also help to mitigate consequences.

The ponds are well marked, but the permit office plays a crucial role in informing new workers and contractors of the hazards in the area. Administrative controls also include notification systems when environmental conditions such as fog or lightning can affect operations on the ponds. At most sites, it is standard for anyone on the pond to evacuate to shelter, away from the pond, in such situations. Dredge operators are to shelter in place in the cab of the dredge until the situation subsides.

Timely emergency response is also crucial. Life ring/throw rope familiarity and training is important because life rings will not be helpful if workers do not know how to throw it or the rope is damp or sun rotten. Mock drills are also helpful to ensure workers have practice pulling in dummies from the tailings pond into a boat.

Working on ice

Working on ice is a large part of the tailing operations as the Athabasca oil sands region experiences below-freezing temperatures for a significant part of the year. The bow tie diagram in Figure 47 show the threats that are of concern and could cause issues while working on ice: (1) tailings ponds in winter, (2) underutilized roads, (3) pipes leaking in cells in a low spot, (4) areas of standing water (precipitation, spring melt or runoff), (5) sumps, and (6) tailings beaches in winter.

The controls for these six threats are mostly administrative controls such as procedures, training, and minimum distance requirements from sumps and the edge of tailings ponds. Additional measures include flagging and signage to notify workers where standing water, sumps, ice, and tailings ponds are located and making sure that workers are working on the stable beach, and not ice, in the winter.

Engineering controls are also in place to prevent beaches from being overbuilt, which can cause water to pond at the discharge point. Cell maintenance also helps to prevent issues from occurring when operators are working on ice or water. The dozers clear travel routes and turn up sand to minimize hazards in the cells. Road maintenance is also essential, especially in underutilized areas; closures and temporary deactivation can occur if roads are not maintained.

Avoiding working on ice in tailings operations is difficult, and such work can introduce different potential consequences such as a person or equipment falling through the ice. Two scenarios when a person could be working on ice are as follows: (1) Worker knows they are over ice, and (2) Worker does not know they are over ice.

If workers are aware they are working over ice, then the risk is quite low and the hazards are well managed by engineering controls such as an engineered ice pad and gas detection when boring holes in the ice. Administrative controls such as ice thickness checks, monitoring, rescue plans, strength testing, lanes of entry for emergency evacuation, standby rescue boats or shore watch, and working alone policies are also important to keep people safe. Ice awareness training from the Government of Alberta, self-rescue, ice rescue, and proper PPE and rescue equipment such as immersion suits, PFDs, communication radios, and life rings also help to mitigate consequences.

However, if workers do not know they are working on the ice, then the risk is very high, and the hazards can be poorly managed. Workers typically end up on ice by accident when they are unfamiliar with the area or are unaware of the existence of a standing body of water. To prevent severe consequences, hazard awareness, signage, area familiarity, and the permit office are very important to communicate the risk to people in the area. To prevent a significant worker injury or even a fatality, training for the area as well as self-rescue training is extremely important. Workers should also be provided with the proper PPE, such as a PFD or immersion suit. However, this can be challenging because workers may not have this equipment if they are unaware they are working on the ice.

Timely emergency response is also important if a person falls into water or through the ice. The 1-10-1 rule states that there is 1 minute to catch a breath and relax, 10 minutes to self-rescue before muscle failure, and 1 hour to receive emergency assistance before death from hypothermia. If self-rescue is not possible, then emergency response teams only have 1 hour to complete a rescue, which is a tight timeline in tailings operations.

First responders should also be practicing thin ice and on-water rescue simulations to keep themselves safe if an incident were to occur. Ice rescue technician training for high-risk over-ice work is valuable for workers, contractors, and emergency services. Life ring/throw rope familiarity and training is also important because the life ring will not be helpful if workers do not know how to it or the rope is frozen or sun rotten.

Operating spill boxes

A spill box is a device, similar to a weir, that is designed to capture sand and allow water to flow into the tailings pond for use as recycled process water (Figures 19 and 20). The operation of spill boxes was identified as one of the top hazardous activities across all oil sands operators. This respect and concern for the operation of a spill box indicates that workers have a low-risk tolerance for this activity and are concerned with the operation, making them extra vigilant when installing the boards.

Figure 19. Out of service spill box with handrails installed.

Figure 20. Spill box being installed for service.

The bow tie diagram in Figure 48 shows the four main activities that could cause an issue with the operation of a spill box: (1) crushing during install of the spill box, (2) slipping off the dozer when adding boards to the box, (3) wrist issues when adding boards to the box, and (4) becoming stuck in soft ground.

Spill boxes act as a weir to capture sand while allowing process water to flow through and be recycled for use in the rest of the mine. As more sand is added to the tailings discharge area, the spill box must be modified accordingly to continue capturing sand; this is done by adding 2' × 10' boards to the spill box. To add the boards to a spill box, a worker must stand on the side of the dozer push arm and install the board. Engineered and administrative controls are used to mitigate the consequences of this activity. The engineered controls include the construction of a platform over top of the spill box and installing handrails (Figure 19). The administrative procedures include training and a spill board maintenance procedure (indicating to switch out and drain the cell, i.e., putting the cell on overboard).

Administrative controls such as spill board and cell maintenance, and procedures prevent the dozer from contacting the spill box while setting up and prevent the spill box from washing out into the pond.

If an issue with spill box operation were to occur, many threat controls are in place to prevent a serious consequence from occurring. The first are related to emergency response: a shore watch must be in place and workers accessing the area must carry a radio and always use the buddy system. Administrative controls include permit policies, including dozer and/or equipment operation only being permitted within a certain proximity of ponded water, spill boxes, and live pours.

Mitigation controls also include appropriate PPE. For example, all personnel are required to have a PFD when working within 15 m of any shoreline, boat, or water access point. Engineering controls such as tailings dyke and deposition cell design are in place to optimize cell spill box location and effectiveness for water drainage/watershed.

Long-term exposure

Long-term exposure hazards in the oil sands industry are becoming a popular topic and area of concern. Historically, this was more of an occupational hygiene area, but is becoming more prominent in the worker safety domain. Five long-term exposure threats to people have been identified (see bow tie diagram in Figure 49): (1) respirable silica and other particulates, (2) respirable coke dust, (3) Naturally Occurring Radioactive Materials (NORMs), (4) hydrocarbons and other chemicals (volatile organic compounds (VOC), hydrogen sulfide (H_2S), etc.), and (5) noise.

Controls have been implemented to prevent workers from coming into contact with these threats. These threat controls include specific awareness training for all five of these threats, standards and procedures, dust suppressants (water or chemical), specific exposure monitoring (in both high- and low-risk areas), and housekeeping of equipment. Handheld monitors can be rented for a nominal cost to complete testing; workers also appreciate a copy of this report. Housekeeping can include keeping equipment clean and filter changes on flight vehicles and heavy equipment. The controls for coke dust controls and silica dust are the same.

The main pathway for exposure to hydrocarbons is falling into a tailings pond or being covered in tailings and bitumen if there is a pipe leak. Engineering controls such as hand and guard rails prevent workers from easily falling into the ponds. Housekeeping and maintenance of equipment are also important to prevent contact with the hazard. Hydrocarbon fumes can still be inhaled, and for this reason exposure monitoring occurs on the ponds. Providing easy access to Safety Data Sheets (SDS) can help to change worker perceptions of the contents of the tailings ponds.

Despite these threat controls, workers will still be exposed to these hazards. To mitigate the consequences, the following controls have been put in place: availability of proper PPE, minimizing exposure, regular health assessments, audits of standards and procedures to ensure they are being followed (including exposure limits), use of survival suits, decontamination/hygiene controls, and timely emergency response.

The PPE required to mitigate consequences associated with long-term exposure threats includes Tyvek, rubber boots, respiratory protective equipment (RPE), hearing protection, PFDs, survival suits, etc. The majority of the sites have protocols for when to mask up, even in low-risk areas. When it is dusty, workers are expected to put their masks on or, if possible, remain in the cab of their vehicle, dredge, or boat.

Threats such as silica and coke dust are inherent to tailings operations, so workers must do their best to minimize exposure by doing things such as driving with their windows up, turning the cabin air filter to recirculate, and avoiding on-ground work in tailings in extreme dry/windy times.

Health assessments such as audiometry for noise and hearing loss and X-ray testing and pulmonary lung function testing after exposure to silica or coke dust (as coke and silica often travel together, especially in tailings environments) are used to assess the detrimental effects of long-term exposure hazards.

Survival suits, decontamination after exposure, and hygiene controls are fundamental strategies for preventing significant worker impact/injuries or even fatalities. Timely emergency response is also significant, especially if someone falls into a tailings pond. Standardization for self-rescue training across sites could be valuable and could include ladders on boats and dredges as well as mock drills for the rescue of conscious and mobile workers, immobile workers, and unconscious workers.

Emergency response

Emergency response or the ability to rescue in tailings operations is a topic that was brought up by multiple frontline workers at multiple operations during the interview process as well as the ESC task force. Six threats could cause issues with emergency response (see bow tie diagram in Figure 50): (1) preparedness of emergency response personnel to rescue workers, (2) road conditions, (3) access to equipment, (4) access to rescue equipment, (5) weather, and (6) emergency meeting points.

One of the biggest concerns regarding emergency response in the tailings operations is the preparedness of emergency response personnel to rescue workers. The best way to mitigate this hazard is by completing mock drills where workers and emergency response personnel work together to rescue a worker from a realistic situation.

The roads are ever-changing in tailings operations, and getting stuck in soft ground or mud is very easy. To mitigate issues with road conditions, engineered controls such as using different materials for road construction can help to improve the road quality. Graders can also be used to maintain the road quality and make it easier for vehicles to travel. Dozers carrying a pipe to compact the sand and even out the road are used to make the roads passable. The permit office also plays an important role by letting people know about changes to road configuration, the location of potential traffic issues, and other poor road conditions for which responders should be prepared.

Redundancy and availability are important to ensure that the equipment is available when it is needed and not being used elsewhere in the mine. It is also essential to have an Emergency Management Program (EMP) in place so responders know what type of equipment is needed and to ensure worker competency. One of the best ways to ensure worker competency is by conducting simulations and drills. Weather can also delay emergency response. Fog, smoke, lightning, and wind can make rescue very difficult, if not impossible, until weather conditions improve. Therefore, it is vital that EMPs take changing weather conditions into account and contingency plans are in place.

The last threat that can cause delayed emergency response is the location of the emergency meeting point and the ability of first responders to find the location. Escorts from the tailings operations are key to making sure that first responders can find the meeting point and be taken quickly to the location of the emergency in the tailings operations. An EMP is important in addition to drills and simulations, so that workers and first responders know how to react to an incident as quickly, safely, and efficiently as possible. Without the practice and the plan, it will be much more difficult to conduct a rescue.

One of the critical mitigation controls to prevent consequences related to delayed emergency response is having the correct rescue equipment; PPE must be available and in good repair, and workers must know how to use it. Rescue equipment includes items such as defibrillators, stretchers, blankets, ring throw ropes, PFDs/immersion suits/life jackets, snow fencing, rescue skids, etc. Some operators have built rescue skids (Figure 21), which are floating platforms that can be pulled behind a dozer and are available at all live cells. Workers receive training in how to hook up the rescue skid and drive out to a stuck or sunk bulldozer to rescue the operator. Each skid is equipped with a backboard in case of a serious incident.

Worker competency is an important mitigation control to prevent a situation from escalating during an emergency, including workers following the appropriate notification and alert system and workers being fit for duty, so their response time is quick and cognitive abilities are not impaired.

Not having people work alone in tailings operations will significantly impact the consequences of an incident. Having a shore watch or redundant staff allows for quick notification of an issue as well as ensuring a first responder is on the job site as opposed to waiting for fire and rescue to reach the location of the emergency.

Administrative controls such as permit policies, emergency shut down procedures, and call in/sign in are very important for keeping people safe in tailings operations. Emergency shut down procedures can be challenging as they are tied to the control room. Call in/sign in allows for a roster to be created for who is in the area and ensures all employees are accounted for. If working alone cannot be avoided, call-in procedures can notify dispatch that a worker is unresponsive; however, the time delay associated with a call-in system means that this should not be the only mitigation strategy.

The last mitigation strategy is training. Emergency response training but also first aid, ice rescue, self-rescue, and Marine Emergency Duties Survival Systems Training (MEDA3) can be mandatory depending on the site and area of tailings where a worker is located. Self-rescue is one of the most essential aspects of training that can be completed.

Figure 21. Rescue skids for a tailings discharge area that can be hooked up to a bulldozer.

Tailings Incident Database Results

The participating companies provided four years (2014-2017) of tailings incident data. These data were analyzed by categorizing incidents into common hazard groups. Table 7 was used for the classification and ground hazard was added to the list of possible categories. Incidents involving ground hazards made up 23% of total incidents, one of which was the 2014 fatality.

The frequency of the total incidents from 2013-2017 related to ground hazards was normalized based on tailings area (m^2) of each site and plotted in Figure 22. Slip/trip/fall (purple bar) made up 2% of the total incidents, which occurred on varying terrain (ice, mud, uneven ground, and water). Stuck and sunk equipment (yellow bars) made up 13 and 3% of incidents, respectively, with 83% of those incidents being stuck or sunk dozers. Reported ground hazards made up 11% of the incidents, with the largest causes making up this category being soft ground (49%), surface erosion features (22%), subsurface erosion features (6%), and slope instability (23%). Damage through contact and geotechnical instrument damage (red bars) made up 5 and 1% of incidents, respectively, with the majority of the damaged instruments being piezometers. The damage through contact category included a range of objects from pipeline components to berms. Pipeline component leaks, failures, and damage made up 38, 17, and 1% of the incidents, respectively, and pipeline missing components, frozen pipelines, and worker error made up 0.4, 4, and 1%, respectively. Leaving drain valves open represented the majority of incidents of pipeline worker error.

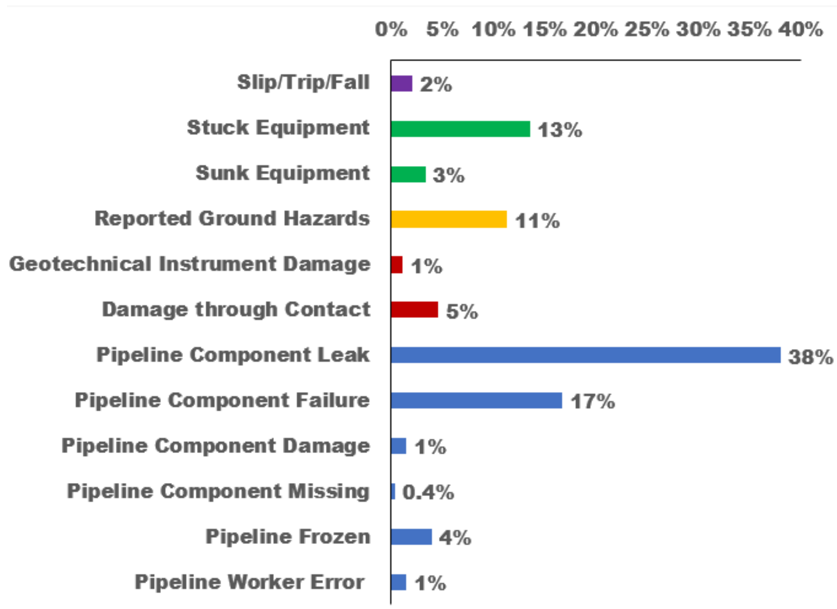


Figure 22. Incidents related to ground hazards, with data from the incident databases of multiple oil sands companies, 2014-2017.

To make this information useful to companies, specific figures were created for the top four incidents caused by ground hazards: pipeline component leak, pipeline component failure, stuck equipment, and reported ground hazards. We subdivided these sections into the particular component that is leaking or failing, piece of equipment becoming stuck, and reported ground hazard, so companies can prioritize appropriately in their maintenance, quality assurance programs, and communications regarding high-risk areas to workers.

Pipeline leaks and failures are the most common hazard in the incident database. If not caught quickly, they become a precursory event to a ground hazard in the form of soft ground, surface erosion, subsurface erosion, or slope instability. The components identified as leaking in the incident database are plotted in Figure 23. The leaks were mainly the pipelines themselves, followed by pipeline connections (gaskets, flanges, seals, couplers, etc.). Miscellaneous items include drains, vents, and pumps. Based on this analysis, leaks in the pipes themselves are the most common (13% of all component leaks). This could lead quality assurance and maintenance to change their programs and potentially rotate pipes more often or check the thickness of the pipes at a different rate. Elimination and substitution principles could also be applied to minimize the number of connections (12% of all component leaks) as these are high wear areas from internal abrasion and prone to leaking.

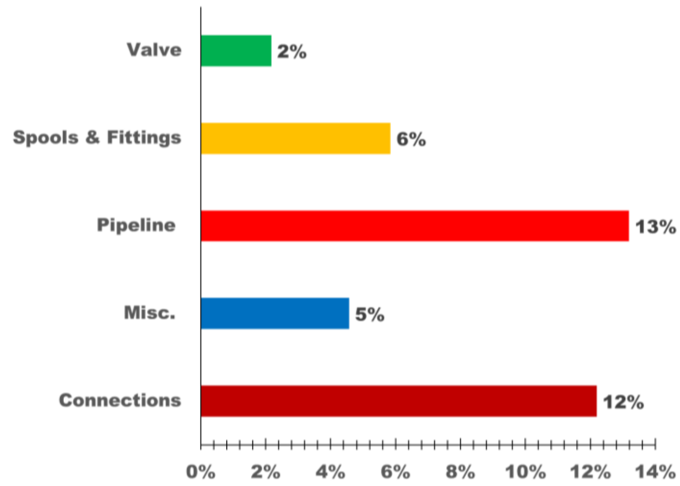


Figure 23. Reported pipeline component leaks from tailings incident databases.

The same method was applied for a more detailed analysis of pipeline component failures (Figure 24). Rupture disc failures were the most common occurrence (7% of component failures), the root cause of which is probably worker error instead of process over pressuring. Rupture disc overpressures typically occur in tailings operations because a valve is accidentally left closed. The second most common are failures of spools, elbows, and other fittings (4% of component failures). Again, quality assurance programs could change their procedures to focus on these high wear points to decrease the occurrence of line failures; design engineers could also attempt to limit the number of spools and fittings in the design.

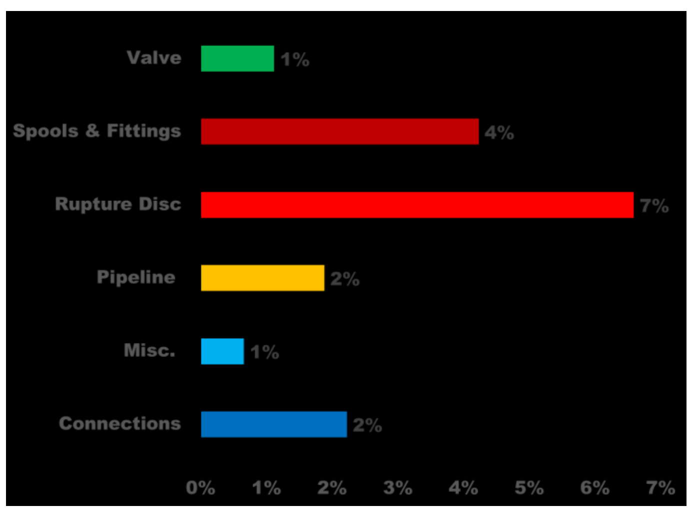


Figure 24. Reported pipeline component failures from tailings incident databases.

Stuck equipment was the next most frequent type of incident reported in the database that relates to a ground hazard. The types of equipment reported as stuck are shown in Figure 25. The most common piece of equipment getting stuck in the tailings operations is bulldozers (11% of total ground hazards). Bulldozers most commonly become stuck in soft ground or cuts (erosion features) in the cells. Trucks can become stuck on any of the roads in tailings areas (1% of total ground hazards). Workers noted the existence of "three seasons: muddy, dusty, and frozen". Each season can cause equipment to become stuck, and heavy precipitation events and spring melt cause extremely deep and muddy soft ground conditions that make driving very challenging. Workers also noted that the dry sand in the summer is akin to driving on flour and can also lead to trucks becoming stuck. Some workers told us that the best driving conditions are actually in the winter when there is hard ice on top of the sand. The other category (1% of total ground hazards) includes one-off occurrences of other equipment becoming stuck in the tailings area, such as a loader, skid steer, back hoe, haul trucks, wiggle wagon, and graders.

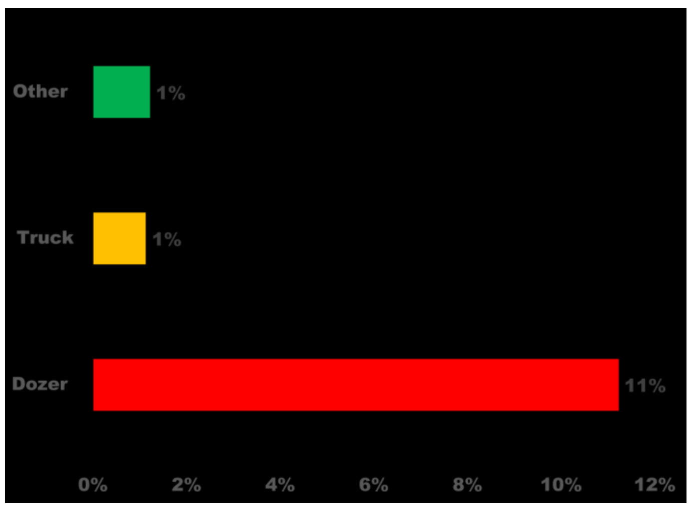


Figure 25. Reported stuck equipment from tailings incident databases.

The last category analyzed in greater detail was reported ground hazards (Figure 26). For the purposes of this project, as the reported ground hazards were explicitly stated by the workers in the incident database and classified into four main categories as per the U of A's ground hazard assessment: soft ground, surface erosion, subsurface erosion, and slope failures. This analysis was completed a little differently to determine the likelihood of reported ground hazards occurring at oil sands tailings operations. All of the reported incidents could cause or did cause a ground hazard; however, there is insufficient detail in the incident database to state that as fact. Any of the incidents classified in the other categories could cause multiple ground hazards simultaneously, and so were not included to determine the likelihood values. Soft ground was the most common ground hazard reported (49% of all reported ground hazards), with incidents including standing water on roads and drainage problems.

Slope instability and surface erosion were close in terms of reported incidents (23 and 22% of the total reported ground hazards, respectively). Incidents classified in these categories included cell berm breaks for slope instability and washouts for surface erosion. Subsurface erosion occurred the least of the four categories (6% of all reported ground hazards). Incidents in this category included the formation of sinkholes and the cavern that caused the 2014 fatality.

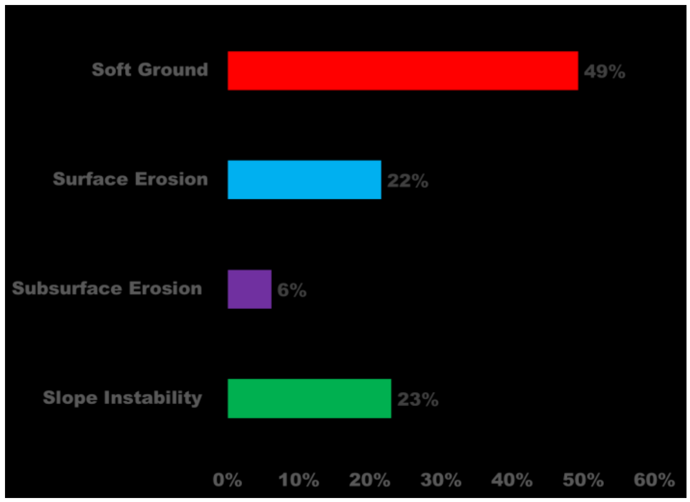


Figure 26. Reported ground hazards from tailings incident databases.

Interview Results

A total of 158 employees (frontline tailings workers, safety advisors, supervisors, leadership, etc.) and regional contractors were interviewed. All workers agreed that tailings operations are a dynamic environment with a high risk of exposure to hazards. The overall impression after analyzing the interviews is one of juxtaposition. People who work in tailings feel like they are forgotten: "tailings is the missing piece of the puzzle". They understand tailings is a waste stream: "The tailings are called the a**-end of the operation. All the good stuff has been taken out and we're dealing with what is left". But there is also an overarching sense of pride, evident in the way workers talk about the operations: "I am proud of what we are doing" and "people don't realize the magnitude and importance of tailings. The long-range plan runs the show and mine life, tailings is everything". This pride is also seen in the respect that the workers have for each other: "Got everyone's back. Everyone is watching out for each other" and "Great guys. Great group of people".

Word clouds were used to ensure we were on the right track with our theorized codes for hazards in the tailings operations (Figure 27). The size of the word represents its frequency of appearance in the interview data. For example, ground, pipe, line, water, and sand were some of the most common hazards mentioned when interviewees were asked what hazards they saw around tailings facilities, dykes, and transport systems. This indicates these hazards are relatively well known to the participants. However, further analysis indicated that 15% of participants did not identify a single ground hazard in their interview. This is concerning as ground hazards are prominent in tailings operations (23% of reported incidents related to ground hazards) and the top two hazards indicated by tailings safety experts were ground hazards (pipeline leak and soft ground). This gap signifies the need for enhanced tools to assist in the identification of ground hazards. These specific tools will be discussed later in the report.

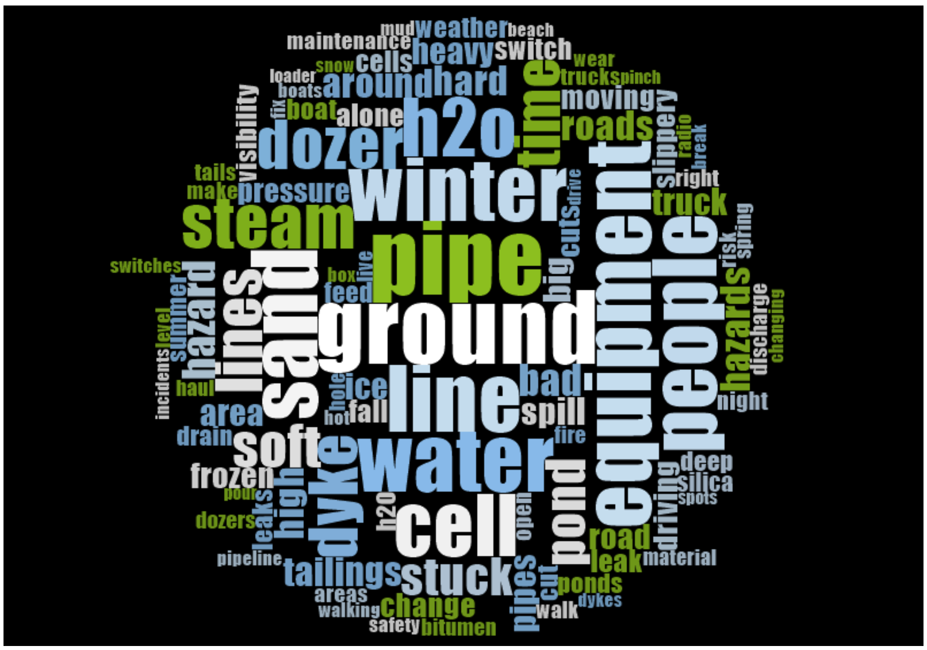


Figure 27. Word cloud of the 100 most common hazards identified when interviewees were asked what hazards they saw around tailings facilities, dykes, and transport systems.

Questions were also posed to the interviewees to assist in the development of recommendations for oil sands tailings safety best practices. The results of this analysis are shown in Figure 28. Seven recommendations emerged from the data analysis: (1) increased communication within industry, (2) increased communication within companies, (3) enhancements to hazard identification tools, (4) critically evaluate current operations, (5) increase resources, (6) tailings-specific training, and (7) regional standardization. On the left-hand side of the figure are representative quotes from the NVivo analysis. These quotes were coded into first-order themes (in the middle of the figure). Once these first-order themes were identified, they were then combined to determine the aggregate dimension or recommendations. These recommendations are for the oil sands industry as a whole, and are not directed at any one organization.

All of these recommendations have an undertone of increasing tailings-specific communications. Many of the procedures that are currently in place to protect workers are related to the mine or the plant. A comment from one participant, noting that "[p]rocedures are black and white, but tailings is a grey area. It is hard to make it black and white", indicates the need for tailings-specific procedures, training, and safety interventions.

Themes of safety culture also emerged in each of the recommendations. Safety culture is an intricate topic, unique to the organization; however, a similar culture is evident across the oil sands tailings industry. This is an important finding that must be shared with the industry. When it comes to safety, all operators and regional contractors are similar; there is no competitive advantage to be had in this regard. The prevention of incidents in tailings operations as well as this shared industrial safety culture are common goals that will hopefully allow for the continued collaboration of the participants in this study.

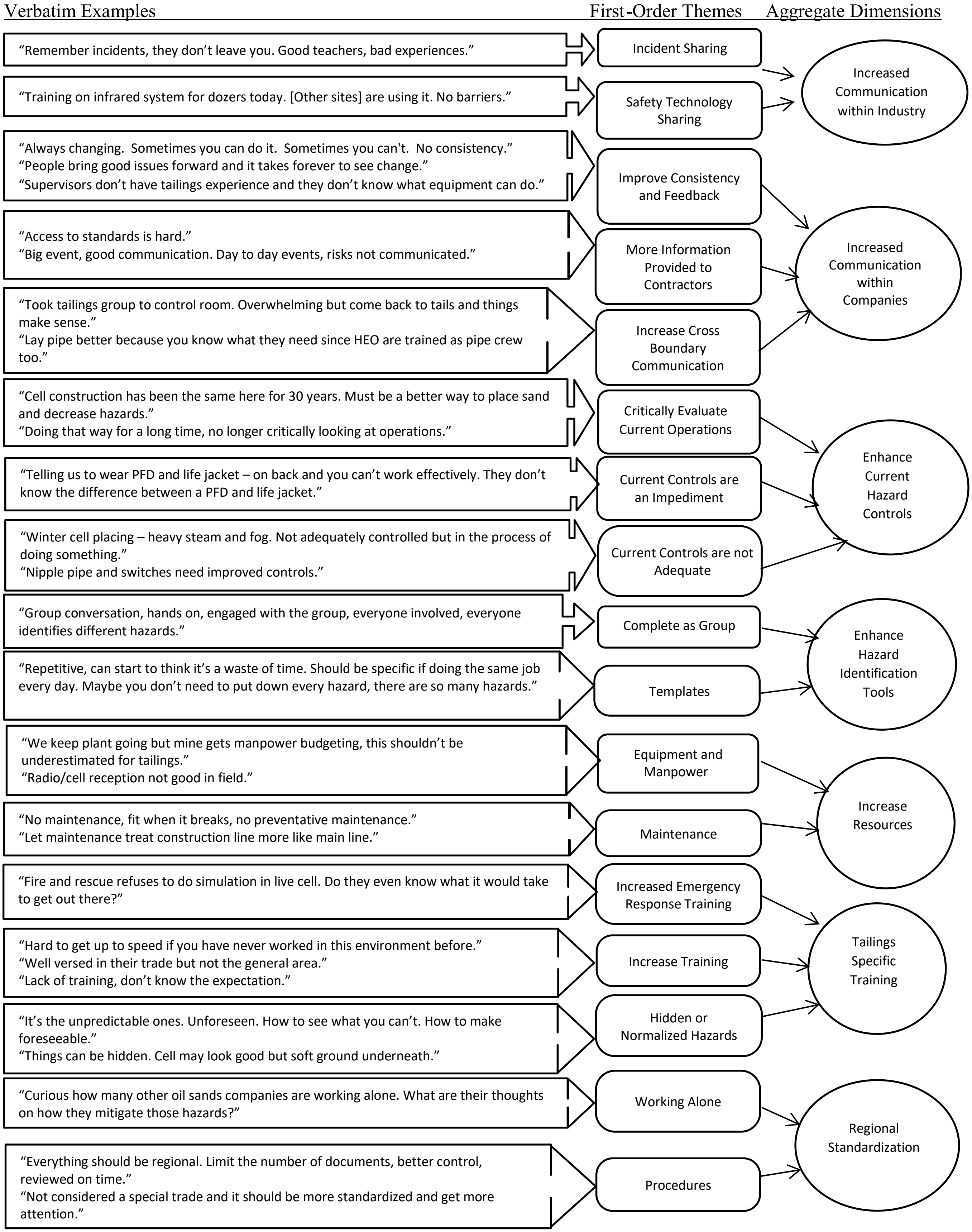


Figure 28. Data structure: representative quotes, themes, and aggregate dimensions for recommendations from interview data.

University of Alberta Ground Hazard Inventory Findings

As tailings operations are unique and constantly changing, summer, winter, and spring site visits were completed and a photo database of over 1000 photos from the different tailings operations was compiled. Geotechnical engineers are well aware of the ground hazards that can manifest in tailings operations, but 15% of the interviewees did not identify a single ground hazard in their interview. Workers with 5-10 years of experience identified 10 ground hazards on average but workers with other levels of experience identified only two ground hazards on average. Additionally, 23% of the incidents in the database related to tailings, indicating that current controls to mitigate ground hazards could be enhanced along with training. Tables 8-11 were developed to inform workers of the ground hazards in their work environment, allowing them to be more effectively controlled. These tools are meant to be used in combination with current hazard identification tools, such as field level hazard assessments (FLHAs) that assist workers in identifying hazards related to their job task. The goal of these ground hazard tools is to increase awareness of work environment hazards that can pose a significant risk to worker safety.

Table 8 discusses the four main ground hazards identified in the oil sands tailings operations: soft ground, surface erosion features, subsurface erosion features, and slope instability. It is important to note that multiple ground hazards can manifest simultaneously. Temporal factors such as heavy precipitation events, dust, spring thaw, and winter conditions (ice, snow-covered ground, steam, and darkness) affect the likelihood of a ground hazard manifesting, such as an increase in soft ground after a heavy precipitation event. Snowfall and steam can mask erosion features such as cuts in the tailings discharge area.

The likelihood values in Table 8 were determined using the incident database. The likelihood of the reported ground hazards was 49% for soft ground, 23% for slope instability, 22% for surface erosion, and 6% for subsurface erosion. The consequences were also determined using the incident database and considering the severity of the incidents related to each ground hazard. Slope instability was ranked as a high consequence, as this could lead to a loss of containment event in the tailings discharge area or at a tailings pond. Loss of containment could have a detrimental affect on workers, environment, and potentially the public. Soft ground is a low consequence event as it usually results in stuck equipment with minimal impact to workers and assets. Surface erosion is ranked as medium consequence as incidents include stuck equipment but also sunk equipment if bulldozers fall into a large cut. Subsurface erosion is high consequence as this can result in the formation of underground caverns similar to the one that led to the fatality in 2014.

The controls for these hazards are similar, and are mainly comprised of operating procedures (including preventative maintenance, structured rounds, and reporting systems) and training. Workers identified hazard mitigation strategies in their interviews, 54% of which related to administrative controls such as safe operating distances from discharge lines or working alone procedures. Engineers confirmed this high proportion of administrative controls. Elimination/substitution controls are incorporated into the design stage, but controls for daily field operations are usually administrative. Engineering controls are also used to manage risk, including end of line devices to dissipate kinetic energy and decrease the severity of cuts forming in the cells (Figure 6), elevating the pipelines on blocking for full visibility (Figure 18), and infrared cameras on bulldozers to increase visibility in steam.

Table 8. Framework for hazards at oil sands tailings operations.

Hazard	Manifestation	Temporal Factors	Likelihood	Consequence	Controls
Soft Ground	Poor/not-trafficable roads, flooded cells, overpoured cells, spill and uncontrolled releases, drainage problems, bubble cap burst in cell, water coming up through the ground	Heavy rain, dust, spring thaw, winter conditions: ice, snow covered ground, steam, reduced daylight hours	Very Likely	Low	Operating Procedures, Training & Engineering Controls
Surface Erosion Features	Washouts, erosion gullies, cell berm breach, cracks in the benches and berms, cuts in the cells, uneven ground		Likely	Medium	
Subsurface Erosion Features	Sink holes, ground instability, caverns		Unlikely	High	
Slope Instability	Sloughing/failures of benches and berms surrounding the tailings discharge areas and tailings ponds, berm, cell and dyke breeches		Likely	High	

In addition to the ground hazard framework, three ground hazard photo databases were created to visually show how these four ground hazards can manifest at tailings operations in different seasons (Tables 9-11). Each photo database contains representative photos of the ground hazards; enhanced versions of the photos can be found in Appendix F as well as potential consequences if the ground hazard were to manifest and not be adequately controlled. Precursory conditions that could indicate a potential ground hazard are listed, and the final column is the temporal factors that affect the likelihood of a hazard manifesting or being identified in the work environment. Similar to the BTs, these photos are another visual tool to increase the probability of hazards being identified in the work environment. They should also be displayed close to the work environment as per Albert et al. (2014).

An illustrative example of information in the ground hazard photo database is given for the manifestation of both surface erosion and soft ground in the tailings discharge area in winter and summer. Spring was not included as the spring manifestation is similar to that in summer. A comparison of photo (c) in Table 9 (summer) shows the tailings being discharged into a cell in the tailings discharge area. The discharge is comprised of silica sand, process water, fine tailings, residual bitumen, and other chemicals at approximately 40-50 °C (depending on the ambient temperature and discharge temperatures from the extraction facility). When this mixture hits the sand, there is the potential for surface erosion features called cuts to form. Cuts can range in size depending on the quality of the feed and the level of compaction of the sand; some interviewees told us that cuts can be as large as ~6 m deep, 9-91 m long, and 9-12m wide. Soft ground also forms in this area as the silica is suspended in water for fluidized transport. The tailings discharge is designed to have water flow to the middle so it can be pumped to other areas of the operation; however, some of the process water becomes entrapped with the silica sand and bulldozers must travel back and forth over the sand ("track packing") to squeeze out the water and achieve the desired level of compaction for reclamation. Interactions between the water, residual bitumen, fines, chemicals, and sand are not fully understood so achieving compaction can be challenging; the cells can feature very soft ground and areas full of material that has a soup-like consistency. With both the soft ground and erosion features, bulldozers can become stuck; if the piece of equipment cannot move, another operator must come out (by track packing) to collect the worker and tow the stuck bulldozer back to solid ground. This consequence is relatively minor, representing decreased efficiency as two operators are not working and potential minor worker injury. However, the potential for more severe consequences can manifest if the bulldozer becomes sunk. Water and sand can rush in and fill a dozer quickly, resulting in the potential for worker injury or even fatality and hefty expenses to recover and refurbish the bulldozer. Water can also rush out of seemingly compacted ground and result in a sudden drop in ground level. This phenomenon can also lead to a bulldozer becoming stuck or sunk.

Photo (d) in Table 10 (winter) also shows the discharge into the tailings operations, but the temperature differential between then discharge and the air (which can be ~80 °C, as temperatures of -30 °C and colder are common in the Athabasca region) creates a thick steam making it extremely challenging to operate let alone identify the soft ground and erosion features mentioned above. Such is an example of a temporal factor that decreases the likelihood of a worker identifying a hazard and could increase the consequences depending on the size of the cut or softness of the ground. Operating in the dust in the summer and at night year-round also decreases the likelihood of a hazard being identified.

Table 9. Summer ground hazard database of potential consequences, precursory conditions, and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

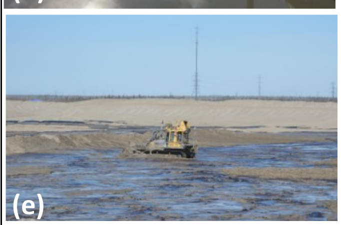
Photo of Ground Hazard	Description	Potential Consequences	Precursory Conditions	Temporal Factors
Slope Instability  	Photo (a): View of the open pit (~30 m deep). Steep slopes (~55°) typical of mining operations. A failed slope can be seen (top) at an inactive pit area Photo (b): Bull dozer creating steep cell walls in tailings discharge area	• Worker injury or fatality by crushing &/or equipment damage • Loss of containment: leaks and cell berm breach	• Sloughing • Soft material created in the cell from tailings discharge • Erosion gullies	• Heavy precipitation events increase instability • Dust and wind reduce visibility • Visibility decreases at night
Soft Ground   	Photo (c): View of tailings discharge area and end of line device (dissipates kinetic energy) Photo (d): Pumps downslope of tailings dam. Pipes and associated structures in wet, soft ground conditions adjacent to slopes Photo (e): Bulldozer working in soft ground at tailings discharge area	• Worker injury by slips, trips, or falls • Light vehicles become stuck in fine sand • Workers becoming stuck in mud or soft ground • Bull dozers will often become stuck in soft ground; worker injury &/or equipment damage • Bull dozers will occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage	• Friction fit pipe is pushed together with bulldozers and has numerous leaks • Pipeline leaks • Excess water in tailings discharge area • Heavy precipitation	• Heavy precipitation events increase soft ground • Dust and wind reduce visibility • Visibility decreases at night
Erosion Features  	Photo (f): Washout (width ~1.5 m) filled with water Photo (g): Photo of a cut in the tailings discharge area	• Worker injury by slips, trips, or falls • Worker injury or equipment damage from undercut slope failing • Bull dozers will often become stuck in cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak	• Heavy precipitation events increase erosion • Dust and wind reduce visibility • Visibility decreases at night

Table 10. Winter ground hazard database of potential consequences, precursory conditions, and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

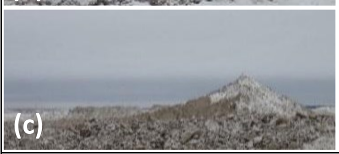
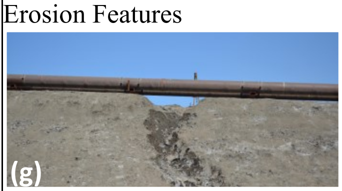
Photo of Ground Hazard	Description	Potential Consequences	Precursory Conditions	Temporal Factors
Slope Instabilities   	Photo (a): View of the open pit. Steep slopes (~55°) typical of mining operations and snow-covered benches Photo (b): View of snow-covered eroded slopes of tailings dam Photo (c): Steep slopes produced when pushing frozen soil and snow	• Worker injury by slips, trips, or falls • Worker injury or fatality by crushing &/or equipment damage • Loss of containment: pipeline leaks and cell berm failure	• Sloughing • Erosion gullies	• Ice and snow reduce visibility • Excessive steam reduces visibility • Visibility decreases at night
Soft Ground   	Photo (d): Close-up of bulldozer in soft ground at tailings discharge area with steam from hot tailings discharge Photo (e): Frozen tailings pond (not clear where beach ends and water begins) Photo (f): Frozen sump pump station	• Bull dozers occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage • Bull dozers will often become stuck in soft ground; worker injury &/or equipment damage • Worker injury, exposure to chemicals or death by breaking through ice and falling into the water • Worker injury by slips, trips, or falls	• Hot tailings discharge hitting frozen sand • Ice • Workers do not know that they are on ice because the frozen deep-water sumps and tailings ponds are not marked • Mounds of tailings material form on pipelines from leaks	• Ice and snow reduce visibility • Excessive steam reduces visibility • Tailing ponds not visible in winter because of snow and ice • Ice thickness unknown • Visibility decreases at night
Erosion Features   	Photo (g): View of tailings discharge area and end of line device (right) while not in use; erosion on ground below end of line device Photo (h): View of tailings discharge area with bulldozer operator working below an undercut slope Photo (i): Open water at tailings pond recycled water inlet with a cut into the tailings material	• Worker injury by slips, trips, or falls • Bull dozers will often become stuck in a cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in a cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak	• Ice and snow reduce visibility • Excessive steam reduces visibility • Visibility decreases at night

Table 11. Spring ground hazard database of potential consequences, precursory conditions, and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

Photo of Ground Hazard	Description	Potential Consequences	Precursory Conditions	Temporal Factors
Slope Instability   	Photo (a): Seepage at the toe of dyke with some unstable areas (middle) seen on the face Photo (b): Seepage from face of dyke with ice and standing water at the toe Photo (c): Water ponding (right) at the toe of loose sand	• Worker injury or fatality by crushing &/or equipment damage • Loss of containment: pipeline leaks and cell berm failure	• Sloughing • Erosion gullies • Standing water at the toe of slopes	• Heavy precipitation events and spring melt increase instability • Snow and ice reduce visibility • Visibility decreases at night
Soft Ground   	Photo (d): Truck stuck in mud and soft ground from spring melt Photo (e): Standing water on road with ice melting on the side Photo (f): Muddy and soft ground conditions between pipelines in working area	• Worker injury or fatality by falling into deep standing water • Stuck vehicles in soft ground conditions or deep water on roads • Bull dozers occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage • Bull dozers will often become stuck in soft ground; worker injury	• Difficult to identify standing water in freeze-thaw • Spring thaw: difficult to distinguish between wet areas and soft ground conditions • Heavy precipitation • Spring melt	• Unknown depth of water • Snow and ice reduce visibility • Heavy precipitation events and spring melt increase soft ground • Visibility decreases at night
Erosion Features  	Photo (g): Slope in the tailings discharge area with pipeline and erosion features Photo (h): View of pipeline that has fallen into an erosion feature next to a road	• Worker injury by slips, trips, or falls • Bull dozers will often become stuck in a cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in a cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak • Spring run-off and melt	• Snow and ice reduce visibility • Spring run-off increases erosion • Heavy precipitation events and spring melt increase erosion • Visibility decreases at night

Tailings Safety Symposium

Sprint Brainstorming Activity Results

As the six groups shared their findings at the TSS, it quickly became apparent that the reasons hazards are not reported or identified are very similar across oil sands tailings operations. There are systemic cultural roots for why hazards are not identified or reported. These roots are lack of training, fear, risk tolerance, external pressures, cultural inaction, complacency, lack of accountability and dynamic work environments. An application for an Alberta Occupational Health and Safety Futures Grant has been submitted with the aim of further analyzing these data.

Brain Writing or "8-1-2" Group Brainstorming Results

It was apparent after reading the "8-1-2" brainstorming documents that people in tailings are critically analyzing the operations and thinking of methods to eliminate or reduce the risk to protect workers. Each participant (105) ended up with enhancements to their original solution to mitigate the risk for the top seven hazards in tailings operations. Some of the responses were enhancements to or suggestions for new administrative controls, such as increasing emergency response training by cross training tailings personnel to be first responders. Many of the respondents discussed the need to implement more automation and remote-controlled vehicles, which would eliminate hazards by removing people from the tailings operations. Suggestions to work with design and planning engineers to completely change the operations and setup of tailings were also common. These suggestions included ideas such as changing the footprint of tailings and providing windbreaks, thoroughly cleaning ponds on start-up, completely redesigning spill boxes, and installing permanent roads in tailings. These suggestions may not be feasible for current operations, but could be implemented for new mines.

Implementing amphibious vehicles was a common suggestion for most of the top seven hazards, as ground hazards would then not be as much of a concern nor would determining the interface between solid ground, ice, and water in winter. These vehicles could also assist with emergency response and spill box operation.

Other suggestions included using new technology such as infrared cameras to detect pipeline leaks; monitoring the quality of feed to the tailings discharge area to obtain better compaction; implementing solar, wind, and battery power as opposed to using cables in the water; installing an agitator to stop the formation of ice on ponds; and using HEPA filters and positive pressure cabs to prevent silica dust from entering the equipment.

These elimination and substitution suggestions were added to the BT diagrams (Figure 17 and Figures 45-50 in red boxes to indicate they have not yet been implemented in daily operation as per DyPASI (Paltrinier et al., 2014).

Discussion

Each dataset was analyzed in a holistic approach to determine recommendations to improve worker safety at oil sands tailings operations. The recommendations followed the themes generated from the interview data and literature for incident database best practices: (1) increased communication within industry, (2) increased communication within companies, (3) enhancements to hazard identification tools, (4) critically evaluate current operations, (5) increase resources, (6) tailings-specific training, (7) regional standardization, and (8) enhancements to incident databases.

Increased Communication Within Industry

Workers know that operations are similar across sites and are curious to know what other operators are doing to mitigate hazards. There is already informal sharing of information (technical and incident) as Fort McMurray is a small town, but interviewees would like to see this dissemination of information formalized so sustainable changes can be implemented.

Increased Communication Within Companies

The oil sands sites are large, and the vastness of the operations makes it physically challenging to communicate information. Everyone on these sites is also very busy; time is a valuable resource. Interviewees would like to see this change, and would like to see more engineering and management presence in the field so they have a better understanding of the operations. One way to increase field visits could be to make "time spent in the field" a regional key performance indicator. Participants would also like more consistency from management with regards to plans, deliverables, goals, and job functions. The existing ambiguity can make it challenging for workers to complete their job or identify and report hazards. Accessing the correct information and procedures is also challenging according to some workers, especially contractors, who do not have direct access to the same information as workers at the owner company. Frontline workers mentioned silos in communication with other frontline groups (e.g., heavy equipment operators (HEO) to pipe crew). Some companies cross-train their employees in multiple job functions; workers noted this is a way to bridge the gap between the different working groups and such implementation could be valuable to many operations.

Enhance Current Hazard Controls

Many controls were also mentioned over the course of the interviews. The majority (56%) of respondents mentioned administrative controls, such as standard operating procedures, permits, and training. End of line devices such as spoons were a very common engineering control that was mentioned (33%), and PPE such as PFDs, dust masks, and traction aids represented 11% of the controls discussed. Some people discussed elimination and substitution alternatives (3%) but many interviewees felt that it was time to start looking more critically at the operations and making some design changes to the fundamental way tailings are handled. This was confirmed by the "8-1-2" brainstorming method at the TSS. There was also a discussion about the appropriateness and effectiveness of current controls. Some controls, such as PFDs and life jackets, actually pose an impediment to completing work as they are bulky and not specifically designed for the job task. A recent fatality investigation shared by Teck recommends the use of inflatable life vests that facilitate machinery cab egress in emergency situations where a cab submerges (Teck, 2018). For certain tasks, these more compact life vests may mitigate the impediment of more bulky models, if the person is not otherwise incapacitated. Interviewees also identified other hazards that they felt were not adequately controlled, including friction fit pipe and spill box board installation. The level of effectiveness and appropriateness of controls is another area that companies should investigate further.

Enhance Hazard Identification Tools

Hazard identification tools are widely used in many industries (OHS, 2009 and 2015). They encourage workers to analyze their work environment and job task prior to beginning work. Many workers felt that the current hazard identification tools (FLHA, LPSA, FLRH, JSA, etc.) are not effective for the tailings environment. They felt that these tools were a "pencil whipping" exercise. To combat the sense of complacency with these tools, many workers told us that they preferred to complete the hazard identification as a group since they could identify more hazards together than alone. Another suggestion was for hazard identification tools to be created for specific job tasks, with the common hazards already identified. The workers can then focus on changes in the job task and environment and add "fresh ink" to the templates. The initial template should be created with safety professionals and frontline workers, following a similar process as a hazard and operability study (HAZOP), to ensure all typical hazards are identified. Workers would then be able to look for variations from the typical work environment, allowing them to identify hazards that may have been previously unseen/unknown.

The ground hazard photo databases and framework were designed to enhance current hazard identification tools and increase mindfulness of the hazards in the work environment that may not necessarily be related directly to the job task. Research has found that workers more easily identify hazards after they have seen examples, and this benefit is amplified when the hazards are displayed near the worksite itself (Albert et al., 2014). Therefore, it is recommended that the visual tools (BT diagrams and ground hazard photo databases) be displayed in the lunch shacks at tailings operations.

Increase Resources

A lack of resources in the form of workforce, equipment, and maintenance was identified by the majority of interviewees. They felt they were working short staffed and did not have access to the appropriate tools to complete the job, which could lead to shortcuts. Lack of maintenance in the form of preventative maintenance on pipelines and other equipment was also identified. A workforce shortage was noted on the maintenance side, with personnel only working day shifts and having to split their time with the mine. A dedicated tailings maintenance staff may be worth investigating, not only to handle maintenance issues but also to create a pool of personnel who would also be more familiar with the hazards in the tailings operations and therefore decrease the potential for incidents.

Tailings-Specific Training

Administrative controls, including training, are one of the most ubiquitous controls across the tailings operations and, yet, no tailings-specific training exists. Instead, all employees and contractors go through mine orientation and training. Workers noted that the tailings environment is extremely different than the mine environment, even for seemingly simple tasks such as driving: “Roads are made of K-spec (trace oil sands) which are slippery like grease. At 3 km/hr the truck can go sideways. Unless you’ve driven, you can’t know how bad it is. Not much driving training for tailings, take mine driving training instead, but it is very different to drive on K spec vs. haul roads”.

There are also hazards that are unique to the tailings operations, such as heavy steam off discharge lines in the tailings discharge area. Known hazards also manifest differently in this area, including ground hazards: “Some ground conditions are bottomless (soft, soft, soft). Hard to get solid ground”.

Given the frequency of exposure in these operations, e.g., “we aren’t building pianos, this is dangerous and heavy work”, the risk tolerance of operations can be high. This is seen through the normalization of hazards such as leaking pipelines. Some hazards are unknown and unseen, including the cavern formation that caused the 2014 fatality.

Given the unique, ever-changing, and challenging nature of tailings operations, time should be spent to develop specific training and procedures that fit the operations. ESC also identified the need for regional tailings training.

Discussions have already begun on the best method to deliver tailings-specific training. Given the seasonality of the hazards, the seasonal workforce, and turnover rates, it was decided that online microlearning modules would be the best way to disseminate this training. Four modules will be created: a general tailings hazard awareness module to be taken during onboarding and then a module for each of the seasons (summer, winter, and spring). Workers will take this training each year, three weeks prior to the season change to refresh their memory about the hazards in their work environment. The photos, ground hazard database, and BT diagrams will be used in these training modules.

Regional Standardization

The processes used to produce tailings may vary from site to site, but the hazards are very similar. This similarity was identified by both the interviewees and the ESC tailings safety task force. Both of these groups are calling for the regional standardization of policies to protect worker safety in tailings operations. Interviewees would like standardized procedures to decrease confusion, limit the number of documents, and treat tailings as a special trade. The interviewees are especially curious about the working alone procedures and what other companies are doing to mitigate hazards. ESC task force members also agree with the need for standardization in the form of regional tailings training as well as with respect to the procedures for different sites (i.e., leaking pipeline approach procedures, at what distance from water PFDs need to be used). By standardizing the procedures, there will be less confusion, especially among contractors, making it easier to complete job tasks and identify hazards.

Enhanced Pipeline Leak Controls

It is recommended that all oil sands tailings operations, through facilitation by ESC, implement the following controls that have been developed as part of the U of A's research project. These controls have been implemented by some industry members and have been very effective at mitigating pipeline leaks and improving collaboration within companies. The suggestions include four small but effective changes for continuous improvement in tailings areas.

1. Elevating the pipeline using a combination of pipe supports/pipe saddles/wooden blocking to provide a full 360° view of the pipeline. The benefits of this practice are twofold, as any leaks

that do occur are easier to see as the line is not laying in the sand and there is less external abrasion on the line from the sand in the work environment.

2. Changing snow clearing and grading procedures so windrows cannot be pushed up against the pipeline. This change also makes it easier to identify leaks as the whole line is visible.
3. Implementing a standardized line approach procedure. This procedure ensures that no leak is investigated by a worker working alone. This procedure includes identifying the leak, notifying the correct personnel about the leak, including the control room operators who can shut down the line to stop the flow of tailings, and bringing in additional workers and heavy equipment to investigate the leak by testing the ground within a safe setback distance from the pipeline.
4. Using larger flag markers to identify the location of drain valves. The areas near drains have a higher potential to see soft ground or erosion features manifesting because of their designed use.

Where these changes have been implemented, they have been extremely effective in promoting a cultural shift towards open, honest, transparent discussions within the tailings operations, not only at the frontline level but between all levels of the organization. There has also been a shift towards the support of questioning attitudes, which has broken down barriers and increased communication within the tailings operations to better identify and control hazards.

Enhancements to Incident Databases

Every company used a different type of database software to collect and house incident data. Therefore, each company had their own definitions for incident level, consequence, likelihood, and risk. These definitions aligned with the process safety definitions for refineries. Many of these definitions are not appropriate for use in tailings operations as incidents in this area occur at a higher frequency and have lower consequences relative to the refinery. By using the refinery's definitions, the severity of the incidents in tailings operations could be masked by trying to fit these incidents into categories that are inappropriate. This could also be leading to the occurrence of more incidents with similar root causes, because the definition provided does not prompt further investigation or remedial action from the company.

In their current form, the incident databases show some incident trends; however, there is room for improvement. To improve the quality of data analysis from the incident databases, the level of reporting in the operations needs to increase. Many of the reported incidents related to production outages and did not provide enough information to be used as an indicative leading indicator. A gap in the level of reporting was identified by interviewees, who noted “no reporting of near misses; such a big tell”. The number of ground hazards mentioned in the interviews was higher than the reported values in the incident database; 60% of interviewees mentioned soft ground (compared to 49% in the database), 52% mentioned surface erosion (compared to 22%), and 39% mentioned slope instability (compared to 23%). Subsurface erosion was mentioned at consistent rates in both cases, at 6%. There is also some discrepancy in terms of the classification of the incidents from company to company and even within companies.

To increase the quality of data analysis and trending, incidents and near misses should be ranked on a potential hurt scale, with multiple employees at higher levels determining the incident level if agreement cannot be reached amongst site supervisors. Near misses should also be included in the reporting process as they serve as learning opportunities without injury outcome occurrence (Hinze, 2002). This way, unique and novel cases are being brought to the attention of upper management prior to the occurrence of potentially serious issues. Utilizing a risk matrix that better reflects the higher frequency events occurring in tailings operations is also suggested. The level of reporting also needs to increase. To better cluster and utilize near misses to trend leading indicators and proactively implement mitigation strategies companies may consider standardizing and sharing incident data.

Work is being done to automate classification of the incident database to identify incident trends and develop a risk matrix (Figure 29) that combines the participating companies and better reflects the tailings operations. This work will be completed within the year and results will be shared with participating companies through ESC. Incident trending with improved reporting and consistent classification will identify higher frequency risk exposures and otherwise unknown hazards for mitigation. “Incidents are a signal that we don’t have it right yet” (personal correspondence with Gord Winkel) and in themselves constitute a leading indicator for driving improvement.

	5	4	3	2	1
Health/Safety	Minor injuries or illnesses that do not require first aid treatment or may require basic first aid treatment	One or more injuries or illnesses requiring medical treatment or resulting in restricted work.	One or more injuries or illnesses resulting in lost time	Single fatality or one or more long term disabilities	Multiple fatalities
Environmental	Inconsequential or no adverse effects, clean up confined to site or close proximity	Minor adverse effects, local emergency response, 0-6 months clean up	Medium adverse effects, local emergency response, short to medium term effects, 7-12 months clean up	Medium to significant adverse effects, intermediate emergency response, 1-4 years clean up	Off property impact requiring remediation taking 5 years or more. Major emergency response with significant adverse effects.
Reputation	No media coverage. Single stakeholder involvement with concerns addressed in the normal course of businesses. Temporary side road closure.	Local media coverage. Multiple stakeholders involved with concerns addressed in the normal course of business. Secondary road closure lasting < 24 hours	Extended local media coverage or one-time national media coverage. One or more key stakeholder involvement with concerns being addressed outside the normal course of business. Extended secondary road closure (> 24 hours)	National media coverage. Involves multiple key stakeholders. Operations interrupted. Major road closure < 24 hours.	International media coverage. Multiple key stakeholders involved. Operations shutdown and/or potential of future operations being prevented. Extended closure of major road.
Financial	C < $1M	$1M < C < $10M	$10M < C < $100M	$100M < C < $500M	C > $500M

Figure 29. Risk matrix designed to reflect the tailings operations (Kurian, 2019).

Future Work

There are many opportunities for future work with these four datasets.

Similar methods could be applied to other tailings hazards utilizing the incident databases and interview results. Site visits could be conducted to compile photo databases for these hazards as well. This could be taken one step further, with each of the different areas of tailings (tailings discharge area, fluid tailings, etc.) analyzed individually as there are unique hazards associated with each working area.

Additionally, the energy wheel mechanism to identify hazards, from Figure 12, could also be applied to classify the incident database based on incident type. The potential consequence and likelihood (or risk) could be determined from the current incident data and a hybrid fuzzy logic approach applied to determine quantitative risk values from incident databases. Hybrid fuzzy techniques are a popular method for quantitatively analyzing data that are qualitative in nature. Incident databases contain thousands of incident reports ranging from near misses to fatal accidents, and these databases continue to expand on a regular basis. While some contributing factors are unavoidable, many are in fact preventable – or at the very least, possible to mitigate. Future research in this area could involve using some aspects of fuzzy logic to quantify incident reports by applying keyword analysis and machine learning and using different numerical analysis techniques to analyze the quantitative data. Quantitative analysis could range from basic statistical analysis (e.g., regression or multivariate ANOVA) to neural networks or applying Bayesian logic. These methods can be applied to search for trends pertaining to certain incidents, to identify leading indicators for incidents that can be avoided, and to increase awareness of the risks involved in working in certain situations.

A grant application has been submitted to Alberta OH&S for a Futures Grant to continue analysis of the sprint brainstorming results from TSS.

Discussions should be held with design engineers and COSIA regarding the potential for elimination, substitution and other inherently safer design principals to be incorporated during the design of new technologies being implemented in the tailings operations.

Chapter 3: Second thesis paper

Risk Communication in Athabasca Oil Sands Tailings Operations

Kathleen E. Baker
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
kebaker@ualberta.ca

Dr. Renato Macciotta
Industrial Professor
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
macciott@ualberta.ca

Dr. Michael T. Hendry
NSERC Industrial Research Chair in Railway Engineering
Associate Professor
University of Alberta
Civil and Environmental Engineering
Edmonton, Alberta, Canada
hendry@ualberta.ca

Dr. Lianne M. Lefsrud
Assistant Professor
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
lefsrud@ualberta.ca

Paper Status and History

Second thesis paper	
Risk Communication in Athabasca Oil Sands Tailings Operations (Kathleen E. Baker, Renato Macciotta, Michael T. Hendry, and Lianne M. Lefsrud)	
Status	Submitted for peer review as a conference paper to the Centre for Risk Integrity and Safety Engineering (C-RISE) Workshop / Symposium on February 25, 2019 and for potential publication in *Journal for Safety in Extreme Environments: People, Risk and Security*
History	
Peer reviewed abstract	Baker, K.E., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Communicating risk across organizations in the oil sands tailings operations. *C-RISE Workshop / Symposium,* July 15-19, 2019, St. John's, NF. Baker, K.E., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Communicating risks across organizations and to contractors in the oil sands tailings operations. *Society of Risk Analysis.* March 25-27, 2019, Luxemburg.
Peer reviewed conference abstracts and presentations	Baker, K.E., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Risk communication in Athabasca oil sands tailings operations. *68th Canadian Society for Chemical Engineering Conference.* October 31, 2018, Toronto, ON. Baker, K.E., Zettl, J. D., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Communicating risks across organizations and to contractors. *Canadian Institute of Mining Convention.* May 8, 2018, Vancouver, BC.

Abstract

Oil sands operations involve many working groups, which can result in communication silos that make effective risk communication challenging. Workers are also directly at risk when they encounter conditions that contain hazards they are not equipped to identify and control. This is illustrated by fatalities in the oil sands related to unseen ground hazards at tailings storage and transport facilities. This research asked how gaps in communication between different working groups can be identified and how information about risks can be effectively disseminated to workers who interact with these facilities. Using ground hazards as a case study, we analyzed four datasets to identify areas for enhanced risk communication. The aim was to determine the hazards that workers see on the job site and compare their responses to tailings safety experts, geotechnical analysis, and recorded incidents. This will allow for the design of effective risk communication strategies at oil sands tailings operations. Traditional risk communication principles to disseminate information to external stakeholders will be applied to an internal audience of workers in tailings operations. The aim is to enhance the dialogue regarding risks across the organization. This will be done by increasing the knowledge and understanding of ground hazards in oil sands tailings operations, resulting in the invisible becoming seen and the risk tolerance among workers being lowered.

Keywords: Risk Communication; Unseen Hazards; Hazard Identification; Visual Tool

Introduction

Our research is motivated by a workplace fatality that occurred around 6:00 am on 19 January 2014; a worker broke through frozen ground and drowned in an underground cavern that had been created by a pinhole-sized leak of hot tailings from a transportation pipeline (OHS, 2017a). In this instance, protocols to ensure the safety of workers had been followed, including the use of pipeline leak detection and mitigation, administrative controls such as call-in procedures, and the use of personal protective equipment (OHS, 2017a). Despite these hazard identifications and controls, none of the frontline tailings team knew that a tailings leak could create an underground cavern. Furthermore, leaks from a tailings pipeline tend to give off steam because of the temperature differential between the hot tailings and the ambient environment. As the tailings were draining elsewhere from the cavern, no steam was emitted at the leak site. It was inconceivable to workers that there could be a leak without steam and, hence, there was no warning that the pipeline was leaking at this location. This hazard was also further hidden from view by the snow- and ice-covered ground and early morning darkness (OHS, 2017a). In sum, while oil sands companies have created industry best practices such as "Life-Saving Rules" (ESC, 2018b) and have hazard identification tools such as Field Level Hazard Assessments, ground hazards remain unidentified and incidents such as this still occur.

To combat the unknown ground hazards in tailings operations, we are proposing the application of well-defined external risk communication principles and visual tools to increase the visibility of these presently unseen hazards. We used a mental models approach and spoke with 158 frontline workers, regional contractors, and leaders from multiple oil sands companies to achieve stakeholder engagement. We also conducted a ground hazard assessment by touring various sites in summer, winter, and spring. Tailings safety experts provided us with access to their hazard inventory and oil sands companies gave us access to their incident databases related to tailings.

Based on responses to the interview questions, the tailings safety expert hazard inventory, and the company incident databases, we identified breakdowns in communication. With these breakdowns in communication identified, and the information from the 2014 fatality, we are using ground hazards as a case study to address the communication problems. From our ground hazard assessment, we created visual tools (a flow chart for hazard identification and mitigation and a ground hazard photo database) to help workers identify ground hazards in their work environment.

By using the breakdowns in communication of ground hazards in the oil sands tailings operations as a case study, we extend the literature on seeing the unseen (Haslam et al., 2005; Albert et al., 2014, 2017; Jeelani et al., 2016; Tixier et al., 2017) and confirm similar mechanisms for why ground hazards are not identified in the oil sands tailings environment. However, we disagree with the root cause of worker inability that is alluded to by many scholars (Haslam et al., 2005; Carter & Smith, 2006; Hinze, 2006; Tixier et al., 2017). We found the root causes of ground hazards not being identified are culturally systemic in nature (hazards not communicated to workers) as opposed to being solely due to unsafe acts by workers (Albert et al., 2014). We also provide a case study for the development of visual tools to effectively communicate the risks of unseen ground hazards to an internal audience and bridge cultural breakdowns in communication.

Oil Sands Tailings Operations

Oil sands tailings operations are extensive, comprising the structures needed to contain waste from the open pit mining and extraction process. Essentially, tailings operations store the solids and water balance from oil sands mining operations. The oil sands (8-13% bitumen, ~60% silica sand, ~30% fine solids, and <5% water) is transported in haul trucks from the open pit mine to the extraction facility where it is processed to extract the bitumen from the sand (Devenny, 2010). The bitumen is transported to the refinery for upgrading, and the tailings material—a slurry of water, sand, other chemicals, and residual bitumen—is transported to primary containment or the tailings discharge area using pipelines. There is also froth treatment waste (mostly water) that is carried directly to the tailings pond. The tailings slurry is discharged into cells in the tailings discharge area to construct structures such as beaches and dykes for reclamation. The material stored in this area has a larger particle size, similar to sand. The tailings discharge area is slightly declined so that water and any residual fine tailings flow to the centre and are transported via dredge to the tailings pond. The tailings pond contains fluid fine tailings (FFT) which become mature fine tailings (MFT) after an extended period, and process water. The process water is removed from the pond to be recycled and used in other areas of the mine. The MFT is sent for further processing including cake production, dewatering, or drying depending on the site (Devenny, 2010).

The incident described at the beginning of this paper occurred in the tailings discharge area of an oil sands tailings operation. Ground hazards such as the one that caused the fatality had been seen at other sites before the incident occurred. There is the potential for ground hazards to manifest in any area of tailings operations.

Methods to increase ground hazard identification in oil sands tailings operations

The identification of hazards through the risk management process, using tools such as Field Level Hazard Assessments, assumes that workers and managers have the skills and knowledge to effectively and accurately complete hazard identification to control hazards and begin work (Bahn, 2013). However, multiple studies (Carter & Smith, 2006; Ramsay et al., 2006; Bahn, 2013; Perlman et al., 2014; Jeelani et al., 2016) show that most workers and managers are not equipped to adequately identify hazards, especially unknown hazards, in dynamic, complex environments (Jeelani et al., 2016; Namian et al., 2016); novice workers are unable to recognize 53% of hazards in their work environments (Bahn, 2013). Our analysis of four datasets—interviews with frontline workers, leadership and regional contractors; a tailings safety expert hazard inventory; incident databases; and a ground hazard assessment—was designed to reveal any similar issues with the communication and identification of ground hazards in oil sands tailings operations.

Interviews

Seven semi-structured interview questions were designed by the authors to build rapport with the interviewees and determine the hazards they are aware of in oil sands tailings operations and the solutions or changes they would like to see with respect to those hazards. The Research Ethics Board (REB) at the University of Alberta approved the methods as well as the interview questions prior to the start of the study. The questions were also vetted by ESC to confirm validity. Each interviewee also signed an informed consent form prior to participating in the study.

We conducted 158 semi-structured interviews with employees and contractors from multiple oil sands companies. Our interviewees included 78 frontline workers (49% of interviewees) (heavy equipment operators, plant operators, and maintenance staff), 33 leaders (21% of interviewees) (site leaders, management, health and safety professionals, and engineers) and 47 regional contractors (30% of interviewees) (dredge and boat operators, geotechnical engineers, roving contractors, and embedded contractors). Many of our interviewees either knew co-workers who had been injured or killed or experienced injuries or near misses themselves. Given this and the sensitive topic of our research, we were pleasantly surprised by the candid nature of the interviewees; this indicated the desire amongst the participants to promote sustainable change.

The authors conducted all interviews. To not interrupt operations, most interviews took place at the oil sands operators' sites; 12 interviews were conducted over the phone by the first author. Most interviews were conducted individually or in pairs. However, a handful of interviews were conducted with 3-4 participants and the authors. Three interviews had more than 4 participants (29 interviewees in total participated in focus group style interviews). Interviews were between 20 and 90 minutes long, with interviewee responses handwritten by the authors and later typed up by a transcriber. Even though interviews occurred on site, participants were very forthcoming. All were given the opportunity to skip any question and to remove their responses up to two weeks after the study; no participants requested this, but multiple participants called after their interview to add more information.

The interviews were analyzed (coded) using QSR NVivo 12.0. Coding is a way to analyze interviews and recognize patterns and themes in the data. The initial analysis focused on the interview questions and specific coding for each interview in its entirety. At this stage, the number of workers who identified a ground hazard in their interview was determined.

Based on the initial analysis and literature review, emergent themes became apparent, and subsequent analysis of the interviews was conducted to code for these themes.

During this second analysis stage the authors used NVivo to develop and relate codes and continually test the plausibility of our theorizing (Lok & de Rond, 2013; Huy et al., 2014; Reinecke & Ansari, 2015). The analysis of the interviews involved cycling between our data and the relevant literature to determine breakdowns in the communication of ground hazards in oil sands tailings operations.

Following grounded theory methods, the coding scheme was amended as the analysis progressed (Kreiner et al., 2009). Such an abductive approach is "most suited to efforts to understand the process by which actors construct meaning out of intersubjective experience" (Suddaby, 2006: pp 634). After cycling iteratively through our interviews, we collapsed these codes into subtheme categories to identify where breakdowns in communication regarding ground hazards is occurring.

Tailings Safety Expert Hazard Inventory

Tailings safety experts from multiple oil sands companies toured each other's sites to identify hazards. Energy Safety Canada facilitated this hazard identification activity before the University of Alberta's involvement in the project. The tailings safety experts created a database of over 100 hazards in the tailings operations and began sharing best practices.

The dataset was given to the University of Alberta in 2017, and process safety management tools such as bow tie analysis (Cockshott, 2005; Chevreau et al., 2006; Khakzad et al., 2012) were used to cluster the data and determine hazards identified by the tailings safety experts. The bow tie diagrams relating to ground hazards were selected for further analysis.

Incident Databases

The participating oil sands companies provided their incident datasets for tailings operations from 2014-2017. These incident databases were analyzed to determine the types of hazards associated with incidents at the tailings operations.

The datasets were searched for the following keywords: tailings, ground, pipeline, leak, stuck, sunk, slip, trip, fall, washout, loss of containment, spool leak, steam, ice, and frozen. These keywords were selected to include all incidents that were occurring in tailings operations, in particular those that could be related to ground hazards such as soft ground, surface erosion, subsurface erosion, and slope instability. They were also selected based on information provided from the initial interview analysis and items that were closely related to the 2014 fatality.

The incident data were read by the first author, who has process engineering experience, and then classified into hazard types (ground, chemical, line of fire, etc.) based on process safety definitions (based on a method applied by Cohen, 2017 and definitions from Hallowell, 2008 and Winkel et al., 2017, for reliability). The incidents were also coded by a research assistant to confirm reliability as well. The focus of this research is on ground hazards, so any incident that was caused by a ground hazard or could cause a ground hazard was included in the analysis. The results from the data analysis can lead to targeted initiatives to improve safety and performance (Hallowell et al., 2013).

Ground Hazard Assessment

The authors conducted site visits in summer, winter, and spring, utilizing the action research model where ground hazards were observed in the field and then reflected upon after the site visits to determine the types of ground hazards that were manifesting (Zuber-Skerritt, 2001). This action research cycle continued after each site visit. It was essential to visit in all seasons as tailings is a unique and dynamic environment, and the ground hazards differ over the course of a year.

Photos of representative facilities were taken with descriptions noted in a field journal at all of the participating oil sands tailings operations in each season. The use of photographs instead of drawings was important as they are a more effective way of communicating risk (Haynes et al., 2007).

Proposed Risk Communication Strategy

The theoretical flow of information within a company was established, from management to frontline workers in a top-down approach, from workers to management through a chain of command, and laterally between workers and contractors (Riggio, 2017). Breakdowns in communication were identified by comparing the results from the interviews, hazard inventory, and incident databases to the typical hierarchical flow of information.

With the breakdowns in communication identified, visual tools designed to decrease risk tolerance and increase knowledge were created, using ground hazards as a case study. Visual tools were selected as the literature shows a 65% increase in retention of information when a multimodal approach to risk communication is used (Kouyoumdjian, 2012). This approach combines visual, verbal, and written texts to simultaneously transfer information about risks with the goal of making the hidden seen and the mundane memorable.

Results

Findings from our analysis of the interviews and the incident database confirm the results from other studies with respect to workers having a difficult time identifying hazards in dynamic and complex environments. Almost a quarter of all incidents are related to ground hazards, and yet 15% of workers did not identify any ground hazards in their interview when asked about hazards they saw around tailings facilities, dykes, and transport systems. While not enormous, this value does represent a significant number of workers who are not concerned about ground hazards in their work environments. We also found that workers with between five and ten years of tailings experience identified on average ten ground hazards during their interviews. This value was almost double the number of ground hazards identified by workers with less than one year of experience or more than ten years (who identified two on average).

Failure to report hazards was also identified during the analysis of the incident database and interview data. Reported ground hazards made up 11% of the total ground hazard incidents, with 50% of the events caused by soft ground, 21% by slope instability, 21% by surface erosion, and 5% by subsurface erosion. Our analysis of interview data suggests the incident database under-reports ground hazards, as 60% of interviewees mentioned soft ground, 52% surface erosion, 39% slope instability, and 6% subsurface erosion.

Further analysis was completed using the interview data to identify breakdowns in the communication of hazards to the different working groups in tailings. These breakdowns relate to all hazards and can be applied to our ground hazard case study. The quotes in Figure 30 are a representative sample of those provided by interviewees regarding communication breakdowns.

For example, some workers believe that hazards are not known to the planning department because they do not spend time in the field. Contractors and other working groups like maintenance told us that they are not receiving information about work environment hazards on a daily basis. Even when information is passed between shifts, interviewees told us that there is no consistency in the message regarding hazards or incidents. Frontline workers and maintenance staff informed us that the plant does not communicate the actual flow rate of the tailings through the transport lines. This could be leading to premature failure of the pipelines, which could lead to ground hazards like soft ground or erosion features.

In sum, communication in the oil sands tailings operations across the industry has been uncertain, “Don’t take anything for granted”, ambiguous, “Message different from different supervisors”, lacking information, “Tribal knowledge: training doesn't cover, and no one knows why it’s being done”, and subject to internal and external demands, “Supervisors ask things of workers that are not safe. They don’t know it’s not safe, but the worker is scared to say so”. Companies have already begun to bridge these gaps in communication. The tailings safety expert hazard inventory is an example of bridging communications between the oil sands companies. This activity included touring each other’s sites and sharing best practices, such as the implementation of infrared cameras on bulldozers to increase visibility in steamy winter conditions. During this collaboration, the participating companies identified two ground hazards (pipeline leaks and soft ground) as the top priority hazards needing further mitigation in the tailings industry.

Discussion

Breakdowns in the communication of ground hazards have been identified by analyzing the tailings incident database, interview data, and hazard inventory.

Systemic cultural roots within an organization, not simply unsafe acts by workers, are causing breakdowns in communication within oil sands tailings operations and causing hazards to go unseen and un-reported (Figure 30).

We propose the use of visual tools to address communication breakdowns, reduce exposure risk, and make workers aware of the potential for unseen ground hazards. The goals of our risk communication strategy are to increase the knowledge and visibility of ground hazards, resulting in decreased risk tolerance.

We developed three visual tools for use in our risk communication approach to make the invisible seen: a Hazard Identification Flow Chart, a Ground Hazard Framework with accompanying Ground Hazard Photo Database.

These visual tools will also be displayed on the work site, ideally in lunch trailers near the operations to encourage collaboration, remind workers of hazards, and promote increased hazard recognition of known and previously unknown hazards. This method of Hazard Identification and Transmission was developed specifically for dynamic work environments and can increase hazard recognition by 29% (Albert et al., 2014).

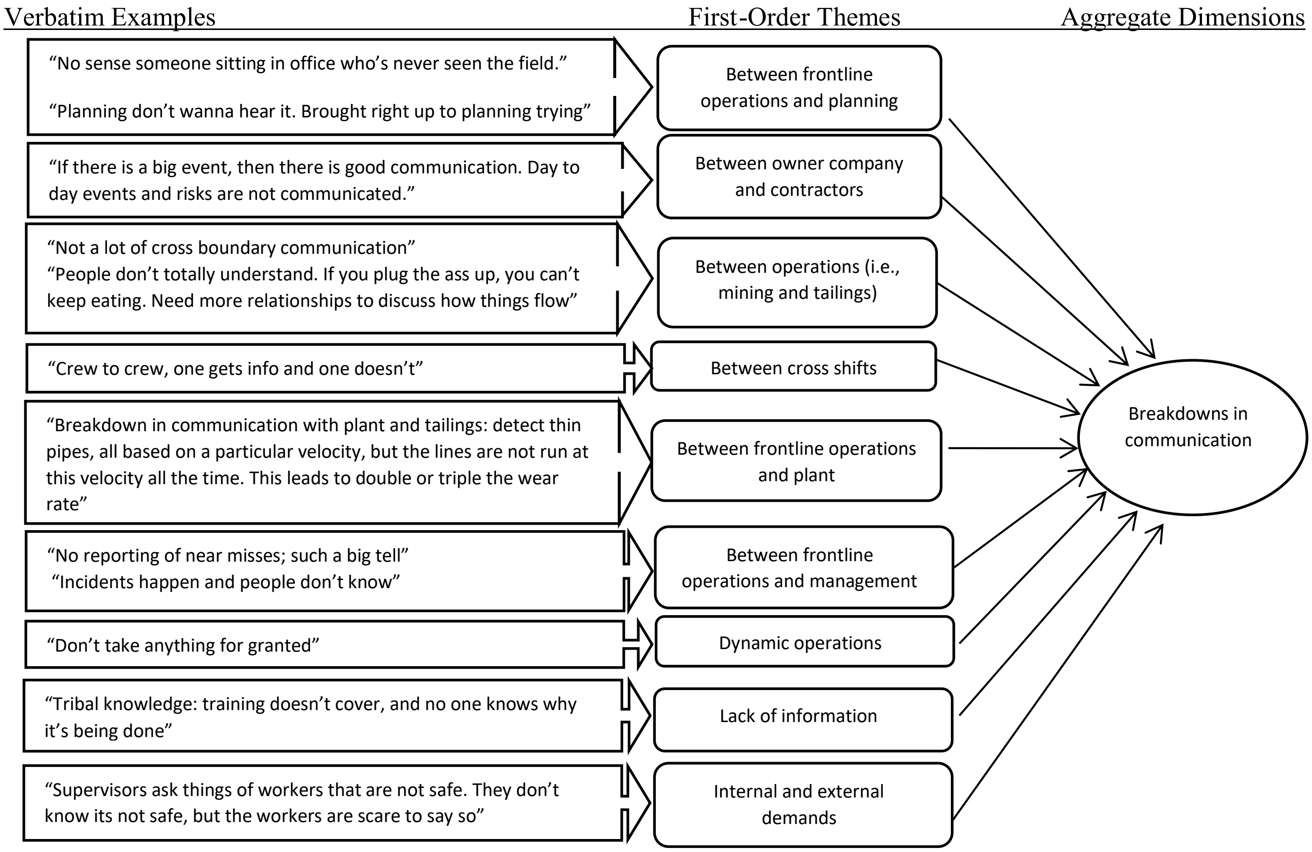


Figure 30. Breakdowns in communication supported by NVivo quotes from interview analysis.

Hazard Identification Flow Chart

Many articles discuss the process of hazard identification and control (Chen et al., 2013; Albert et al., 2014; Hallowell & Hansen, 2016; Jeelani et al., 2016). They all commence with seeing or identifying the hazard, as noted in Figure 31 (Hallowell & Hansen, 2016). We found that many of these discussions are missing a key component: the differentiation between understanding (or perceiving the risk) and tolerating the risk. The perception of risk is influenced by many external and internal factors, including state of mind, inattention, and training/ knowledge of hazards (Sylvester, 2017). Without perception of the hazard, the likelihood of an incident occurring increases as there is no critical thinking about the risk (Albert et al., 2013). If the hazard is not understood, it is not fully seen, and it is therefore impossible for the worker to choose if they want to or can tolerate the risk.

Risk tolerance is also a challenging topic as it too is influenced by both internal and external factors. Some workers may be predisposed to a high risk tolerance compared to others, and this was recognized by the interview participants: “some people don’t see hazards in anything…some people have higher risk tolerance”. The company itself may also be unintentionally influencing a worker’s risk tolerance, such as if “[workers] feel under pressure to work fast and go closer to equipment than they should”. The risk tolerance factors in Figure 31 are based on Sandman’s (1987) outrage factors, Jeelani et al. (2016), and ExxonMobil (2015).

The last stage of the hazard identification figure is the effective control of the hazard through the hierarchy of controls. Elimination or substitution is the ideal mitigation strategy, followed by engineering controls, administrative controls, and personal protective equipment. It is also important to build in redundancy and have multiple controls in place in case one or more fail; this is called the layers of protection approach (Baybutt, 2002; Summers, 2003).

One of the key takeaways from Figure 31 is the need for a multifaceted approach to risk communication, where information is disseminated to workers, but their perception and risk tolerance are also taken into account in the communication strategy. If risks are not understood/perceived, the rest of the risk mitigation strategy is not executed, and hazards may be left uncontrolled.

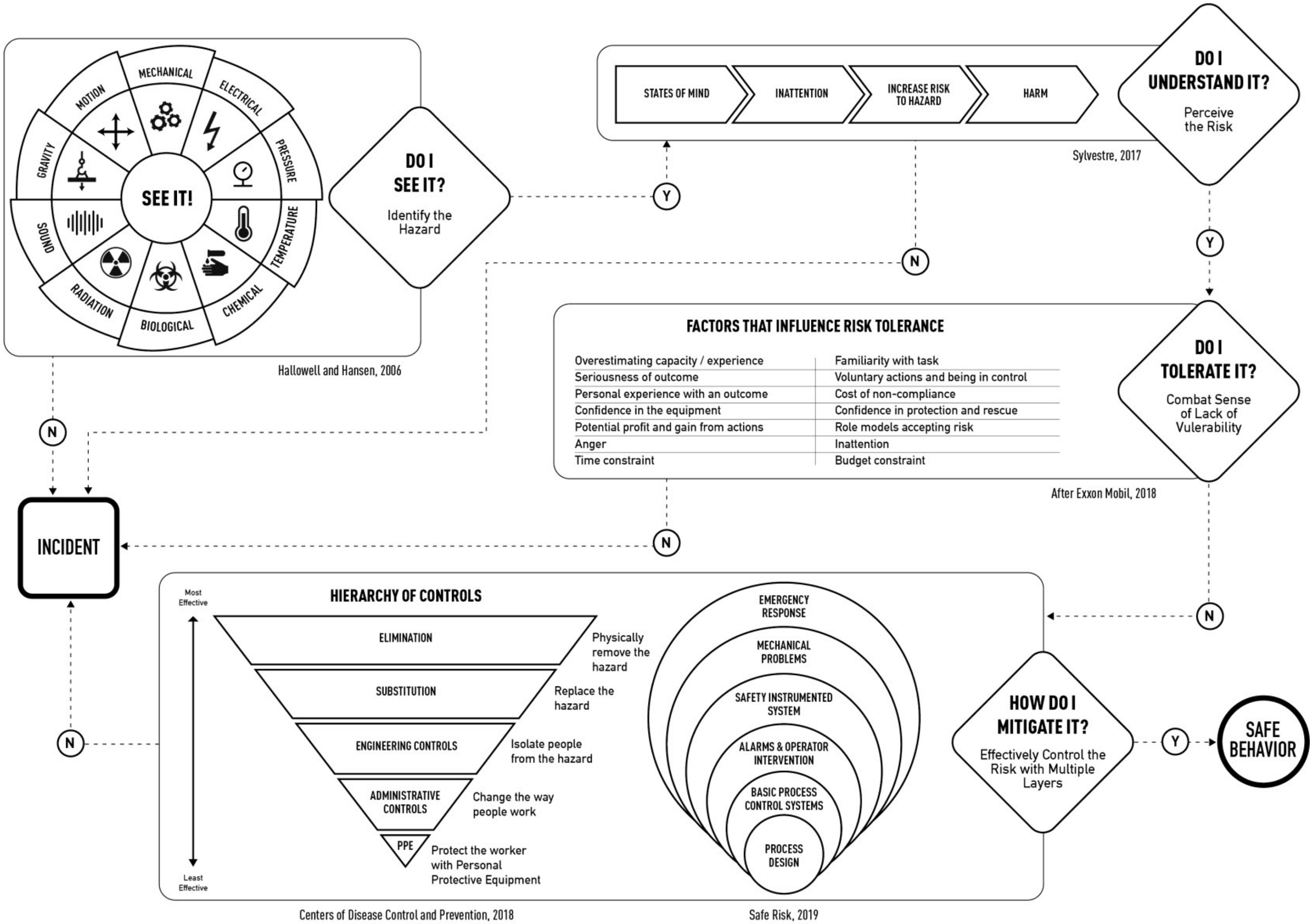


Figure 31. Hazard identification and control flow chart.

Ground Hazard Framework

Tailings operations are unique and dynamic, and these attributes are emphasized during seasonal transitions. Therefore, we created a tailings ground hazard framework and three work environment photo databases (Tables 12-15) as mechanisms to communicate the risk of ground hazards to personnel in the field including contractors.

The framework for communicating the risk of ground hazards to all workers is provided in Table 12. The geotechnical engineers in industry and academia are aware of ground hazards and their manifestations, yet 15% of participants did not identify a single ground hazard in their interview. This high number of people not identifying ground hazards, in addition to the other breakdowns in communication (Figure 31), indicate that knowledge of hazards is not translated to all workers in oil sands tailings operations.

The framework discusses the four main ground hazards identified by the authors on the site visits: soft ground, surface erosion, subsurface erosion, and slope instability. This classification was based on the authors' experience, the incidents recorded in the incident database, and how these ground hazards manifest. Notably, multiple ground hazards were seen at the same time in the oil sands tailings operations.

Soft ground includes such manifestations as poor/untrafficable roads, flooded or overpoured cells, spills and uncontrolled releases, drainage problems, pipeline misalignment, and water coming up through the ground. Surface erosion includes cuts in the cells, washouts, erosion gullies, pipeline misalignment, cell berm breaches, cracks in the benches and berms, and uneven ground. Subsurface erosion includes uneven ground, sinkholes, ground instability, and cave-ins. This type of erosion is very dangerous as it is visually obscured and physically unseen. Slope instability includes sloughing (sand or soil falling off slopes in sheets and slumps due to loss of cohesion) or failures of the benches and berms surrounding the coarse tailings dump and tailings ponds.

All of these ground hazards are influenced by temporal factors such as heavy rain, dust, spring thaw, and winter conditions such as ice, snow-covered ground, steam, and reduced daylight hours. These temporal factors can affect the likelihood of a ground hazard manifesting, i.e., increased amounts of standing water on roads during spring melt. They can also impact the likelihood of a ground hazard being identified, i.e., snow and ice could make it challenging to identify surface erosion in the tailings discharge area, or steam could decrease the visibility for a bulldozer operator in the tailings discharge area and make it challenging to identify cuts (surface erosion) in the cell.

The likelihood values in Table 12 were determined using the incident database. These values were used to determine qualitative likelihood values (very likely, likely, unlikely, very unlikely) for each of the four ground hazards: soft ground, surface erosion, subsurface erosion, and slope instability.

The consequence was also determined by using the incident database and looking at the severity of the incidents related to each ground hazard. Slope instability was ranked as a high consequence as this could lead to a loss of containment event in the tailings discharge area or on a tailings pond, which could affect workers, the environment, and potentially the public. Soft ground is a low consequence as it usually results in stuck equipment with minimal impact on equipment and workers. Erosion features are ranked as a medium consequence as incidents included stuck equipment but also sunk equipment if bulldozers fall into a large cut. Subsurface erosion is a high consequence as this could result in the formation of an underground cavern similar to the one that led to the fatality in 2014.

The controls for these hazards are mainly operating procedures (including preventative maintenance, structured rounds, and reporting systems) and training; 54% of the hazard controls mentioned in the interviews related to administrative controls such as safe operating distances from discharge lines or working alone procedures. This value was confirmed after discussions with tailings engineers, who indicated engineering and elimination/ substitution controls are built into the design, but daily operating controls are typically administrative. Engineering controls are also used to manage risk, including end of line devices to dissipate kinetic energy and decrease the severity of the cuts that form in the cells (Figure 32), elevating the pipelines on blocking for full visibility (Figure 33), and infrared cameras on bulldozers to increase visibility in steam.

Table 12. Ground hazard framework.

Hazard	Manifestation	Temporal Factors	Likelihood	Consequence	Controls
Soft Ground	Poor/not-trafficable roads, flooded cells, overpoured cells, spill and uncontrolled releases, drainage problems, bubble cap burst in cell, water coming up through the ground	Heavy rain, dust, spring thaw, winter conditions: ice, snow covered ground, steam, reduced daylight hours	Very Likely	Low	Operating Procedures, Training & Engineering Controls
Surface Erosion Features	Washouts, erosion gullies, cell berm breach, cracks in the benches and berms, cuts in the cells, uneven ground		Likely	Medium	
Subsurface Erosion Features	Sink holes, ground instability, caverns		Unlikely	High	
Slope Instability	Sloughing/failures of benches and berms surrounding the tailings discharge areas and tailings ponds, berm, cell and dyke breeches		Likely	High	

Figure 32. End of line device.

Figure 33. Pipelines elevated on blocking.

Ground Hazard Photo Database

Site visits to multiple oil sands companies were completed in summer, winter, and spring and photo databases compiled, each including photos of tailings storage facilities (i.e., process water ponds, fine tailings ponds, and tailings discharge area), tailings transport facilities (i.e., the pipeline from extraction to the tailings discharge area and pumps from the fine tailings pond), and dykes (i.e., the slope of the tailings pond).

The summer, winter, and spring ground hazard databases are summarized in Tables 13, 14, and 15, respectively. These databases include specific locations and photos in the oil sands tailings operations and a description of the ground hazard shown in the picture. Possible consequences if the ground hazard were to manifest and not be adequately controlled are also listed, along with precursory conditions that could indicate the formation of one or more of these ground hazards. The last column is the general temporal factors that might impact the likelihood or consequences of the ground hazard manifesting or being identified.

Each figure was divided into simplified ground hazard classifications as the workers in the tailings operations are not formally trained on geotechnical hazards. The more encompassing geotechnical definitions are based on natural phenomena whereas the ground hazards that manifest in tailings operations are in a hydraulically placed area; therefore, these simplified definitions are appropriate given the environment and the audience.

Not included in any of the tables is differential settlement. The authors chose to exclude differential settlement from the analysis as any manifestations of hazards with a high consequence to workers were included under one of the other ground hazards; for example, uneven ground is classified under surface erosion and sink holes and cavern formation are classified under subsurface erosion. Other instances of differential settlement are considered a maintenance issue as well as a potential cause of slips, trips, and falls, which are ubiquitous around any heavy industry and also included in the other ground hazard classifications.

This framework is designed to be a tool to show workers what potential unseen ground hazards in tailings operations could look like. Workers should still identify the hazards associated with their job task using the hazard identification tools provided, such as Field Level Hazard Assessments, but these photo databases will highlight examples of ground hazards that may manifest in their work environment. It is extremely rare for these ground hazards to manifest in isolation. Instead, there is a higher probability that a worker will see surface erosion features as well as soft ground, such as cuts and soft ground that manifest in tailings discharge cells and pose a threat to bulldozer operators becoming stuck or sunk.

An example for spring conditions is discussed here for illustrative purposes. Photo (f) in Table 15 depicts muddy and soft ground conditions between pipelines in a working area. Workers need to maneuver between the pipes to complete maintenance activities as well as daily operations. Consequences of soft ground in this working environment range in severity from loss of productivity if a worker is stuck in soft ground to worker injury or fatality if the soft ground is deeper than anticipated.

A precursory event for soft ground and muddy conditions could be the beginning of spring thaw. The speed of melt and amount of snow will affect the severity of soft ground conditions. Distinguishing between wet areas and soft ground conditions can also be difficult, especially when there is a narrow space between the pipes to work. Temporal factors that affect the consequence and likelihood of soft ground manifesting in this area include spring melt and heavy precipitation events increasing the amount of soft ground. Additional factors are the unknown depth of water, snow and ice reducing visibility, and soft ground being even more difficult to identify at night without proper lights to illuminate the working area.

Controls to mitigate the consequences of soft ground will include (1) administrative controls such as snow removal to decrease the amount of snow during spring melt and (2) personal protective equipment such as steel-toed rubber boots.

Table 13. Summer ground hazard database of potential consequences, precursory conditions and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

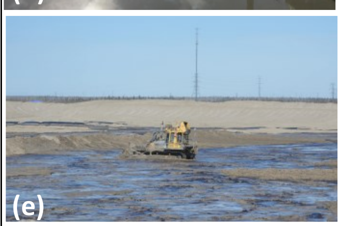
Photo of Ground Hazard	Description	Potential Consequences	Precursory Conditions	Temporal Factors
Slope Instability  	Photo (a): View of the open pit (~30 m deep). Steep slopes (~55°) typical of mining operations. A failed slope can be seen (top) at an inactive pit area Photo (b): Bull dozer creating steep cell walls in tailings discharge area	• Worker injury or fatality by crushing &/or equipment damage • Loss of containment: leaks and cell berm breach	• Sloughing • Soft material created in the cell from tailings discharge • Erosion gullies	• Heavy precipitation events increase instability • Dust and wind reduce visibility • Visibility decreases at night
Soft Ground   	Photo (c): View of tailings discharge area and end of line device (dissipates kinetic energy) Photo (d): Pumps downslope of tailings dam. Pipes and associated structures in wet, soft ground conditions adjacent to slopes Photo (e): Bulldozer working in soft ground at tailings discharge area	• Worker injury by slips, trips, or falls • Light vehicles become stuck in fine sand • Workers becoming stuck in mud or soft ground • Bull dozers will often become stuck in soft ground; worker injury &/or equipment damage • Bull dozers will occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage	• Friction fit pipe is pushed together with bulldozers and has numerous leaks • Pipeline leaks • Excess water in tailings discharge area • Heavy precipitation	• Heavy precipitation events increase soft ground • Dust and wind reduce visibility • Visibility decreases at night
Erosion Features  	Photo (f): Washout (width ~1.5 m) filled with water Photo (g): Photo of a cut in the tailings discharge area	• Worker injury by slips, trips, or falls • Worker injury or equipment damage from undercut slope failing • Bull dozers will often become stuck in cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak	• Heavy precipitation events increase erosion • Dust and wind reduce visibility • Visibility decreases at night

Table 14. Winter ground hazard database of potential consequences, precursory conditions and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

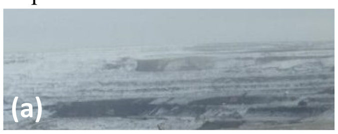
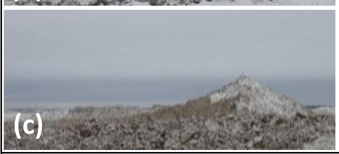
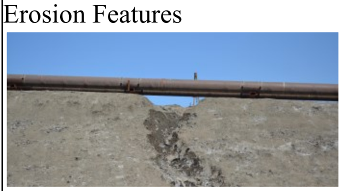
Photo of Ground Hazard	Description	Potential Consequences	Precursory Conditions	Temporal Factors
Slope Instabilities   	Photo (a): View of the open pit. Steep slopes (~55°) typical of mining operations and snow-covered benches Photo (b): View of snow-covered eroded slopes of tailings dam Photo (c): Steep slopes produced when pushing frozen soil and snow	• Worker injury by slips, trips, or falls • Worker injury or fatality by crushing &/or equipment damage • Loss of containment: pipeline leaks and cell berm failure	• Sloughing • Erosion gullies	• Ice and snow reduce visibility • Excessive steam reduces visibility • Visibility decreases at night
Soft Ground   	Photo (d): Close-up of bulldozer in soft ground at tailings discharge area with steam from hot tailings discharge Photo (e): Frozen tailings pond (not clear where beach ends and water begins) Photo (f): Frozen sump pump station	• Bull dozers occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage • Bull dozers will often become stuck in soft ground; worker injury &/or equipment damage • Worker injury, exposure to chemicals or death by breaking through ice and falling into the water • Worker injury by slips, trips, or falls	• Hot tailings discharge hitting frozen sand • Ice • Workers do not know that they are on ice because the frozen deep-water sumps and tailings ponds are not marked • Mounds of tailings material form on pipelines from leaks	• Ice and snow reduce visibility • Excessive steam reduces visibility • Tailing ponds not visible in winter because of snow and ice • Ice thickness unknown • Visibility decreases at night
Erosion Features   	Photo (g): View of tailings discharge area and end of line device (right) while not in use; erosion on ground below end of line device Photo (h): View of tailings discharge area with bulldozer operator working below an undercut slope Photo (i): Open water at tailings pond recycled water inlet with a cut into the tailings material	• Worker injury by slips, trips, or falls • Bull dozers will often become stuck in a cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in a cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak	• Ice and snow reduce visibility • Excessive steam reduces visibility • Visibility decreases at night

Table 15. Spring ground hazard database of potential consequences, precursory conditions and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

Location and Photo	**Description**	**Potential Consequences**	**Precursory Conditions**	**Temporal Factors**
Slope Instability   	Photo (a): Seepage at the toe of dyke with some unstable areas (middle) seen on the face Photo (b): Seepage from face of dyke with ice and standing water at the toe Photo (c): Water ponding (right) at the toe of loose sand	• Worker injury or fatality by crushing &/or equipment damage • Loss of containment: pipeline leaks and cell berm failure	• Sloughing • Erosion gullies • Standing water at the toe of slopes	• Heavy precipitation events and spring melt increase instability • Snow and ice reduce visibility • Visibility decreases at night
Soft Ground   	Photo (d): Truck stuck in mud and soft ground from spring melt Photo (e): Standing water on road with ice melting on the side Photo (f): Muddy and soft ground conditions between pipelines in working area	• Worker injury or fatality by falling into deep standing water • Stuck vehicles in soft ground conditions or deep water on roads • Bull dozers occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage • Bull dozers will often become stuck in soft ground; worker injury	• Difficult to identify standing water in freeze-thaw • Spring thaw: difficult to distinguish between wet areas and soft ground conditions • Heavy precipitation • Spring melt	• Unknown depth of water • Snow and ice reduce visibility • Heavy precipitation events and spring melt increase soft ground • Visibility decreases at night
Erosion Features  	Photo (g): Slope in the tailings discharge area with pipeline and erosion features Photo (h): View of pipeline that has fallen into an erosion feature next to a road	• Worker injury by slips, trips, or falls • Bull dozers will often become stuck in a cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in a cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak • Spring run-off and melt	• Snow and ice reduce visibility • Spring run-off increases erosion • Heavy precipitation events and spring melt increase erosion • Visibility decreases at night

Conclusion

A breakdown in communication of ground hazards within oil sands tailings operations was identified, with 15% of workers not identifying a single ground hazard during their interview. Ground hazards are also under-represented in incident databases compared to interview responses. The consequence is that fatalities related to ground hazards still occur (Government of Alberta, 2017). Workers with between five and ten years of tailings experience were better at identifying ground hazards than those of other experience levels.

The result of the breakdowns in communication in tailings operations is that ground hazards are not being seen or understood. There is a need to communicate these risks to workers so they can be adequately controlled.

The inclusion of visuals in the ground hazard photo database is useful and effective for communicating risks to workers and making the invisible seen. It is also essential to bridge systemic culture roots that impede the flow of communication to protect workers in the challenging and dynamic oil sands tailings operations. This research used ground hazards as a case study, however, this work is applicable to other hazards in the oil sands tailings operations as well.

Limitations

Six main limitations are identified with respect to the interviews: (1) not all interviews had identifiable speakers, as some were conducted as focus groups; (2) interviews were handwritten by the authors, which could have resulted in comments being missed during the interview process; (3) workers could have been using the interview as a forum to complain about management; however, this did not seem to be the case as the authors got a sense of pride with respect to the tailings operations from the employees and contractors; it was a positive, refreshing, and informative process; (4) contractors could have provided answers with a positive spin so as not to lose contracts; and (5) some interviews were cut short if they ran over the scheduled hour and workers had to return to their jobs.

Chapter 4: Third thesis paper

Combining Safety Approaches to bring Hazards into Focus: An Oil Sands Tailings Case Study

Kathleen E. Baker
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
kebaker@ualberta.ca

Dr. Renato Macciotta
Industrial Professor
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
macciott@ualberta.ca

Dr. Michael T. Hendry
NSERC Industrial Research Chair in Railway Engineering
Associate Professor
University of Alberta
Civil and Environmental Engineering
Edmonton, Alberta, Canada
hendry@ualberta.ca

Dr. Lianne M. Lefsrud
Assistant Professor
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
lefsrud@ualberta.ca

Paper Status and History

<table>
<tr><th colspan="2">Third thesis paper</th></tr>
<tr><td colspan="2">Combining Safety Approaches to bring Hazards into Focus: An Oil Sands Tailings Case Study

(Kathleen E. Baker, Renato Macciotta, Michael T. Hendry, and Lianne M. Lefsrud)</td></tr>
<tr><td>Status</td><td>Submitted for peer review as a conference paper to the C-RISE Workshop / Symposium on February 25, 2019 and for potential publication in Journal for Safety in Extreme Environments: People, Risk and Security</td></tr>
<tr><th colspan="2">History</th></tr>
<tr><td>Peer reviewed abstracts</td><td>Baker, K.E., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Applying process safety management tools in the oil sands tailings operations. C-RISE Workshop / Symposium, July 15-19, 2019, St. John’s, NF.

Baker, K.E., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Using process safety management tools to assess oil sands tailings hazards. Society of Risk Analysis. March 25-27, 2019, Luxemburg.</td></tr>
<tr><td>Peer reviewed conference abstracts and presentations</td><td>Baker, K.E., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Using process safety management tools to identify and assess oil sands tailings hazards. 68th Canadian Society for Chemical Engineering Conference. October 29, 2018, Toronto, ON.

Baker, K.E., Zettl, J. D., Macciotta, R., Hendry, T.M., and Lefsrud, L.M. 2019. Using process safety management tools to identify and assess tailings hazards. Canadian Institute of Mining Convention. May 8, 2018, Vancouver, BC.</td></tr>
</table>

Abstract

At least 50 hazardous occurrences associated with tailings facilities occurred in the Canadian mining industry from 2000 to 2014. Further investigation revealed a dearth of information on worker safety around tailings storage and transport facilities. Workers at oil sands tailings operations are exposed to hazards including loss of containment and line of fire. These are the same hazards that manifest in traditional process industries, with the notable differences between traditional process industries and tailings operations being the frequency of incidents, pressures, volumes, and temperatures. The hazardous incidents and lack of literature illustrate the need for increased attention to be paid to worker safety at oil sand tailings operations as well as enhancements to current hazard identification tools. Process Safety Management tools such as Bow Tie diagrams can be applied to tailings operations to visually identify unwanted events (process and occupational health and safety related), potential threats, consequences, and controls used to prevent incidents from occurring. They also serve as a tool for continuous improvement and show any over-reliance on one type of control, such as administrative controls or personal protective equipment. This research combines safety approaches using the Bow Tie analysis of seven hazardous operational activities in the oil sands tailings operations as a case study. The impact of behavioural safety on the controls is also analyzed. Through this research, the authors facilitated the sharing of tailings safety best practices among oil sands operators and regional contractors.

Keywords: Process Safety; Occupational Health and Safety; Behavioural Safety; Bow Ties; Myopia

Introduction

At least 50 hazardous occurrences associated with tailings facilities occurred in British Columbia and Alberta between 2000 and 2014 (Hoekstra, 2014; Government of Alberta, 2017). These hazardous occurrences included incidents such as tailings dam failures (e.g., the Mount Polley Tailings Dam collapse in 2014, which had a considerable impact on the public and the environment (Seucharan, 2017); leaking tailings pipelines on mine sites (Hoekstra, 2014); and a worker fatality by drowning in an underground cavern formed by a pin-hole leak in a tailings pipeline (Government of Alberta, 2017). Further investigation of tailings storage and transport facility safety literature and legislation reveals a focus on preventing catastrophic failures such as the Mt. Polley tailings dam failure (Government of Alberta, 1999, 2000, 2015a). Geotechnical engineers monitor the performance of tailings storage facilities to prevent similar incidents from occurring and impacting the public and the environment.

The authors completed an analysis of the Occupational Health and Safety (OH&S) legislation in Alberta and identified a gap regarding worker safety. The OH&S legislation focuses on job-related hazards and purposeful interactions with the work environment (OHS, 2009 and 2015). Discussions are vague with respect to unintentional interactions with hazards, unidentified hazards in the work environment, and the effects of behavior safety (human factors) on the control of risks. Given the high frequency of incidents that affect (or could affect) worker safety, the lack of information (both academic and legislative) on personal safety, and the potential for unidentified hazards, more attention should be paid to hazards specific to oil sands tailings operations.

The authors propose that the conventional practice of separating process safety, OH&S, and behavioural safety is leading to unintentional blindness in the management of hazards. Safety concerns can fall into all three of these fields and until solutions and controls that address all three areas are provided, the risk will not be adequately managed or mitigated.

This paper presents a case study for the combination of Process Safety Management (PSM), OH&S and behavioural safety approaches using Bow Tie diagrams. In addition to retrospectively implementing controls and learnings, these diagrams can also be used as a dynamic visual tool to promote dialogue, ownership, and innovation of the controls used to mitigate OH&S, behavioural and process safety hazards.

Proposed PSM approaches for oil sands tailings operations and the role of OH&S and behavioural safety

Process Safety Management Approaches

PSM methods are classified into qualitative (non-numerical), quantitative (numerical), and hybrid (both numerical and non-numerical) (Khan et al., 2015), and became the conventional practice for the process industry after many incidents and two salient catastrophes: Flixborough, UK (1974) and Bhopal, India (1984) (Mecza, 2008; Khan et al., 2015). The goals of PSM are to identify, understand, and proactively prevent incidents by controlling hazardous substances (Mecza, 2008; Hardy, 2014; Mannan et al., 2015). Every industry has these goals, including oil sands tailings operations, yet incidents still occur (Hoekstra, 2014; Government of Alberta, 2017). With these common goals, PSM principles and tools should become an integral part of daily field operations of oil sands tailings facilities, dykes, and transport systems. These facilities contain hazardous tailings substances (silica, process water, residual bitumen, and other chemicals). Analysis of the 50 hazardous occurrences identified between 2000 and 2014 shows many relate to loss of primary containment events (Hoekstra, 2014; Government of Alberta, 2017), defined as "unplanned or uncontrolled release of material from primary containment, including non-toxic or non-flammable materials" (CCPS, 2018a). Such events are the primary cause of process safety incidents (PSRG, 2018).

These mining incidents can be viewed, investigated, and managed using PSM tools such as Bow Tie diagrams. PSM tools are also already a common language in use to identify hazards in the extraction and upgrading operations at these mine sites (Khan et al., 2015). Therefore, a practical extension is to use these same tools and terminology in daily tailings operations to better identify and control local hazards. The main difference between tailings operations and conventional process facilities are temperatures and pressures. Temperatures and pressures in tailings operations are typically lower (between 40 and 50 °C, depending on the ambient temperature and discharge temperatures from the extraction facility; and around 30 psi) than in a refinery or upgrader (hydrocracking units can operate at about 500°C and 2000 psi; Qader & Hill, 1969); but at >15 psi tailings is still considered a pressurized process (Davidson, 2018). Pipelines in tailings operations can also experience external pressure (internal low pressure/vacuum), which can also be a hazardous condition (Davidson, 2018).

Bow Tie Analysis

Bow Tie Analysis (BT) is a visual risk assessment tool that shows relationships between causes and consequences (Khan et al., 2015; Sigmann, 2018). BT diagrams are useful and well known in the process safety world as well as risk management and risk analysis communities (Khakzad et al., 2012). BT diagrams, e.g., Figure 34, are a visual representation of the top event (unwanted event), threats, potential outcome, and controls. The top event or unwanted event (red circle in the centre of the bowtie) is what could go wrong. On the far left-hand side is a list of all of the threats that could cause the top event or unwanted event (similar to a fault tree; Khakzad et al., 2012). On the far right-hand side is a list of all of the possible consequences if the top event were to occur (similar to an event tree; Khakzad et al., 2012). Controls are then added. On the left-hand side are blue threat controls (e.g., engineering or administrative controls) put in place to avoid contact with the top event or hazard. Strong threat controls are essential to avoid the top event from occurring. Yellow controls on the right-hand side are mitigation controls. These are typically administrative or personal protective equipment (PPE). If a threat occurs that could lead to the top event, these mitigation controls aim to prevent the undesired event from occurring or, if the event occurs, aim to minimize the consequences to people, property, and/or environment. Bow ties also provide a holistic view of the threats, consequences, and controls, and can identify any over-reliance on one type of control (Cockshott, 2005).

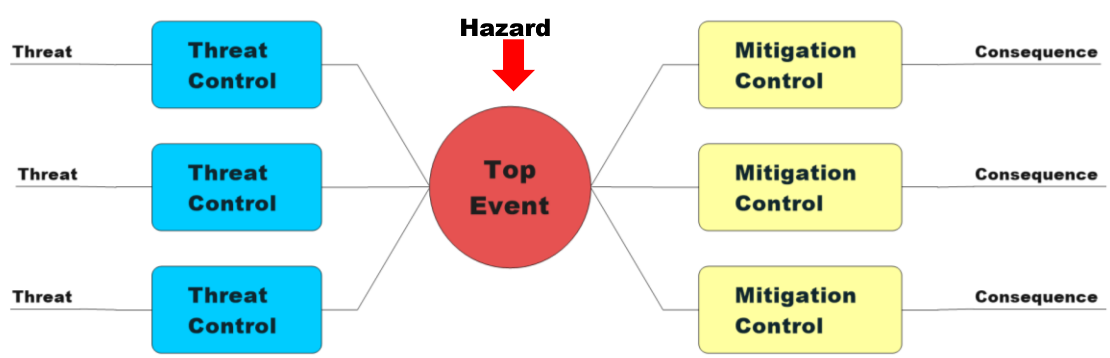


Figure 34. Example of a bow tie diagram.

Drawbacks to BT analysis include the static nature of BT diagrams, which is especially challenging when they are intended for use in a dynamic environment, such as tailings, and that they are typically prepared during the design phase of a project (Khakzad et al., 2012). To combat the static nature, Paltrinieri and colleagues (2014) developed a method to assess dynamic risk using BTs by monitoring the effectiveness of controls during the life of the operation.

Another drawback to the BT method is the high level of uncertainty due to limited or missing data. However, the utilization of expert knowledge can address this limitation (Ferdous et al., 2012). The focus of this paper is on the qualitative portion of BT analysis, with the addition of expert opinion to create local BTs for the tailings operations (after Chevreau et al., 2006). The creation of local or site-specific BTs can increase organizational learning, communication within the organization, and accountability for maintaining the BT diagrams (Chevreau et al., 2006).

Hierarchy of Controls

The hierarchy of controls approach is a systematic method to bring a risk to a level that is as low as reasonably practicable by implementing the most effective controls first and having multiple controls in place to prevent an incident (layers of protection approach) (Figure 35) (CCPS, 2001; Amyotte et al., 2009; Ferdous et al., 2012).

The hierarchy of controls approach lists the most effective methods for reducing risk at the top and the least effective at the bottom. Physically removing the hazard or eliminating it altogether is the most effective method of controlling a hazard (Amyotte et al., 2009). If elimination is not possible, the next best option is to substitute the hazard for something else, for example replacing a toxic chemical in a process with a non-toxic alternative (Amyotte et al., 2009). If the hazard cannot be removed or replaced, then engineering controls should be used, where people are isolated from a hazard, e.g., using a guard on a pump to protect workers from pinch points and rotating equipment. If the risk level is still not as low as reasonably practicable, then administrative controls such as training, standard operating procedures (SOPs), and permitting systems are implemented. The last line of defense and the least effective control is PPE and, in most cases, is used in conjunction with other controls.

Current accident causation theories, such as Reason's *Swiss Cheese Model* show that there are flaws in every level of control and at some point in time, these flaws will align and an incident will occur (Reason, 1990). Therefore a layer of protection approach should also be utilized and monitored for effectiveness to manage risk.

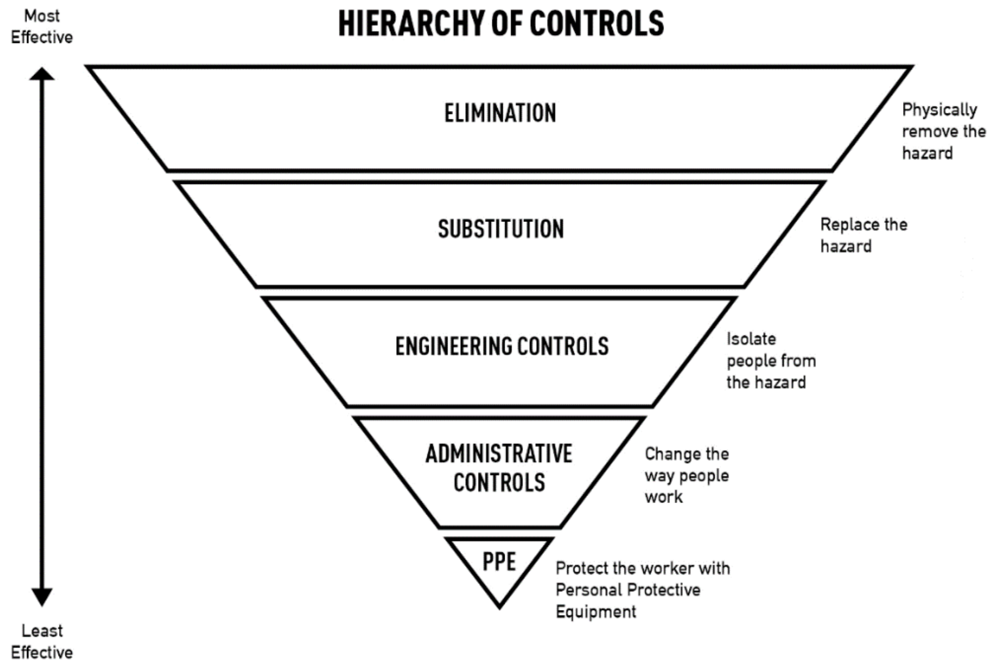


Figure 35. Hierarchy of controls (after CDC, 2015).

The Role of OH&S and Behavioural Safety

BT diagrams can lay the groundwork for discussing hazards in other challenging s industries; however, current PSM analysis tools such as BT diagrams do not focus on high-frequency events associated with OH&S or the impact of the behaviours of workers and management on safety. Instead, PSM is concerned with catastrophic but unlikely events (Mecza, 2008). This focus channels available resources towards preventing high-consequence events, but is leading to potential threats to workers being left out of the BT analysis and therefore potentially going unmitigated (Stoop et al., 2017).

The two main areas that are not a focus in BT analysis are OH&S and behavioural safety issues (i.e., human factor contributions). OH&S is concerned with protecting workers from hazards in their work environment, including occupational diseases and ensuring that workers are physically, mentally, and socially able to conduct their work (Mecza, 2008; Khan et al., 2015). In contrast, behavioural safety focuses on the safety challenges introduced by human behaviours, such as normalization of deviance and complacency, and their effects on safety (Ludwig, 2017).

When OH&S and PSM are implemented together as an effective Safety Management System, the number of lost time incidents in the workplace can decrease (Mecza, 2008). Parts of PSM, such as hazard identification, are already widely used in industry when considering OH&S hazards (Khan et al., 2015). Instead of a hazard and operability study (HAZOP), frontline operations use a Field Level Hazard Assessment tool. Both tools are systematic methods to identify and control hazards. Academics also support the combination of behavioural safety and PSM. Although behavioural safety and PSM focus on different outcomes, the approach does not need to be entirely different (Ludwig, 2017). Many overlapping intentions exist wherein improving one area will lead to improvements in the other.

Caution must be used when discussing OH&S, behavioural safety, and PSM, as they focus on unique areas within the operation and each has a different perspective regarding safe operations (Ludwig, 2017). However, we argue it is prudent to think about the three as related instead of isolated occurrences. They all have the goal of protecting workers from hazards; the hazards are just on different scales. The authors believe that treating these three as independent or entirely different is myopic and does not adequately address the middle "grey" area where a process could have an impact on an individual worker. This interaction becomes especially apparent when looking at socio-technical systems that are concerned with processes, people, and how they interact (Leveson & Stephanopoulos, 2014).

Socio-Technical Approach to Safety

The dynamic nature of hazards in operations presents an additional challenge. This dynamism arises from technical factors, the work environment, the regulatory regime, and human intervention. Regardless of the effectiveness of controls or the safety of the design, dynamic factors can increase risk during the operation of the process unless additional controls are implemented (Leveson & Stephanopoulos, 2014). These should address the multiplicity of external inputs that could lead to an incident, and the multiple sequences of occurrences that can lead to similar undesirable events (Reason, 1990; Leveson & Stephanopolous, 2014). A third challenge lies in the difficulty in effectively learning from incidents, as retrospective analysis can be biased and systemic cultural factors (behavioural safety factors) are typically overlooked during incident investigations (Venkatasubramanian, 2011; Leveson & Stephanopoulos, 2014).

Incident causation models do not account for the potential unseen/unknown hazards, which are typically not controlled, thereby increasing the probability of an incident occurring (Reason, 1990). The socio-technical approach to safety allows for the identification and management of hazards that would previously have gone unidentified in the traditional PSM approach. This is because all aspects of the system (process— PSM; human— OH&S; and social, cultural, and regulatory—behavioural safety) are analyzed as an integrated operation (Ramo, 1973; Paltrinieri et al., 2014). These non-technical aspects and human interactions with the process cannot be overlooked, primarily because human actions are highly influenced by perceived pressures within the organization (Leveson & Stephanopoulos, 2014). Systems are fragile and these non-technical influences, especially human behavioural factors, can have just as much impact on the safety of a process as design errors or component failures (Venkatasubramanian, 2011; Venkatasubramanian & Zhang, 2016). The oil sands tailings field operations are no exception.

Methods

This research applies a mixed method approach to identify hazards (PSM, OH&S and behavioural), threats and possible consequences. There are four datasets (tailings safety expert hazard inventory; interviews with frontline workers, contractors and leaders; incident databases; and ground hazard assessment) that were collected and analyzed as part of a larger research project (Baker et al., 2019b).

The focus of this paper is on the tailings safety expert hazard inventory where BT analysis was selected as a case study to combine safety approaches while increasing the accessibility of the tools for workers of all background and experience levels. BT diagrams are uniquely suited for this analysis based on their visual nature and ability to transcend boundaries within organizations (Cockshott, 2005). This study was developed in two phases: (1) creation of BT diagrams based on an expert assessment of tailings specific hazards (including both process and OH&S hazards) and (2) brainstorming sessions for potential elimination and substitution controls with frontline workers, leaders, and regional contractors from oil sands tailings operations to combat the effect of behavioural safety on the controls. The detailed methods for Phase I and II are given in the following sections.

A brief overview of the other three methods will be provided. For detailed methods and results please refer to Baker et al. 2019b and c.

The authors conducted 158 interviews with frontline workers, contractors and leadership from multiple oil sands companies. The interviews were analyzed using QSR NVivo 12.0 and following the grounded theory methods of Suddaby, 2006; Kreiner et al., 2009; Reinecke & Ansari, 2015; Huy et al., 2014; Lok & de Rond, 2013.

Participating oil sands companies provided the authors with access to their incident data related to tailings from 2014-2017. This data was analyzed following Cohen (2017).

Ground hazard assessments were completed by the authors in summer, winter and spring. This data was analyzed using an action research cycle (Zuber-Skerritt, 2001). In addition to identifying ground hazards, this process familiarized the authors with the tailings operations and allowed them to develop rapport with the interviewees.

Phase I: Bow Tie Diagrams for Tailings-Specific Hazards

Energy Safety Canada (ESC) identified a lack of information surrounding worker safety at oil sands tailings operations (personal communication with ESC, 2017). In 2014, ESC created a tailings safety task force to tour oil sands mines and identify hazards in the tailings operations as well as share knowledge and best practices amongst operators. The authors began working with ESC in 2017 and were provided with their database.

The data from ESC were analyzed following the method of Paltrinieri et al. (2014). This process is called the dynamic procedure for atypical scenarios identification (DyPASI), and is used to create BT diagrams to identify uncommon scenarios (Paltrinieri et al., 2014). This method begins with a search for undetected risks. The ESC task force initially completed this search during their site visits and identified many hazards and current controls. ESC provided to the authors the risk matrix that was used to conduct the risk review and prioritize the hazard inventory, given the prevalence of the hazard at multiple sites or inadequate controls (Figure 36). This risk matrix is based on risk defined as likelihood multiplied by potential consequence. Using the matrix, each hazard was discussed to determine the likelihood of occurrence and potential consequences. The hazards were then assigned to a group, with Group 1 being an intolerable risk requiring immediate corrective action, Groups 2 and 3 being medium risk requiring reduction measures, and Group 4 as risks that are currently being appropriately managed but must be monitored for continuous improvement. Hazards assigned to a group were then weighted to determine the final priority. This prioritized list still contained over 100 hazards or hazardous activities.

			LIKELIHOOD				
			A	B	C	D	E
			VERY LIKELY	SOMEWHAT LIKELY	UNLIKELY	VERY UNLIKELY	PRACTICALLY IMPOSSIBLE
		SAFETY / HEALTH	- Has occurred once or more in the region in the last 10 years or so - Has occurred several times in the industry in the last 10 years or so	- May occur more than once in the region in 10 - 40 years - Has occurred several times in the industry	- May occur once in the region in 10 - 40 years - Has occurred a few times in the industry	- Similar event may occur every 40 - 100 years at one of the regional sites - Have been isolated occurrences in industry	- Has not happened in the regional sites - Has happened a few times or not at all in industry
POTENTIAL CONSEQUENCE	I	Fatalities; Serious Injury to members of public	1	1	1	2	3
POTENTIAL CONSEQUENCE	II	Serious or Lost Time Injury / Illness	1	1	2	3	4
POTENTIAL CONSEQUENCE	III	Restricted Work or Medical Treatment	2	2	3	4	4
POTENTIAL CONSEQUENCE	IV	First Aid / Minor Injury	3	4	4	4	4

Group 1	Intolerable risk - immediate corrective a
Group 2	Incorporate risk-reduction measures
Group 3	Consider incorporating risk-reduction measures
Group 4	Manage for continuous improvement

Figure 36. Energy Safety Canada risk matrix (ESC, 2018d).

Table 16. Process safety management hazard definitions (after Winkel et al., 2017 unless otherwise stated).

Hazard	Definition
Administrative control failure	when an administrative control fails to work, resulting in a near miss or incident
Biological	poses a threat due to exposure to something in the environment, e.g., dust, wildlife, NORMs, etc.
Chemical	poses a threat that is toxic, corrosive, flammable, explosive, reactive, or creates an oxygen-deficient atmosphere
Electrical	poses a threat that could cause electrocution due to exposure to live circuits or stored energy in systems
Ergonomic	poses a threat to a moving body part or the moving body
Line of fire	direct contact between a person and a force their body cannot endure; includes contact with stored energy, striking hazards, and crushing hazards (ESC, 2018c)
Loss of containment	an unplanned or uncontrolled release of material from primary containment, including non-toxic and non-flammable materials (CCPS, 2018a)
Potential gravitational	poses a threat due to a fall to the same or a lower level
Thermal	poses a threat due to exposure to a hot or cold substance or enclosed environment
Worker error/ negligence	when worker error or negligence is one of the causes of an incident

Entries in the ESC database were classified according to process safety management definitions of hazards to cluster activities. The different types of hazards and definitions are listed in Table 16, for reliability and repeatability. Each item in the inventory was assigned a hazard(s) to which people, the environment, assets, or production could be exposed if the unwanted event were to occur. Some activities were associated with multiple hazards. For example, a pipeline leak could expose workers to chemical hazards (contact with hazardous tailings material and asphyxiation/drowning in an oxygen-deficient environment), loss of containment hazards (process water and tailings no longer contained in the pipeline), and gravitational hazards (falling into erosion feature or cavern formed by the leaking pipeline).

Assessment of risk notion relevance was then completed (Paltrinieri et al., 2014). The authors ranked the hazard inventory based on their expertise, experience in the field, and interviews with workers at multiple oil sands companies and regional contractors.

A facilitated discussion was held with the authors and the ESC task force to determine the top hazards at oil sands tailings operations. The seven selected were those the task force felt had a currently unacceptable risk level in the tailings industry and that could have actionable solutions created in a relatively short amount of time.

Process safety and OH&S threats were brainstormed by the authors. Following methods from Chevreau et al. (2006), the first author created seven local BT diagrams to show causes and consequences for unwanted events. These diagrams are used to visually showcase the hazardous events, potential threats, potential consequences, current mitigation techniques, and proposed elimination or substitution solutions to prevent the hazardous event from occurring. This analysis was qualitative and simplified compared to a traditional PSM design phase BT analysis so they could be used by anyone regardless of experience, background, or profession.

Finally, current threat and mitigation controls were discussed by the ESC members (who represent the various oil sands companies) and added to the BT diagrams.

Expert knowledge was solicited to ensure the BTs were useful and correct using What If Analysis sessions at ESC task force meetings. These What If Analysis sessions were facilitated by the authors, who solicited feedback on draft BT diagrams from oil sands operators and regional contractors. ESC members also broke into smaller teams of subject matter experts to provide specific feedback on the BT analysis. This collaboration with ESC allowed this project to become an industry-wide initiative involving multiple oil sands companies and regional contractors. The sharing of best practices and communication between the oil sands operators is unique and valuable.

Phase II: Brainstorming Session for Potential Elimination and Substitution Controls

Instead of waiting until project completion, the authors wanted to present interim findings to the most important stakeholders—the workers in the tailings operations. A Tailings Safety Symposium was held in Fort McMurray to present the findings, obtain feedback from the stakeholders, and brainstorm solutions to some of the issues identified.

One of the preliminary findings from Phase I analysis, was an over-reliance on administrative controls (56% of those mentioned in interviews and 75% of the controls identified in Phase I of the BT analysis). Tailings engineers confirmed this finding, noting that engineering, elimination, and substitution controls are included in the designs but there is limited enhancement to current facilities from a hierarchy of controls perspective once the facilities are put in service.

With these findings and the hierarchy of controls in mind, the authors decided that the question “How do you eliminate or substitute for certain hazards in the bow ties?” be posed to stakeholders at the Tailings Safety Symposium. Brainstorming was completed using the “Brain Writing” or “6-3-5” method (Donald, 2018). This group brainstorming method is used to efficiently generate enhanced solutions to a common problem, and features 6 people, with 3 ideas, and 5-minute rotations to enhance the solution, therefore “6-3-5”. We adapted this method for our group and called it the “8-1-2” as we had larger groups and a more focused problem (8 people, 1 idea, 2 minutes per rotation). We asked each table of 8 people to focus on one of the seven BT diagrams and generate ideas for elimination or substitution; as we had 15 tables (105 participants total), some diagrams were given to multiple tables.

At the end of the session, each person had seven enhancements to their original idea for the elimination or substitution of a hazard at tailings operations. The authors were provided with the brainstorming sheets for further analysis. Based on these ideas and the authors’ engineering expertise, proposed elimination and substitution controls were added to the BT diagrams.

Results and Discussion

Phase I Results and Discussion

Analysis of the ESC tailings hazard inventory indicated that many of the hazards are similar across the participating oil sands sites despite differences in operations and were related to OH&S incidents like slips, trips and falls, long-term exposure and worker injuries. Traditionally, these OH&S hazards would not be included in BT diagrams as they are higher frequency events that are not induced in PSM analysis.

The activities identified as the highest risk and requiring enhanced controls to return the operation to an acceptable risk level, in order of importance, were: (1) pipeline leak, (2) soft deposit, (3) working on water, (4) working on ice, (5) operating spill boxes, (6) long-term exposure, and (7) emergency response. Each of these hazards could have an impact on people, environment, assets, or production. As the focus of this research is personal safety, the consequences to workers are considered foremost. There is potential to extend this analysis to other impact areas in the future.

To showcase the results of Phase I and II, the final pipeline leak BT diagram is discussed as an illustrative example. Details of all seven BT diagrams and analysis can be found in Baker et al. 2019b. To quickly see what types of controls are in place, each control type in the BTs is colour coded: elimination or substitution controls are purple, engineering controls are green, administrative controls are blue, and PPE solutions are yellow.

Investigation of these BT diagrams revealed a heavy reliance (75%) on administration controls. These presently established controls inadequately prevent target incidents for tailings operations given the current frequency of incidents (1500 incidents in the oil sands tailings industry from 2014-2017). This over reliance on administrative controls was confirmed in the interview analysis with 56% of the controls mentioned being related to administrative controls. Some companies may have controls implemented while others do not, leading to ineffective control on an industry level. Controls are not sufficiently effective because safety has been analyzed in isolation; controls have also been created in isolation with a narrow view of the hazard (i.e., not looking at the potential for process safety and OH&S hazards to manifest).

When reading the in-text descriptions of the controls, many appear to relate to hazards identified by workers, with the information being communicated at permit offices or during training. With these administrative controls comes a reliance on organizational culture for maintenance. This is where behaviour safety comes into play with the normalization of deviance, or normalized myopia. In this case, unintentional blindness towards the effectiveness of the controls occurs. The authors found that myopia in organizations is caused by ambiguity, uncertainty, external and internal pressures, and lack of information (Baker & Lefsrud, 2019). All four of these factors could impact the main administrative controls that are in place.

A holistic view of the operations where PSM and OH&S hazards and the effect of behavioural safety are analyzed together will help to increase the effectiveness of controls. Risk mitigations can be enhanced by using a layer of protection approach and adding elimination, substitution, and engineering controls to operational facilities. The addition of elimination and substitution controls will be discussed in the Phase II results and discussion section.

Pipeline leak

The threats that could cause a pipeline leak were clustered into two main topics: (1) pipeline failures when a pipeline is struck, crushed, or splits due to internal or external corrosion or interaction with other pieces of equipment in the tailings operations and (2) process line up incorrect, which can occur when a drain is left open, a rupture disc overpressures because a valve is accidentally left closed, or when other worker errors occur. Figure 37 is the BT diagram for pipeline leaks.

The threat controls that prevent a pipeline leak from occurring are engineered controls such as design specifications, elevating the pipeline on blocking, equipment strategies, or material selection. Threat controls also include maintenance, such as quality assurance/control programs, joint integrity, and preventative maintenance programs (e.g., line rotation). The last threat control is operating procedures such as structured rounds, predetermined operating envelopes, open-air calls to notify workers when operations are occurring, and proper housekeeping in the tailings area. All workers, including contractors, in tailings areas should have access to a radio so they can be notified when different operations are occurring.

If a pipeline leak were to occur in the tailings operations, mitigation controls are intended to prevent a consequence from occurring. A pipeline leak response is implemented when a leak is detected. This procedure is designed to mitigate unwanted events including worker injury or death. The steps in a typical pipeline leak response are: (1) leak identified by worker, (2) notification procedure followed to ensure supervisors and other appropriate personnel are aware of the leak, (3) the system is shut down, so there is no flow in the leaky line, and (4) a line approach procedure is followed to investigate the leak further.

Additional mitigation controls in the tailings area to prevent consequences affecting people are permit policies, proper visibility so that leaks can be identified and managed, the area and hazards being known to workers, and a timely emergency response. If the area and the hazards are unknown to workers, there is an increased probability of a more severe consequence occurring because their awareness is hampered. The permit policy attempts to mitigate this hazard by having a risk-based approach in place when workers are working alone as well as a call-in procedure. During typical rounds, a worker will be alone; however, they will be paired up if there is anything out of the ordinary (e.g., a known line leak or steam). Proper visibility is achieved by elevating pipes on blocking and not pushing windrows up against the side of the pipe; these allows the whole pipe to be easily seen during rounds so leaks can be more easily identified. The speed at which first responders can arrive at a location will also influence the outcome of an incident.

Tailings operations are dynamic, and ESC members have identified the need for increased training in tailings operations to ensure area familiarity. Line names are unknown to people who are not involved in operations or planning. Some suggestions to mitigate this issue from ESC are making maps with line names, cell names, and landmarks available to workers, potentially in the permit office. Increased supervision, area tours, and permit processes specific to the tailings area should also be in place. Rules and expectations exist with respect to crossing pipelines on foot, and training is required to ensure area personnel are aware of these expectations. People working in tailings operations also need to be aware of soil subgrades that are more likely to erode and create underground caverns. More research should be done to determine how different subgrades such as clay or sand react to pipeline leaks. Radio training and awareness is also required as new workers can be uncomfortable using radios.

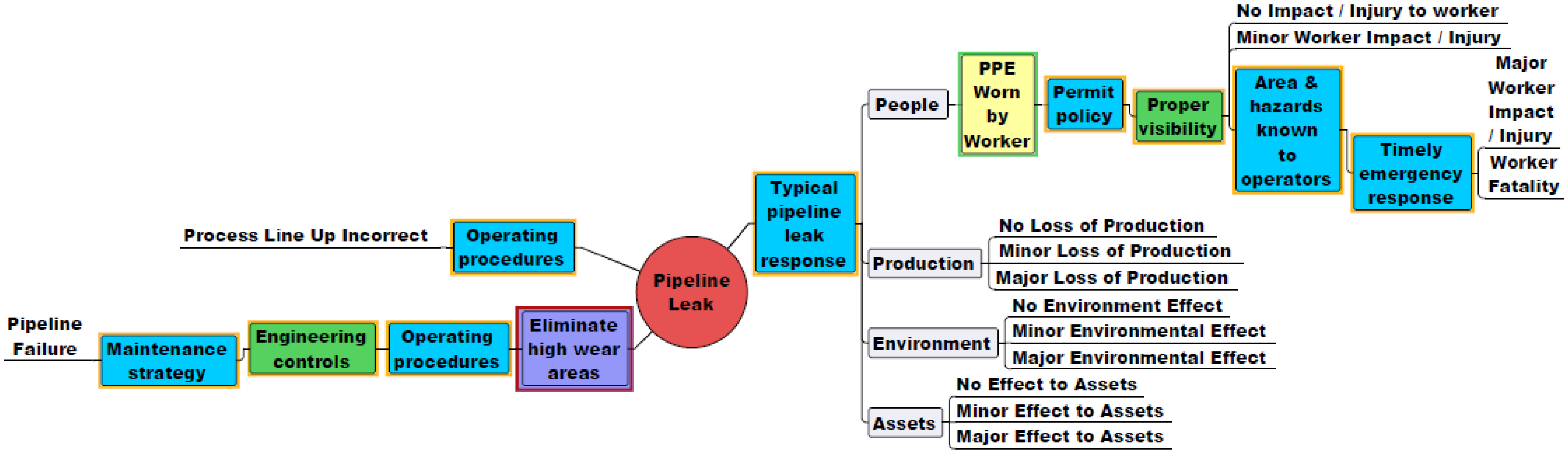


Figure 37. Pipeline leak bow tie diagram.

Phase II Results and Discussion

By including elimination and substitution controls, the impact of human behaviors on the effectiveness of controls can be mitigated (e.g., relying on workers to identify the hazards when they have received no tailings specific hazard training). A total of 105 participants provided enhanced solutions for the top seven hazards in tailings operations using the "8-1-2" brainstorming method. Many were enhancements to administrative and engineering controls or maintenance strategies that are already in place. The majority of the suggestions represented full elimination and involved entirely removing workers from the tailings operations and utilizing autonomous or remote-controlled vehicles. Some of the suggested methods would be challenging to implement (should have been implemented during the design phase) or are not cost-effective (e.g., change the footprint of tailings and provide windbreaks, thoroughly clean ponds on startup, installation of permanent roads in tailings). These suggestions are still valuable and could be implemented by new startup operations.

The remaining elimination and substitution suggestions indicate much potential for technological advancement in tailings operations, such as the use of amphibious vehicles. These solutions may not be cost-effective or operationally feasible, but are worth investigating further to enhance the current controls in place for the seven hazards considered. These elimination and substitution suggestions were added to the BT diagrams (Figure 37) with a red box around them, indicating they have not yet been implemented in daily operation (Paltrinieri et al., 2014). Yellow and green boxes were added around existing controls from Phase I based on the effectiveness of the control. Responses from the "8-1-2" method, the ESC hazard inventory, and analysis of interview data suggest most existing controls are adequate but could be enhanced from an industry standpoint (yellow box). Some companies may have already implemented these controls where others may have not; for this reason, these hazards were identified by ESC as areas of enhancement for the oil sands tailings industry as a whole.

Pipeline leak

For the pipeline leak BT (Figure 37), many participants mentioned the need for enhanced maintenance programs with increased line rotation, identification of misaligned areas, improving quality assurance logs to identify root causes of high wear areas, and real-time monitoring for pipeline thickness (UT thickness meters, infrared cameras, smart pigs). Other elimination/ substitution recommendations included changing the pipeline design to reduce the length of the pipeline, number of connections, and high wear points (straighten the pipe, decrease the number of elbows) and using/ incorporating different materials (e.g., rubber, urethane). Utilizing alternative technologies such as inline sampling systems, autonomous or amphibious vehicles, chemicals to coat the tailings and decrease abrasion, positive displacement pumps, and flow meters at the end of the line (so a mass balance can be completed and losses determined) were also suggested. Other suggestions included removing the pipeline completely, drying the tailings using centrifuges or chemicals, and transporting them to tailings discharge or a third-party buyer using trucks or trains.

Conclusions

Analyzing safety as a component of a system without considering the effect of external factors is a nearsighted view and leads to ineffective mitigation of risk in dynamic oil sands tailings operations. Traditional BT diagrams focus on loss of containment events, but they do not discuss the potential for OH&S incidents to occur (e.g., worker injury from a slip, trip or fall in eroded sand caused by loss of containment) or highlight on the impact of behavioural safety on the effectiveness of the controls (e.g., lack of tailings specific training). The BT analysis that was completed in this study using the tailings safety expert hazard inventory combines OH&S and process safety to include hazards that were previously unidentified. Behavioural safety is also scrutinized through analysis of the controls that are put in place. In the tailings operations, controls are mainly administrative, which are impacted by company culture.

The cultural influence on controls can be combatted by implementing elimination and substitution controls in a layer of protection approach. However, systemic cultural issues must also be addressed for all of the controls to function effectively. Most companies analyze these facets of safety individually as opposed to holistically and such a discrete approach can lead to gaps and a myopic view of the operations. Elimination and substitution controls can also be used to address Reason's *Swiss Cheese Model* (1990), by removing the hazard completely and eliminating the need for controls that may fail.

Process safety, OH&S, and behavioural safety, need to be analyzed together; one impacts the other in a socio-technical approach as workers are interacting directly with the technology in oil sands tailings. Existing threat controls are no longer effective if all the hazards have not been identified, e.g., because OH&S hazards were not included in the initial PSM analysis, or influenced by cultural factors, e.g., where hazards are not identified, procedures are not followed, or there is a lack of training, leading to unintentional blindness within these organizations.

A holistic view of safety in these operations requires that all three approaches to safety (OH&S, behavioural safety, and PSM) be analyzed together as a socio-technical system. BT diagrams created as part of this research are one way to showcase threats and controls in this regard.

Chapter 5: Fourth thesis paper

Organizational myopia:
How organizations create complexity, ambiguity, and uncertainty to blind their risk management efforts

Kathleen E. Baker
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
kebaker@ualberta.ca

Dr. Lianne M. Lefsrud
Assistant Professor
University of Alberta
School of Engineering Safety and Risk Management
Department of Chemical and Materials Engineering
Edmonton, Alberta, Canada
lefsrud@ualberta.ca

Paper Status and History

Fourth thesis paper	
Organizational myopia: How organizations create complexity, ambiguity, and uncertainty to blind their risk management efforts (Kathleen E. Baker and Lianne M. Lefsrud)	
Status	Working draft for *European Group of Organizational Studies Colloquium* (EGOS) on July 4-6, 2019; full paper to be submitted on June 15, 2019.
History	
Peer reviewed extended abstract	Baker, K.E., and Lefsrud, L.M. 2019. Organizational myopia: How organizations create complexity, ambiguity, and uncertainty to blind their risk management efforts. *European Group of Organizational Studies Colloquium.* July 4-6, 2019, Edinburgh, UK.
Peer reviewed conference abstracts	Baker, K.E., and Lefsrud, L.M. 2019. Deviance? Wrongdoing? Myopia? *Society of Risk Analysis.* March 25-27, 2019, Luxemburg.

Abstract

Normalization of deviance has been discussed since Diane Vaughn's 1996 Challenger Space Shuttle Explosion publication. This concept has applicability to many industries including the oil sands tailings operations in Fort McMurray. However, 'deviance' has a negative connotation and can be associated with purposeful negative actions. Much of the literature on these organizational structures presumes intentionality. This is not what we are seeing in the oil sands, people do not come to work planning to have an incident. Layers of controls are in place to prevent incidents and yet, there are still fatalities occurring. There is a need for a theoretical framework that describes this phenomenon and considers unintended variance within organizations (so called organizational "wrongdoing" by Palmer (2012)).

A group of 158 individuals were interviewed from multiple oil sands companies and regional contractors with representation from leadership, frontline workers and health and safety professionals. From this data, it was determined that workers experience a blend of physical and organizational factors that cause hazards to be unidentified. These factors are then affecting the worker's abilities to recognize hazards and effectively control them. We will discuss our findings, outline our theoretical model, and suggest methods of combatting this organizational myopia like: (1) risk communication practices to combat silos, (2) standardizing administrative controls like procedures and hazard identification tools, and (3) specific training to address hazards and risk tolerance.

Keywords: hazard identification; risk management; complexity; ambiguity; uncertainty; organizational myopia

Introduction and theory

The primary goal for organizations in heavy industries—agriculture, forestry, fishing, energy, manufacturing, transportation—is to deliver on mandates while managing organizational factors that can introduce risk. To accomplish this, "risk" has become an umbrella construct (Beck, 1992; Hirsch & Levin, 1999) to quantify and manage uncertainty for technical reliability, process safety, occupational health and safety, environmental, economic, and even reputational objectives (Register & Larkin, 2005; CCPS, 2007; Zinn, 2008; ISO, 2010). Besides managing the uncertainty and consequences of physical hazards, the "adoption of world-level risk management principles has become a badge of both benchmark legitimacy and a source of reputational variation with regulatory bodies" (Power et al., 2009: 316).

To continuously improve risk management systems, it is assumed that organizations engage in 'risk work' to routinely reward the discovery of error, investigate incidents, determine responsibility for latent causes (inadequate programs, inadequate standards, and/or inadequate compliance to standards), review and provide feedback, and institute mitigations and controls to prevent similar incidents from re-occurring (LaPorte, 1996; ISO, 2010; Power, 2016). Ideally, risk management not only serves to protect value, but it enables sustained, optimized performance (Farrell & Gallager, 2015).

Despite these risk work efforts, only 3.4% of organizations have mature processes to actively identify, evaluate, and manage their risks (Marks, 2011). Up to 80-90% of incidents are caused by individual and organizational failures (European Agency for Safety and Health at Work, 2016). While the frequency of incidents is decreasing, the frequency of fatalities is not (U.S. Department of Labour, 2016; Grant, 2017; OHS, 2017b). Production loss, absenteeism, medical costs, and compensation equate to 4% of the annual global gross domestic product (Takala et al., 2014). Why?

Safety is an effortful, dynamic non-event (Weick, 1991) and decoupling between safety messaging "What is said" and behaviourally "What is done" often leads to non-events, which then become taken-for-granted (Reason, 1998). Thus, there is slippage in organizations' risk management systems. This noncompliance with an organization's risk management system has been described as the *normalization of deviance*: "people within the organization become so much accustomed to a deviant behaviour that they don't consider it as deviant, despite the fact that they far exceeded their own rules" (Interview of Dianne Vaughan by Villeret, 2008; see also Vaughan, 1996; Nolke & May, 2018). CCPS (2018c) describes the normalization of deviance as requiring: 1) human-based decisions that are 2) occurring repeatedly over time and 3) have no immediate consequences, such that these mistakes become tolerated. As a result, organizations institute behaviours that they believe are safe but instead increase the likelihood of future accidents. This "create[s] a way of seeing that [is] simultaneously a way of not seeing" (Vaughan, 1996: 394). For example, if investigations are completed, but hazards not fully identified, then these cannot be effectively controlled by the organization (CTSB, 2014).

Unintended variance, or so called, organizational "wrongdoing" by Palmer (2012), is theorized as *abnormal* or *normal* (Palmer, 2012). See Figure 38. *Abnormal wrongdoing* is enabled by mindful, rational actors, engaged in socially isolated, culturally normalized decision-making (Palmer, 2012; Mannion & Braithwaite, 2017; Searle et al., 2017; Tarrant et al., 2017; CCPS, 2018c). Even though wrongful acts are recognized as such, these behaviours are rewarded by *perverse* structures and processes for personal or organizational gain (Palmer, 2012; Brief & Smith-Crowe, 2016; Van Halderen & Kolthoff, 2016). *Normal wrongdoing* is caused by mindless, boundedly rational actors, who are embedded in a social context, with delayed but escalating events. Individuals never develop positive inclinations for wrongdoing, because they are blinded by *pervasive* structures and processes (Palmer, 2012; Vesa et al., 2018). In such cases, organizational wrongdoing is most often not intentional, obviously unremarkable, nor has clear-cut responsibilities and undeniable latent causes (Vaughan, 1999).

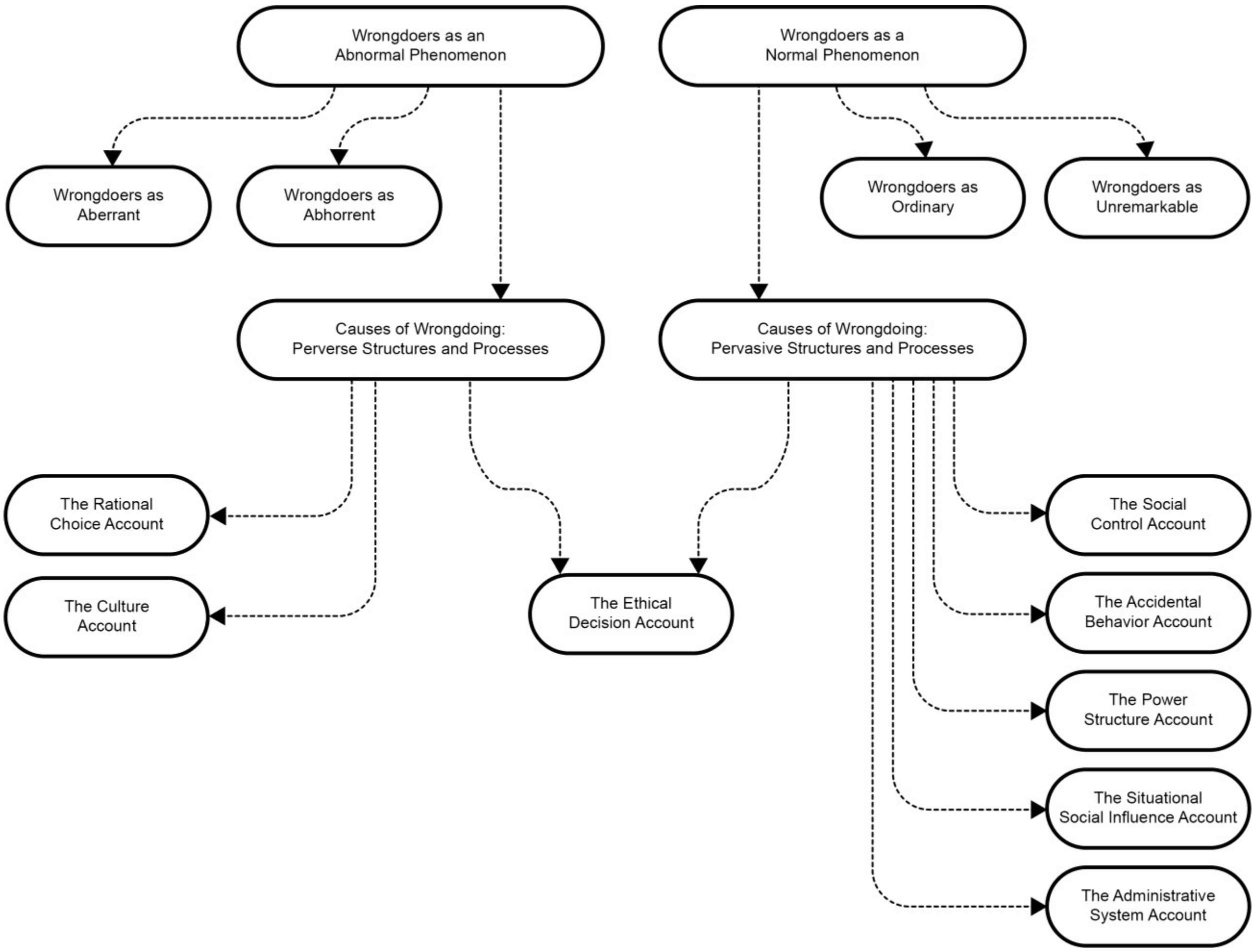


Figure 38. Two Perspectives on organizational wrongdoing (Palmer, 2012).

To complicate their risk management efforts, organizations face the double dilemma of uncertainty (insufficient information about an unknown future) and ambiguity (multiple interpretations of the future and methods of estimating uncertain outcomes) within their context (March, 1999). Thus, individuals and organizations exhibit bounded rationality in their information processing (March & Simon, 1958; Simon, 1972; Palmer, 2012; Catino, 2013), which also constricts their decision making. Limits to rationality include complexity in cause-effect linkages, inability to foresee outcomes and detect signs of danger (Catino, 2013), limits on processing capacity (Palmer, 2012) and decision alternatives leading to ambiguity in interpretation, uncertainty about operations, and incomplete information about alternative solutions (Palmer, 2012). Bounded ethicality identifies individuals' inability to recognize moral issues and judging before thinking, such that they behave inconsistently with their own ethical preferences, as caused by internal and external influences on their judgement (Chugh et al., 2005; Bazerman & Tenbrunsel, 2011). Bounded rationality/ethicality are also factors that influence the organizational theory of accidental wrongdoing. Accidental wrongdoing where incidents are not caused by perverse or pervasive structures, but instead from other external factors such as, an individual's bounded rationality and a lack of information (Palmer, 2012), the unintended impact of safety management systems, that lead to more failures and incidents due to tight coupling and complexity (Perrow, 1999) and lack of organizational foresight to detect signs of danger or opportunities (Catino, 2013), also thwart risk management efforts.

By unpacking organizational-level bounded rationality/ethicality, we contend that there is a theoretically useful expansion of Palmer's (2012) perspectives, especially on accidental wrongdoing. Thus, we ask: *Besides being faced with complexity and ambiguity, uncertainty, incomplete information in their contexts, and external and internal influences on ethical decision-making, how do organizations create these obfuscating conditions through their own risk management structures and processes. As a result, how do these structures and processes become a source of risk in themselves?*

To answer our research questions, we examine the Alberta oil sands; an industry that is the economic driver for Canada, continually implements novel technology in a dynamic and everchanging environment and is striving to incorporate resiliency into operations. Following a workplace fatality (there were seven fatalities in the oil sands between 2011 and 2015, with three being caused by unseen/unknown hazards (Government of Alberta, 2017)), we examined the risk management processes of the four major oilsands operators. We visited their tailings operations in summer, winter, and spring and developed an inventory of over one hundred hazards in their tailings operations. We used bow-ties to cluster these into cause-effect linkages, including possible controls and mitigations. We also analyzed their incident databases, comprised of over 1500 tailings incidents over the past three years, to determine the frequency and consequences associated with these hazards. And we completed 158 interviews with frontline workers, leadership, safety professionals and regional contractors to examine what and how hazards are identified and controlled by individuals within these organizations, relative to the hazard inventory and incident databases.

Our preliminary analysis suggests that, in this industry, respondents are aware of the challenging nature of their work, set high standards for safety to deliver on performance and yet, there are still challenges that the industry needs to address. Like all industries, organizational factors such as dynamic work environments, complexity leading to ambiguity, lack of information and internal and external influences, can subvert these well-intentioned risk management efforts, are leading to unintentional blindness or myopia, where hazards are not being identified, understood or effectively controlled.

With this, we make three contributions. First, we expand organizational theories of wrongdoing in which individuals are bounded in their choices (Vaughan, 1996; Perrow, 1999; Chugh et al., 2005; Griffin & Lopez, 2005; Assadi, 2008; Palmer, 2012; Catino, 2013; Larkin & Pierce 2015; Brief & Smith-Crowe, 2016; Stackhouse & Stewart, 2016) by considering how organizations' well-meaning risk management systems inadvertently create rational and ethical boundedness, even myopia, for themselves. We also expand the organizational theory of "organizational myopia" to include unintentional blindness in addition to lack of foresight and inability to detect or predict incidents (Catino, 2013). Second, while most organizational research focusses on financial harm of 'white collar crime' like fraud (Perri, 2011; Cooper et al., 2013; Friedrichs, 2015) and tax evasion (Harrington, 2018) or psychological harm like bullying (Vardi & Weitz, 2016) to others, we examine workplace fatalities whereby risk decision-makers can become the victims of their own crime. Third, we make an empirical contribution to understanding mining operations. Research has tended to focus on catastrophic failure of tailings dams and environmental or public health impacts, like the Mt. Polley tailings dam failure in 2014 in Canada (Morgenstern et al., 2015; Hoffman, 2015) or the Samarco iron ore 2015 tailings dam failure in Brazil (Agurto-Detzel et al., 2016). Three articles published out of China (Wei et al., 2003; Li et al., 2010; Tang et al., 2012) discuss worker safety in tailings and they focus on the environmental impacts and individual factors that could affect worker safety; not how they interact. Finally, by identifying these organizational factors and unintentional blindness, we create the opportunity for all industries to strengthen their risk management approaches.

Methodology

Research Context

Our research is motivated by a workplace fatality. Around 6:00 am on 19 January 2014, a worker broke through the frozen ground and drowned in an underground cavern, created by a pin-hole sized leak of hot tailings from a transportation pipeline in the tailings discharge area (OHS 2017a).

Protocols to ensure the safety of workers were followed, including the use of pipeline leak detection and mitigation, administrative controls such as call-in procedures, and the use of personal protective equipment (OHS, 2017a). Despite these hazard identifications and controls, none of the frontline tailings team knew that an underground cavern could be created by a tailings leak. This was a previously unknown hazard. Furthermore, leaks from a tailings pipeline tend to give off steam because of the temperature differential between the hot tailings and the ambient environment As the tailings were draining elsewhere from the cavern, little or no steam was being emitted at the leak site. Hence, there was little warning that the pipeline was leaking at that location.. It was inconceivable to workers that there could be a leak without steam. Lastly, this hazard was further hidden from view by the snow- and ice-covered ground and early-morning darkness (OHS, 2017a). In sum, while oil sands companies have created industry best practices like "Life-Saving Rules" (ESC, 2018b), hazards remain unidentified and incidents like this still occur.

Data collection

To answer our research questions, we analyzed four datasets, interviews, hazard inventory, incident data, and ground hazard assessment. The detailed interview methods will be described in this paper. The methods for analysis of the other datasets have been reported elsewhere (Baker et al., 2019a, b, c).

We developed seven semi-structured interview questions designed to build rapport with the interviewees and answer these questions while allowing for candid conversation with participants. The Research Ethics Board (REB) at the University of Alberta approved the interview questions and our research method prior to the start of the study. The interview questions were also vetted by ESC to ensure validity.

We conducted 158 semi-structured interviews with employees and contractors from multiple oil sands companies. Our interviewees included: 78 frontline workers (heavy equipment operators, plant operators, and maintenance staff), 33 leaders (site leaders, management, health and safety professionals, and engineers) and 47 regional contractors (dredge and boat operators, geotechnical engineers, roving contractors, and embedded contractors). We are most interested in the ability of workers—those who interact with the tailings daily—to 'see' hazards and whether they can suggest enhancements in hazard identification, reporting, and control. Many of our interviewees had either had co-workers injured or killed or have had incidents themselves.

All interviews were conducted by the authors. To not interrupt operations, most interviews took place at the oil sands operators' sites, with 12 interviews occurring over the phone by the first author. Most interviews were conducted individually or in pairs, however, there were a handful of interviews with 3-4 participants and the authors. There were three interviews with more than 4 participants (29 interviewees in total participated in focus-group-style interviews) and the authors were not able to assign direct attribution to individuals. The remainder (129) had identified speakers. Interviews were between 30 and 90 minutes long, interviewees' responses were handwritten by the authors, and typed up by a transcriber. Despite the sensitivity of the research topic and the fact that interviews were conducted on-site, interviewees were surprisingly forthcoming.

Data analysis

We began by analyzing the responses to each interview question in QSR NVivo 12.0. We derived general concepts from the interviewees' answers and analyzed each interview in its entirety. From our research questions, we then developed theoretically informed coding categories based upon a review of the literature. Our analysis proceeded abductively and in stages, using NVivo in our empirical coding. During this analysis stage, both authors used NVivo to develop and relate codes and continually test the plausibility of our theorizing (Lok & de Rond, 2013; Huy et al., 2014; Reinecke & Ansari, 2015). A detailed codebook was created to ensure reliability. The analysis of the interviews involved cycling between our data, explanations why hazards were not being identified or reported, and the relevant literature to determine if there are precedents or if we are discovering new concepts (following grounded theory methods and Gioia et al., 2013) and we revised the coding scheme as required. Such an abductive approach is "most suited to efforts to understand the process by which actors construct meaning out of intersubjective experience" (Suddaby, 2006: 634). We progressively refined categories and themes to develop our data structure. After cycling iteratively through our interviews, we collapsed these codes into subtheme categories. Next, we looked for links between subthemes and clustered these into over-arching dimensions that provide the basis of our theory development. Figure 39 outlines our emerging data structure, verbatim examples, and relationships between subthemes and the overarching dimensions. Based on these interviews, we mapped the processes by which individuals and their companies fail to see hazards.

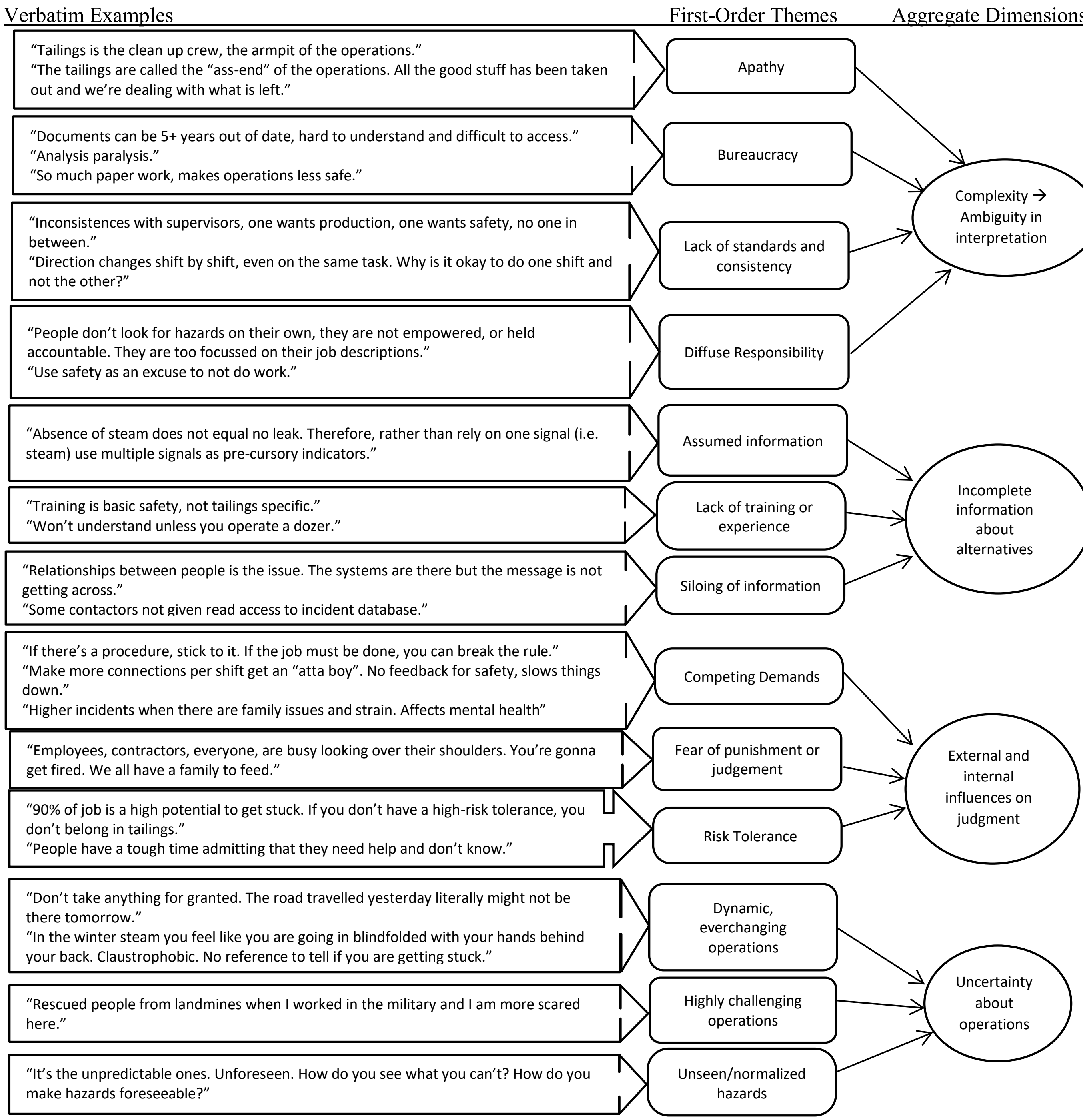


Figure 39. Data structure: representative quotes, themes, and aggregate dimensions.

Results

Based on our coding of these semi-structured interviews from frontline workers, safety professionals, engineers, leadership and regional contractors at multiple oil sands companies, we are seeing organizational wrongdoing manifest. This wrongdoing is being caused by a combination of organizational factors not distinct paths for identifying, managing and controlling hazards, namely, complexity leading to ambiguity in interpretation; incomplete information about alternative methods, procedures, operations, etc.; external and internal influences on judgement; and uncertainty about operations (as shown in Figure 39 under the aggregate dimension column). More detailed discussion regarding the classification of these four organizational factors will be described in the following sections. Some of the organizational factors consist of multiple subthemes, in these cases, detailed figures of the subtheme data structure will be provided.

Complexity leading to ambiguity in interpretation

Industries like nuclear power generation, petrochemical refineries, dam operation, and aviation are examples of complex operations (Perrow, 1999). Through our analysis of the interview data and organizational theory, we have determined that the oil sands tailings operations are also a complex industry. We see complexity leading to ambiguity in interpretation manifest as apathy, bureaucracy, diffuse responsibility and lack of standards and consistency.

Apathy

We extend Stackhouse and Stuart's (2016) findings on failing to fix what is found and cultures of risk accommodation with our discovery of the apathy spiral. We identified multiple subthemes, such as conditioning, lack of appreciation, lack of resources, and complacency, among others, that were contributing to the first-order theme of apathy within organizations (details of the subtheme data structure can be seen in Figure 40). These findings were consistent with Stackhouse and Stuart's (2016) results that the lack of corrective action, or feedback, to workers, decreases the reporting of hazards and incidents. Upon further analysis of our data, we found that additional factors, not only lack of corrective action, interact, compound and amplify to create an apathy spiral, as seen in Figure 41, which prevents organizational learning, mindfulness, and resiliency from forming. All too often there is no transparency from leadership and no follow-up, i.e., hazards reported, and no corrective action implemented (Stackhouse and Stuart, 2016). The lack of communication and feedback conditions workers to neither look for hazards nor question processes. The absence of questioning is seen as disengagement by management, which leads to less equipment, staff and other resources being provided to the workforce. The frontline workers become frustrated with the lack of feedback and resources, their apathy increases, and motivation can decrease among all workers. This spiral continues with increases in the level of apathy from everyone involved, making it increasingly challenging to effectively identify and control hazards.

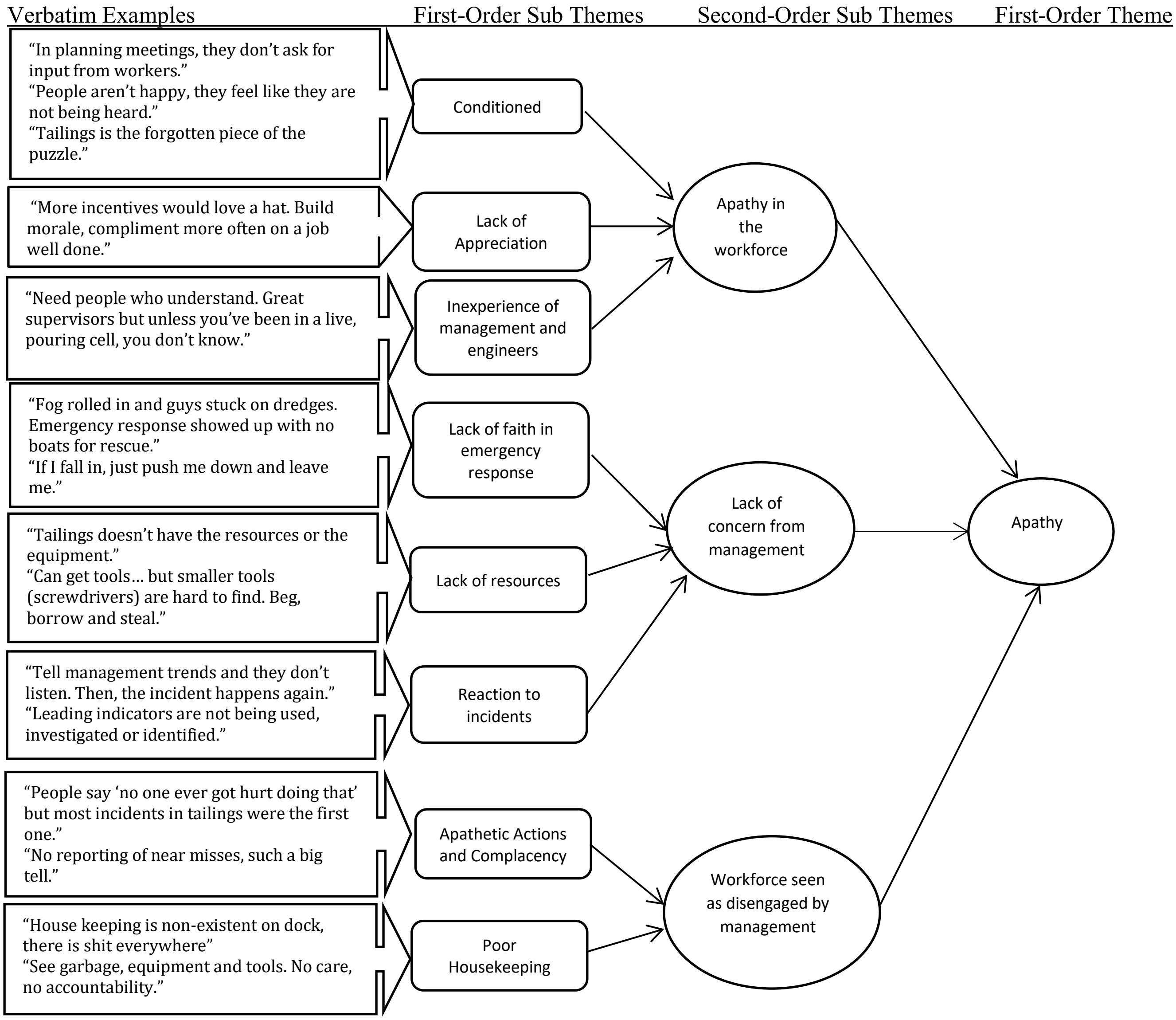


Figure 40. Apathy subtheme data structure: representative quotes and subthemes that can lead to apathy within organizations.

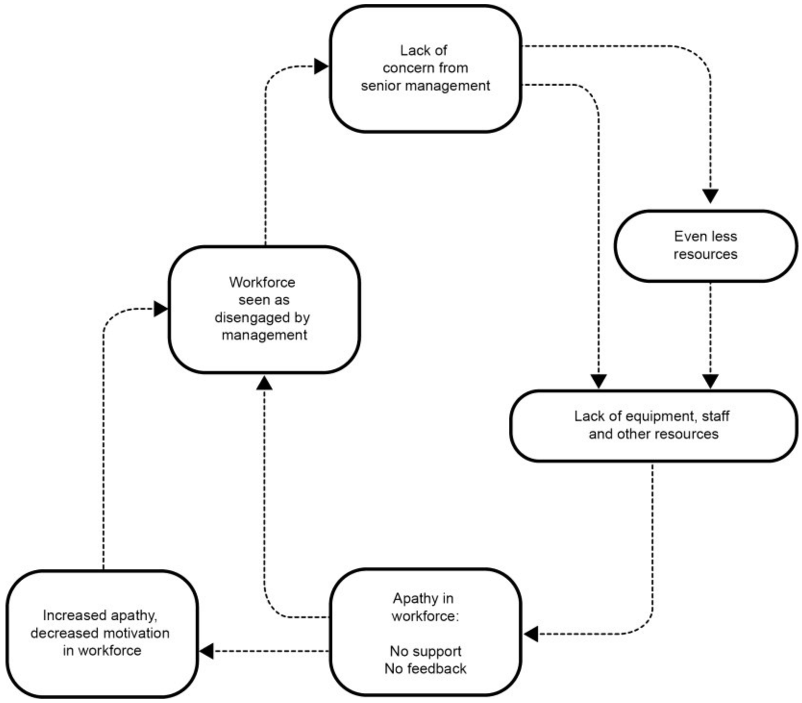


Figure 41. Apathy spiral in hazard identification.

Bureaucracy

Bureaucracy and complexity coexist in a tumultuous relationship that can serve to bolster efficient operations or hinder them (Marion and Uhl-Bien, 2011). Our first order themes show the negative side of this relationship between bureaucracy (e.g., time lag to get document versions updated, copious permits and procedures, etc.), breeding complexity in the operations with the sheer volume of paperwork. To add to the complexity, it is challenging for workers and contractors alike to find the correct information in the bureaucratic system, which creates ambiguity, distracting workers from their work task and hazard identification. People are paralyzed by the amount of paperwork, they cannot effectively do their jobs, leading to hazard identification being stopped prematurely as workers feel they have "met" the bureaucratic requirement.

Diffuse responsibility

Diffuse responsibility is when someone holds others accountable by blaming others for negative actions, rationalizing that the work environment is safer than it actually is, not following procedure because others do not or it is not in their job description, and/or placing sole responsibility for safety to the company by means of processes and procedures (Tamuz & Harrison, 2006; Probst et al., 2018). We see all four of these definitions of diffuse responsibility appear in our first order themes and serve to increase the complexity of the operations. First, the systemic blame within organizations makes it challenging to improve reporting and identification of hazards. Second, many workers have a high-risk tolerance and do not see hazards in anything, this tolerance for risk can be passed down to new workers through infield training and mentorship activities. Third, the organizational structure also leads to diffusion of responsibility as workers are less likely to identify and report hazards as they feel that this activity is outside their job scope. Finally, people trust that the permits, procedures and other controls will keep them safe, so they do not feel empowered to critically analyze the operations. These permits and procedures can also be used to avoid work by claiming the procedure prohibits a particular task and not attempting to mitigate the risks.

Lack of standards and consistency

When information is subject to interpretation, is vague or complex, ambiguity can enter the operation (CCPS, 2018c). We see this theme manifest in our data with the lack of standards and consistency in the oil sands tailings operations. The impact of lack of standards is especially felt by the regional contractors, who see across sites and are subject to different standards for the same task across the industry. For example, many sites have different rules for donning a Personal Flotation Device (PFD) when working near water and every company has different working alone and discipline procedures. Employees of owner companies are not immune to this phenomenon as different standards are used for preventative maintenance and operation of facilities. In some cases, quality control is lacking standards altogether. Inconsistency is seen within organizations with some information being given to one shift and not to another; different managers asking for different outcomes from workers; incident investigations leading to myopic root causes; and no standardization for operations, for example, the way a cell is poured varies between operators or workers are sometimes asked to do a task and other times they are reprimanded for doing the same task. When standards and consistency are ambiguous, workers waste time and energy trying to decipher and interpret information, which distracts from their task at hand and identifying hazards.

Incomplete information about alternatives

Palmer identified lack of information as one of the causes of accidental wrongdoing (Palmer, 2012). We enhance his discussion with the identification of three areas where workers are not being provided with adequate information, much information is assumed based on empirical observations, or “the way things have always been done”; there is a lack of tailings specific training and experience in the tailings operations; and boundaries within organizations create silos of information.

Assumed Information

In order to increase standardization across sites, many organizations apply similar processes, procedures or definitions from other areas of the operation, e.g., mine driving and process safety definitions for incidents instead of people safety. While this approach makes sense to decrease complexity within the organization, what works in the mine or upgrader may not be applicable in tailings due to the unique work environment. There is a lot of “tribal knowledge” (personal correspondence with interviewee) in tailings, where people do things because that is the way they have always been done. Other assumptions are made in the tailings operations when necessary information is not available, up to date or correct. For example, velocities of tailing through the pipelines are not known, this makes it challenging to predict pipeline wear rates; it can be challenging to find the correct procedures; and steam does not always mean there is no leak (i.e., workers used to believe that no steam meant no leak).

Lack of training or experience

A lack of hazard knowledge can increase the likelihood of exposure (Ji et al., 2018); currently, there is no tailings specific hazard training in the oil sands industry, workers are trained generally on hazards and mining operations. If the hazards are unknown, it is challenging, if not impossible for a worker to anticipate and control the risk for a safe working environment. Adding to the complexity of hazard identification, much reorganization occurs in these operations where workers, move into tailings roles, as operators, planners, engineers or management, and have never worked in tailings before, and they are not being provided with tailings specific orientation. To exacerbate this challenge, the tailings operation is constantly changing, based on the nature of the operations (i.e., continuously producing tailings waste to be contained in tailings storage facilities and treated for reclamation). Interview participants across the industry indicated that the only way to learn tailings operations is to work in tailings, indicating the value of experience. Providing adequate training and experience is especially challenging with the seasonal workforce, turnover rates and various literacy rates and learning styles within the workforce.

Siloing of information

Poor communication is one of the contributing factors to incidents on construction sites (Bashir et al., 2012). Through our coding analysis, we identified first order themes that indicated silos within the organizations where information is not passed from one group to another and where groups like planning, management and engineers do not have field experience and ask the frontline workers to complete tasks that are not feasible. The first-order subtheme, siloing of information, consists of multiple breakdowns in communication between different working groups. Verbatim examples of the breakdowns in communication are shown in Figure 42 (after Baker et al., 2019c).

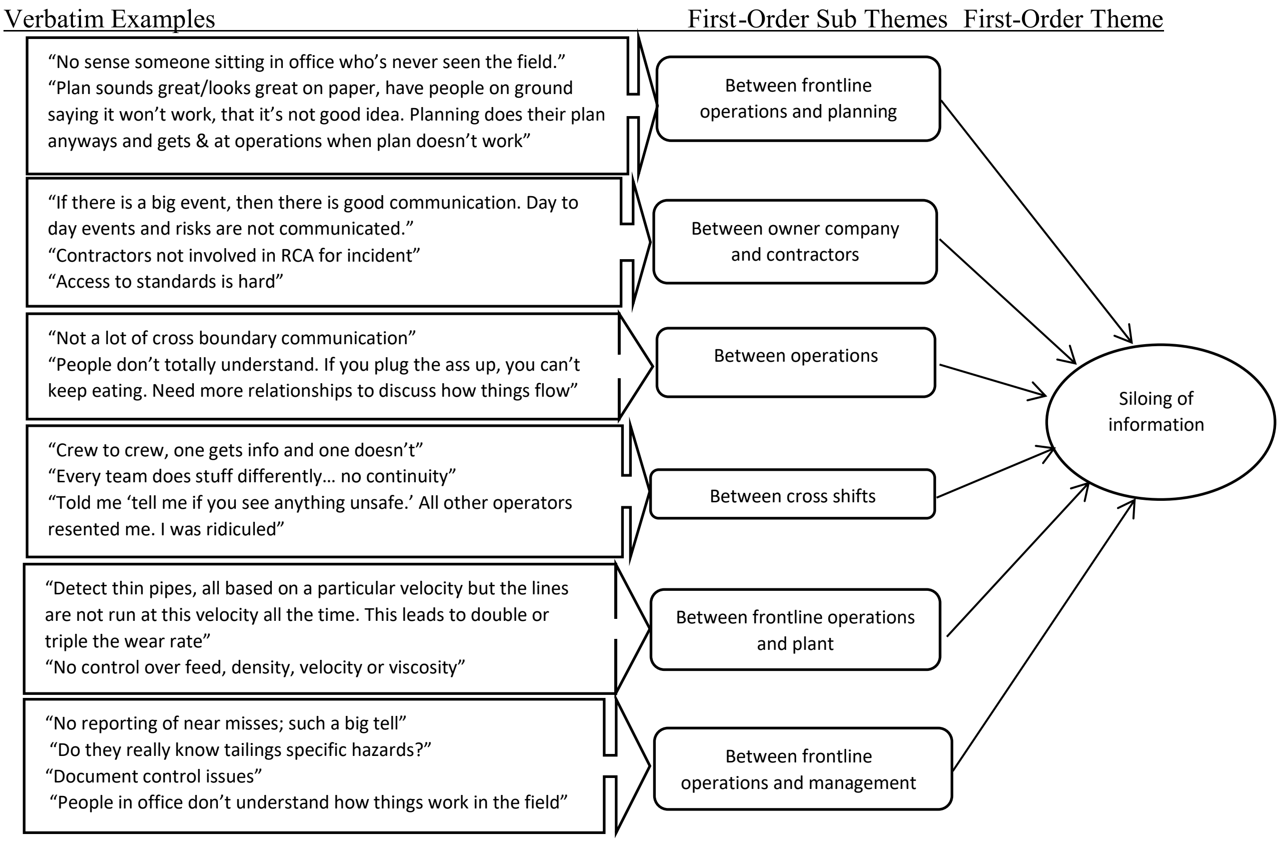


Figure 42. Siloing of information subtheme data structure: representative quotes and subthemes that can lead to siloing of information within organizations (after Baker et al., 2019c).

External and internal influences on judgement

People are bounded rationally in their decision-making processes based on available information, cognitive ability and the limited amount of time to make decisions (Simon, 1972). Through our analysis, we identified first order themes of external and internal influences that further bound the worker's decision-making capabilities. The themes are competing demands, fear of punishment or judgement and risk tolerance.

Competing demands

Workers are exposed to competing values every day in the workplace. Some of these are admittedly self-imposed, personal (e.g., health, mental health, and stress at home), whereas others seem to be more ingrained in the organizational culture (e.g., production vs. safety, time, money, controls as an impediment, etc.). No matter if they are self-imposed or not, these competing demands impact the decision-making process of workers, which is already bounded rationally, and may be causing hazards to not be identified, reported or effectively controlled. This conflict may be causing workers to act differently than they would in their every-day life as workers may not have the time to think before acting or they may feel forced to take shortcuts.

Fear of punishment

Throughout the coding analysis, we identified a lack of psychological safety as workers expressed fears of being punished. Not only were interview participants scared of getting fired or reprimanded by management, but they were also scared of being ridiculed by their peers, or letting their peers down (e.g., reporting an incident that ends a "zero incident" streak). Academics have found that workers who fear to lose their job or are stressed are not as engaged with safety practices (Palmer, 2012; Probst et al., 2018). Confirming that fear of punishment leads to hazards not being identified or reported. New workers are also subject to this as they are less likely to report issues as they want to please management and make a good impression.

Risk tolerance

Fear is related to risk tolerance, as those who are scared, have a lower risk tolerance, compared to those who are angry, who exhibit higher risk tolerances (Lerner & Keltner, 2001). Fear and anger are not the only factors affecting risk tolerance, personal predisposition/ experience/motivation, overestimating experience, familiarity with the task, seriousness of an outcome, voluntary actions, over-alignment with organizational purpose, cost of non-compliance/potential gains from actions, confidence with equipment/protection/rescue, influence of peers, ego (e.g., workers overconfident in their abilities), inattention and competing demands (e.g., budget and time constraints) can also increase or decrease a person's tolerance for risk (Lerner & Keltner, 2001; ExxonMobil, 2015; Ji et al., 2018). Knowledge of hazards is also related to risk tolerance; those with low knowledge of hazards are unable to identify and effectively control the hazard, compared to workers with high knowledge of hazards who are more mindful of the hazards in their work environment and take additional steps to manage the risk that they are exposed to (Ji et al., 2018).

Uncertainty about operations

Uncertainty is insufficient information about an unknown future (March, 1999). The last set of themes indicated that uncertainty is a major contributor to the lack of hazard identification and reporting because of the dynamic everchanging operations, challenging nature of the work in the tailings operations and the tacit prevalence of unseen/normalized hazards.

Dynamic everchanging operations

Researchers have determined that workers have a hard time identifying hazards in their work environments, especially when they are dynamic (Jeelani et al., 2016). Tailings operations are an example of a dynamic environment for multiple reasons. First, the goals of tailings operations are to contain the waste streams that come from the extraction process (i.e., water, sand, residual bitumen and chemicals), treat tailings for reclamation and transport process recycle water to the rest of the mining and upgrading operations; by the very nature of these operations, the tailings work environment is constantly changing. Second, the tailings operations are vast, and it can take over an hour in some places to drive from the permit office to the work location in tailings. With operations being so spread out, it is difficult to have visibility on all workers to provide coaching to help them do their work properly and safely. Third, these operations are busy with workers from multiple companies (i.e. owner company and regional contractors) and operations (i.e., heavy equipment operators, maintenance, etc.) all working in the same area. This can lead to traffic and congested areas, and at some sites, there is added traffic from haul trucks as the boundaries between tailings and the mine can sometimes overlap. To add to the congestion, dynamics and uncertainty, some tailings areas are seasonal with new workers coming in every year. Finally, the working environment in the Athabasca oil sand region is harsh, there are large fluctuations in temperature from summer to winter, i.e., extreme temperatures of 37°C in the summer and -50.6°C in the winter have been recorded (Environment Canada, 2018). The weather can also change quickly (e.g., lightning storms) where it is challenging to identify and control hazards. All this constant change and the ever-moving parts make it challenging to predict the future.

Highly challenging work

Many interview participants addressed how challenging it can be to manage multiple risks in the tailings operations. This theme is related to other factors such as, fear, risk tolerance and dynamic environment, but we felt that it was important to leave highly challenging work as its own theme because of the level of uncertainty that the difficult nature of the work introduces. Physical conditions such as the environment (e.g., temperature swings), seasons (e.g., snow, spring melt and run-off, etc.), and nature of hydraulically placed sand in the tailings discharge area (e.g., soft ground conditions), add to the challenge and difficulty identifying hazards workers face. Not only do conditions make it challenging to complete work, but the extreme cold also creates large amounts of steam (Figure 43) in the tailings discharge area because of the temperature differential between the tailings discharge and ambient air temperature. The hydraulic sand placement continues in this environment despite the reduced visibility. Exposure to hazardous chemicals (hydrocarbons, NORMs, silica, coke dust), wildlife (bears, coyotes, deer, etc.) and standing water (e.g., tailings ponds, deep water sumps, etc.) are also inherent to the operation. With challenge comes uncertainty as no one can be sure what hazards will manifest in the future.

Figure 43. A bulldozer shrouded in steam in the tailings discharge area.

Unseen/normalized hazards

Again, unseen/normalized hazards relate to other first-order themes, but we felt that it was important to keep this as its own sub-theme. This decision was made because unseen/normalized hazards are extremely inherent to uncertainty in tailings as workers cannot be sure if/when/where these hazards will be manifesting. This category includes hazards that are visually obscured or unperceivable (e.g., internal pipeline corrosion, ground hazards obscured by snow- and ice-covered ground, stored energy in a pipeline, etc.), unknown (e.g., the potential for caverns to form after a pipeline leak) and normalized hazards (e.g., soft ground conditions on roads, etc.).

Discussion

We have identified four factors that can lead to unintentional blindness in the oil sands tailings operations: complexity leading to ambiguity, lack of information, internal and external demands, and uncertainty about operations. Our research questions are answered by determining how organizations introduce the four themes into their risk management structures and how these structures introduce risk themselves. One of the key risk management structures that are employed by organizations is hazard identification and reporting, this allows for companies to enhance controls that are no longer appropriate to maintain risk at a level that is as low as reasonably practicable. These factors each affect different facets of risk management structures (detailed in Table 17), but they are all tightly coupled to the worker's ability to identify and report hazards and therefore, effective control of the hazards.

With the identification of these factors manifesting in the well-intended risk management structures and the introduction of new risk, we would be remiss to not provide potential solutions to broaden the organizational view, remove the unintended risk and increase the frequency of hazard identification and reporting.

First, combatting complexity leading to ambiguity is very challenging (Perrow, 1999). Complexity is inherent to organizational structures as many moving parts and boundaries are needed to promote effective operation (Busby, 2006). Complex operations also introduce unintended interactions that can lead to incidents (Perrow, 1999; Palmer, 2012). Being aware of these interactions by promoting interdisciplinary discussions when implementing new risk management systems would be beneficial to address unintended interactions. To decrease ambiguity in the tailings operations, there needs to be more emphasis on feedback to workers and remediation actions in addition to incident investigations.

Second, tailings are a dynamic, albeit not glamorous, part of oil sands operations with their own unique complications and technical challenges and the amount of hazard information provided to workers needs to increase. To effectively achieve this, tailings should be considered a special trade and be more standardized not only within companies but within the industry. Specific and seasonal training should be provided to workers and regional contractors. Communication in general and incident investigations also needs to be expanded across boundaries as the current results are leading to myopic root causes because of organizational boundaries and time-delayed incidents. In current operations the "activation energy" has not been reached to share information across boundaries, leading to insufficiently deep root causes, that may not include interdisciplinary analysis.

Third, external and internal influences can be addressed by minimizing fear felt on the job by providing psychological safety where workers can voice concerns in a respectful environment; in turn, performance will improve (Edmondson, 2018). Leaders must inspire workers by setting expectations through coaching and discussing the purpose of the task, demonstrating situational humility, listen and provide valuable feedback and appreciation, destigmatize failure, and providing psychological safety in their work environment, in addition to combatting fear, implementing these practices will decrease apathy in the workplace (Edmondson, 2018). Risk tolerance should also be addressed as researchers have found that workers want to impress their employers; 90% of workers are not afraid to take risks to advance production, even though they know it will lead to unsafe conditions and practices; workers may be aware of the hazards and risks but take this risk, and the potential for unseen hazards as implicit to the operations (Job & Smith, 2010; Ji et al., 2018). The motivation could lead workers to have a higher risk tolerance as they think of new ways to solve a problem while introducing new, unmitigated risks (Ji et al., 2018). Competing demands that imply a high value on production, will unintentionally reward these risky behaviours, and they will, in turn, become normalized, and will potentially lead to an incident (Vaughan, 1996; Stackhouse and Stuart, 2016). The risk tolerance of both the individuals and organization needs to be addressed increase hazard identification and reporting.

Fourth, workers should be empowered to be mindful while working in tailings and encouraged to critically analyze the situation with programs such as "See it, Own it, Solve it, Do it" no matter who you are or where you work (Connors et al., 1998).

Table 17. How organizations introduce complexity, lack of information, internal and external demands and uncertainty into their risk management structures and the resulting unintended risk.

First order theme	Manifestation in risk management structures by organization	Introduced Risk
Complexity leading to ambiguity	-Risk management structures are so complicated workers do not know where to get information from - Risk management structures are time intensive -Introduce new safe guards	-Inappropriate or out of date safety procedures are used - Safety is used as an excuse to not do work/make work too complicated - Risk information is not reported because management does not have time to provide feedback -Increase complexity of the system, increasing the likelihood of more incidents (Perrow, 1999)
Incomplete information	-Decrease complexity by standardizing across organization -Incident investigations	-Inappropriate standards are used from other areas of the mine -Training is not adequate for tailings -Information not being passed across boundaries -Incidents are delayed; investigations do not address actual root cause
External and internal influences	-Positive health and safety culture -Safety reward programs	-Workers want to impress, so they will find creative ways to address a problem -Workers hesitant to report hazards for fear of repercussions
Uncertainty	-Use of hazard identification tools	-Tools do not account for unseen/normalized hazards

Conclusion

In summary, organizational myopia is unintentionally created by organizations' own risk management efforts—which generate complexity and ambiguity, uncertainty, unknown alternatives, and external and internal influences on judgment — to mask workers' ability to see, report, and effectively control the hazards in their workplace operations. Further, this can lead to an apathy spiral, which compounds the effects. As Perrow states, it is challenging to address incidents within organizations as the addition of safety subsystems can lead to unexpected failures, to combat this phenomena and normalized myopia in the oil sands we can follow Perrow's suggestion where systems susceptibility to failure is reduced by concentrating on reducing the complexity and relationships of the system (1999). Tailings specific training, improving psychological safety in the workplace and empowering critical thinking during hazard identification activities will also increase the quality and frequency of hazard identification and reporting and better allow hazards to be controlled.

References

Agurto-Detzel, H., Bianchi, M., Schimmel, M., Callaco, B., Ciardelli, C., Barbosa, J. R., & Calhau, J. (2016). The tailings dam failure of 5 November 2015 in SE Brazil and its preceding seismic sequence. *American Geophysical Union: Geophysics Research Letter*, *43*(10), 4929-4936.

Albert, A., Hallowell, M. R., & Kleiner, B. M. (2013). Enhancing construction hazard recognition and communication with energy-based cognitive mnemonics and safety meeting maturity model: Multiple baseline study. *Journal of Construction Engineering and Management, 140*(2), 04013042.

Albert, A., Hallowell, M. R., & Kleiner, B. M. (2014). Experimental field testing of a real-time construction hazard identification and transmission technique. *Construction Management and Economics*, *32*(10), 1000-1016.

Albert, A., Hallowell, M. R., Skaggs, M., & Kleiner, B. (2017). Empirical measurement and improvement of hazard recognition skill. *Safety Science, 93*, 1-8.

Alberta Agriculture and Forestry. (2018). *Current and Historical Alberta Weather Station Data Viewer*. Edmonton, AB: Government of Alberta. Retrieved from https://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp

Alberta Energy Regulator (AER). (2018). *EnerFAQs Oil Sands. Government of Alberta*. Retrieved from https://www.aer.ca/providing-information/news-and-resources/enerfaqs-and-fact-sheets/enerfaqs-oil-sands

Allen, W., Grant, A., Earl, L., MacLellan, R., Waipara, N., Mark-Shadbolt, M., Ogilvie, S., Langer, E.R.L., & Marzano, M. (2018). The use of rubrics to improve integration and engagement between biosecurity agencies and their key partners and stakeholders: a surveillance example. In *The Human Dimensions of Forest and Tree Health* (pp. 269-298). Palgrave Macmillan, Cham.

Amyotte, P. R., Pegg, M. J., & Khan, F. I. (2009). Application of inherent safety principles to dust explosion prevention and mitigation. *Process Safety and Environmental Protection, 87*(1), 35-39.

Assadi, P. (2018). *Empirical Investigation of the Causes and Effects of Misconduct in the US Securities Industry* (Doctoral dissertation), Beedie School of Business Faculty: Segal Graduate School, Simon Fraser University, Burnaby, BC.

Association of Professional Engineers and Geoscientists of Alberta (APEGA). (2006). *Guidelines for the Management of Risk in Professional Practice*. Retrieved from https://www.apega.ca/assets/PDFs/risk.pdf

Bahn, S. (2013). Workplace hazard identification and management: The case of an underground mining operation. *Safety Science*, 57, 129-137.

Boxenbaum, E., Jones, C., Meyer, R. E., & Svejenova, S. (2018). Towards an articulation of the material and visual turn in organization studies. *Organization Studies*, *29* (5-6), 597-616.

Brooks, T. & Spillane, J. (2017). Lies, dammed lies and quality management systems: a pilot case study. In Chan, P. W. & Neilson, C. J. (Eds.), *Proceedings of the 33rd Annual ARCOM Conference*, 4-*6 September 2017, Cambridge, UK, Association of Researchers in Construction Management,* (pp. 582-591).

Baybutt, P. (2002). Layers of protection analysis for human factors (LOPA-HF). *Process Safety Progress, 21*(2), 119-129.

Baker, K.E., and Lefsrud, L.M. (2019). *Organizational myopia - How organizations create complexity, ambiguity, and uncertainty to blind their risk management efforts*. Working paper for EGOS 2019, Edinburgh: UK, July 4-6.

Baker, K.E., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. (2019a). *Combining Process Safety and Personal Safety to bring Hazards into Focus*. Center for Risk, Integrity and Safety Engineering Workshop / Symposium Conference Paper. St. John's, Newfoundland, July 15-19, 2019.

Baker, K.E., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. (2019b). *Final Report for Creative Sentencing: Protecting worker safety in Alberta by enhancing field level hazard assessments and training for ground hazards associated with tailings facilities, dams and transport systems*. Prepared for Investigations, Alberta Labour.

Baker, K.E., Macciotta, R., Hendry, M.T., and Lefsrud, L.M. (2019c). *Risk communication in the Athabasca oil sands tailings operations*. Center for Risk, Integrity and Safety Engineering Workshop / Symposium Conference Paper. Newfoundland, July 15-19, 2019.

Bashir, A. M., Suresh, S., Oloke, D., Proverbs, D., & Gameson, R. (2012). Effect of Lean Construction tools on accident prevention in UK contracting organizations. *Journal of International Real Estate and Construction Studies*, *2*(1/2), 37.

Bazerman, M.H., & Tenbrunsel, A.E. (2011). *Blind spots: Why we fail to do what's right and what to do about it.* Princeton, New Jersey: Princeton University Press.

Beck, U. (1992). *Risk Society: Towards a New Modernity*. London, England: Sage.

Brief, A.P., & Smith-Crowe, K. (2016). Organizations matter. In A. Miller (Ed.), *The Social Psychology of Good and Evil* (pp. 390-414). New York, NY: Guilford Press.

Busby, J. S. (2006). Failure to mobilize in reliability-seeking organizations: two cases from the UK railway. *Journal of Management Studies*, *43*(6), 1375-1393.

Canadian Transportation Safety Board (CTSB). (2014). *Guide to investigating for organizational and management factors*. Ottawa, Canada: Government of Canada. Retrieved from http://www.safetyculturesymposium.ca/uploads/2/6/7/3/26734471/guide_for_investigating_for_o_and_m_factors_-_2nd_edition_v2_february_2014_en.pdf

Canadian International Mining (CIM). (1997). *Standards and Guidelines for Resources and Reserves*. Retrieved from http://web.cim.org/standards/menuPage.cfm?menu=177

Canada's Oil Sands Innovation Alliance (COSIA). (2012). *Oil Sands Tailings Technology Roadmap*. Retrieved from https://www.cosia.ca/uploads/documents/id10/Tailings%20Roadmap%20Volume%202%20June%202012.pdf

Carter, G., & Smith, S. D. (2006). Safety hazard identification on construction projects. *Journal of Construction Engineering and Management*, *132*(2), 197-205.

Catino, M. (2013). *Organizational myopia: Problems of rationality and foresight in organizations*. New York, NY: Cambridge University Press.

Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE). (2007). *Guidelines for risk-based process safety*. Hoboken, New Jersey: John Wiley and Sons, Inc.

Center for Chemical Process Safety (CCPS). (2011). *Layer of Protection Analysis: Simplified Process Risk Assessment*. Wiley.

Center for Chemical Process Safety (CCPS). (2018a). *Loss of Primary Containment, In CCPS Process Safety Glossary.* American Institute of Chemical Engineers. Retrieved from https://www.aiche.org/ccps/resources/glossary/process-safety-glossary/loss-primary-containment-lopc

Center for Chemical Process Safety (CCPS). (2018b). *Process Safety Management (PSM).* Retrieved from https://www.aiche.org/ccps/resources/glossary/process-safety-glossary/process-safety-management-psm

Center for Chemical Process Safety (CCPS). (2018c) *Recognizing and responding to normalization of deviance.* (1st ed.). New York, NY: Center for Chemical Process Safety of the American Institute of Chemical Engineers (CCPS).

Centers for Disease Control and Prevention (CDC). (2015). *Hierarchy of Controls.* Retrieved from https://www.cdc.gov/niosh/topics/hierarchy/default.html

Chambers, D. (2016). *Post-Mount Polley Tailings Dam Safety in Transboundary British Columbia*. Center for Science in Public Participation. Bozeman, MT: Mining Watch.

Chen, A., Golparvar-Fard, M., & Kleiner, B. (2013). SAVES: A safety training augmented virtuality environment for construction hazard recognition and severity identification. *CONVR*, *2013*, 373-384.

Chevreau, F. R., Wybo, J. L., & Cauchois, D. (2006). Organizing learning processes on risks by using the bow-tie representation. *Journal of Hazardous Materials, 130*(3), 276-283.

Christiansen, L. H. (2018). The use of visuals in issue framing: Signifying responsible drinking. *Organization Studies*, *39*(5-6) 665–689.

Chugh, D., Bazerman, M.H. & Banaji, M.R. (2005). Bounded ethicality as a psychological barrier to recognizing conflicts of interest. In D.A. Moore, D.M. Cain, G. Loewenstein, & M.H. Bazerman (Eds.), *Conflicts of interest: Challenges and solutions in business, law, medicine, and public policy*, (pp.74-95). New York, NY, US: Cambridge University Press.

Cockshott, J. E. (2005). Probability bow-ties: a transparent risk management tool. *Process Safety and Environmental Protection, 83*(4), 307-316.

Cohen, T. N. (2017). *A Human Factors Approach for Identifying Latent Failures in Healthcare Settings*. (Doctoral dissertation). Department of Human Factors, Embry-Riddle Aeronautical University, Daytona Beach, FL.

Connors, R., Smith, T., & Hickman, C. (1998). *The Oz principle: Getting results through individual and organizational accountability*. New York, NY: Penguin.

Cooper, D. J., Dacin, T., & Palmer, D. (2013). Fraud in accounting, organizations and society: Extending the boundaries of research. *Accounting, Organizations & Society, 38*(6-7), 440-457.

Coslor, E. (2018). Physical and epistemic objects in museum conservation risk management. In N. Mitev, A. Morgan-Thomas, P. Lorino, F.X. de Vaujanu, & Y. Nama (Eds.), *Materiality and Managerial Techniques. Technology, Work and Globalization* (pp. 193-220). Palgrave Macmillan, Cham.

Davidson, R. S. (2018). Safety awareness: A chemical engineering imperative. *AIChE Journal*, *64*(3), 798-809.

Deighton, M.G. (2016). *Facility Integrity Management: Effective Principles and Practices for the Oil, Gas, and Petrochemical Industries*, 1st ed. Cambridge, MA: Gulf Professional Publishing, an imprint of Elsevier.

Devenny, D. W. (2010). *A screening study of oil sand tailings technologies and practices*. Prepared for Alberta Energy Research Institute.

Donald, J. (2018). *Experimental Learning Session Descriptions: Brain Writing or "6-3-5" Method*. Presented at the NICKEL 2018 Conference, Toronto, ON.

Edmondson, A.C. (2018 November 14). *How fearless organizations succeed.* Retrieved from https://www.strategy-business.com/article/How-Fearless-Organizations-Succeed?gko=fdfc6

Energy Safety Canada (ESC). (2018a). "*Get a Grip on Safety"*. Retrieved from http://shopdevco.com/more/ossa/get-a-grip/.

Energy Safety Canada (ESC). (2018b). "*Life-Saving Rules"*. Retrieved from http://www.energysafetycanada.com/resources/life-saving-rules.cfm

Energy Safety Canada (ESC). (2018c). *Line of Fire*. Retrieved from https://escsafety.devcogroup.com/?page_id=40#lineoffire

Energy Safety Canada (ESC). (2018d). Tailings Hazard Inventory. Calgary, AB.

Environment Canada. (2018). *Canadian Climate Normals 1971 – 2000 Station Data for Fort McMurray*. Government of Canada. Retrieved from http://climate.weather.gc.ca/climate_normals/results_e.html?stnID=2519&autofwd=1

Environmental Protection Agency (EPA). (2018). *Risk Communication.* Retrieved from https://www.epa.gov/risk/risk-communication

European Agency for Safety and Health at Work. (2016). *OSH Wiki: Human Error*. Retrieved from: https://oshwiki.eu/wiki/Human_error

ExxonMobil. (2015). *Ten Factors that Affect Risk Tolerance*. Retrieved from https://www.ishn.com/articles/101620-understanding-and-influencing-risk-tolerance

Farrell, M., & Gallagher, R. (2015). The valuation implications of enterprise risk management maturity. *Journal of Risk and Insurance*, *82*(3), 625-657.

Ferdous, R., Khan, F., Sadiq, R., Amyotte, P., & Veitch, B. (2012). Handling and updating uncertain info in bow-tie analysis. *Journal of Loss Prevention in the Process Industries, 25*(1), 8-19.

Fischhoff, B. (1995). Risk perception and communication unplugged: twenty years of process. *Risk Analysis, 15*(2), 137-145.

Forbes, F., Winkel, G., Hendry, M., Lefsrud, L., & Macciotta, R. 2017. *Protecting Worker Safety in Alberta by Enhancing Field Level Hazard Assessments and Training for Ground Hazards Associated with Tailings Facilities, Dams and Systems*. Proposal for Creative Sentencing, prepared for Investigations, Alberta Labour.

Friedrichs, D. O. (2015). Crimes of the powerful and the definition of crime. In *The Routledge International Handbook of the Crimes of the Powerful.* New York, NY: Routledge, 39-49.

Gioia, D.A., Corley, K.G., & Hamilton, A.L. (2013). Seeking Qualitative Rigor in Inductive Research Notes on the Gioia Methodology. *Organizational Research Methods*, *16*(1), 15-31.

Götz, M., Bollmann, G., & O'Boyle, E. H. (2019). Contextual undertow of workplace deviance by and within units: a systematic review. *Small Group Research*, *50*(1), 39-80.

Government of Alberta. (1999). *Dam and Canal Safety Guidelines*. Alberta Environment, Edmonton, AB.

Government of Alberta. (2000). *Oil Sands Conservation Act*. Alberta Queen's Printer, Edmonton, AB.

Government of Alberta. (2009). *Responsible Actions: A Plan for Alberta's Oil Sands*. Government of Alberta, Edmonton, AB.

Government of Alberta. (2011a). *Occupation Injuries and Diseases in Alberta: 2010 Summary*. Table 8.1, page 73.

Government of Alberta. (2011b). *Occupational Health and Safety Data Analysis*. Table 2, page 2.

Government of Alberta. (2011c). *Occupational Health and Safety Data Analysis.* Table 7, page 4.

Government of Alberta. (2011d). *Occupation Injuries and Diseases in Alberta: Upstream Oil and Gas Industries 2006 to 2010*. Table 5.2, page 23.

Government of Alberta. (2013a). *Occupational Health and Safety Results.* Table 2, page 2.

Government of Alberta. (2013b). *Occupational Health and Results*. Table 7, page 5.

Government of Alberta. (2015a). *Lower Athabasca Region: Tailings Management Framework for Minable Athabasca Oil Sands (TMF).* Government of Alberta, Edmonton, AB.

Government of Alberta. (2015b). *Workplace Injury, Disease and Fatality Statistics Provincial Summary.* Table 2, page 6.

Government of Alberta. (2016a). *Workplace Injury, Disease and Fatality Statistics Provincial Summary.* Table 2, page 6.

Government of Alberta. (2016b). *Workplace Injury, Disease and Fatality Statistics Provincial Summary.* Table 18, page 16.

Government of Alberta. (2017). *Occupational Health & Safety Statistics and Employer Records.* Retrieved from http://work.alberta.ca/occupational-health-safety/employer-records-how-to-use-database.html

Grant, T. (2017, November 6). Statistics Canada looks to close data gap on workplace deaths, injuries. *The Globe and Mail.* Retrieved from https://www.theglobeandmail.com

Griffin, R. W., & Lopez, Y. P. (2005). "Bad behavior" in organizations: A review and typology for future research. *Journal of Management*, *31*(6), 988-1005.

Halgin, D. S., Glynn, M. A., & Rockwell, D. (2018). Organizational actorhood and the management of paradox: A visual analysis. *Organization Studies*, *39*(5-6), 645-664.

Hallowell, M. R. (2008). *A formal model for construction safety and health risk management*. (Doctoral dissertation). Oregon State University, Corvallis, OR.

Hallowell, M. R., Hinze, J. W., Baud, K. C., & Wehle, A. (2013). Proactive construction safety control: Measuring, monitoring, and responding to safety leading indicators. *Journal of Construction Engineering and Management, 139*(10), 04013010.

Hallowell, M. R., & Hansen, D. (2016). Measuring and improving designer hazard recognition skill: Critical competency to enable prevention through design. *Safety Science*, *82*, 254-263.

Harrington, B. (2018). Professional agency in the ecology of wrongdoing. *CMI Working Paper.*

Haslam, R. A., Hide, S. A., Gibb, A. G., Gyi, D. E., Pavitt, T., Atkinson, S., & Duff, A. R. (2005). Contributing factors in construction accidents. *Applied Ergonomics*, *36*(4), 401-415.

Hardy, T.L. (2014). Case studies in process safety: lessons learned from software-related accidents. Process *Safety Progress, 33*(2), 124-130.

Haynes, K., Barclay, J., & Pidgeon, N. (2007). Volcanic hazard communication using maps: an evaluation of their effectiveness. *Bulletin of Volcanology, 70*(2), 123-138.

Health Canada. (2007). *Strategic Risk Communications framework within the context of health Canada and the PHAC's integrated risk management*. Retrieved from: https://www.canada.ca/en/public-health/services/reports-publications/2007/strategic-risk-communications-framework-within-context-health-canada-phac-s-integrated-risk-management.html

Hinze, J. (2002). *Safety Plus: Making Zero Injuries a Reality. Construction Industry Institute, Research Report 160-11*, The University of Texas at Austin.

Hinze, J. (2006). *Construction Safety*, Prentice Hall, Englewood Cliffs, NJ.

Hirsch, P. M., & Levin, D. Z. (1999). Umbrella advocates versus validity police: A life-cycle model. *Organization Science*, *10*(2), 199-212.

Henderson, L. (2016). *Toolkit for Hazardous Materials Transportation Education. Power Point Presentation* for the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration created by 3 Sigma Consultants, LLC, Nashville, TN. Retrieved from http://slideplayer.com/slide/6035162/

Hoekstra, G. (2014 August 24). 49 'dangerous occurrences' at B.C. mine tailings ponds in past decade: ministry data. *Vancouver Sun*. Retrieved from http://www.vancouversun.com/dangerous+occurrences+mine+tailings+ponds+past+decade+ministry+data/10148841/story.html

Hoffman, A. (2015). *Mount Polley Mine - Tailings Storage Facility Breach: Investigation Report of the Chief Inspector of Mines*. Victoria, BC: British Columbia Ministry of Energy and Mines.

Höllerer, M. A., Jancsary, D., Meyer, R. E., & Vettori, O. (2013). Imageries of corporate social responsibility: Visual recontextualization and field-level meaning. In M. Lounsbury & E. Boxenbaum (Eds.), *Institutional Logics in Action, Part B* (pp. 139-174). Emerald Group Publishing Limited.

Höllerer, M. A., Jancsary, D., & Grafström, M. (2018). 'A picture is worth a thousand words': multimodal sensemaking of the global financial crisis. *Organization Studies*, *39*(5-6), 617–644.

Hopkin, P. (2018). *Fundamentals of Risk Management: Understanding, Evaluating and Implementing Effective Risk Management*. London, UK: Kogan Page Publishers.

Huy, Q. N., Corley, K. G., & Kraatz, M. S. (2014). From support to mutiny: Shifting legitimacy judgments and emotional reactions impacting the implementation of radical change. *Academy of Management Journal*, *57*(6), 1650-1680.

International Organization for Standards (ISO). (2010). *Safety of machinery—General principles for risk assessment and risk reduction. Title of the standard (Standard No. 12100)*. Retrieved from https://www.iso.org/standard/51528.html

International Organization for Standards (ISO). (2002). *Risk Management Vocabulary – Guidelines for Use in Standards (Guide 73).* Retrieved from https://www.iso.org/standard/51528.html

Jardine, C. G., (2008). Stakeholder participation in risk management decision making. In: B. Everitt and E. Melnick (Eds.), *Encyclopedia of Quantitative Risk Analysis and Assessment* (pp. 1668-1672). Chichester, UK: John Wiley & Sons, Ltd.

Jeelani, I., Albert, A., & Gambatese, J. A. (2016). Why do construction hazards remain unrecognized at the work interface?. *Journal of Construction Engineering and Management*, *143*(5), 04016128.

Ji, Z., Pons, D., & Pearse, J. (2018). Why do workers take safety risks?—A conceptual model for the motivation underpinning perverse agency. *Safety*, *4*(2), 24.

Job, J., & Smith, D. (September 2011). *Motivations, Attitudes, Perceptions and Skills: What They Said about Work Health and Safety in 2010.* Safe Work Australia. Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1702/motivations_attitudes_perceptions_skills_what_they_said.pdf

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., Kasperson, J. X., and Ratick, S. (1988). The social amplification of risk: A conceptual framework. *Risk Analysis*, *8*(2), 177-187.

Kerin, T. 2017. *Bridging the divide - OHS and process safety.* Paper presented at the 27th Institution of Chemical Engineers Symposium on Hazards 2017. Birmingham, United Kingdom 10-12 May 2017.

Khakzad, N., Khan, F., & Amyotte, P. (2012). Dynamic risk analysis using bow-tie approach. *Reliability Engineering and System Safety, 104*(2012), 36-44.

Khan, F., Rathnayaka, S., & Ahmed, S. (2015). Methods and models in process safety and risk management: past, present and future. *Process Safety and Environmental Protection, 98*, 116-147.

Knapp, J., Zeratsky, J., & Kowitz, B. (2016). *Sprint: How to Solve Big Problems and Test New Ideas in Just Five Days*. New York, NY: Simon and Schuster.

Kouyoumdjian, H. (2012). Learning Through Visuals: Visual Imagery in the Classroom. *Psychology Today*. Retrieved from: https://www.psychologytoday.com/us/blog/get-psyched/201207/learning-through-visuals.

Kreiner, G. E., Hollensbe, E. C., & Sheep, M. L. (2009). Balancing borders and bridges: Negotiating the work-home interface via boundary work tactics. *Academy of Management Journal*, *52*(4), 704-730.

Kurian, D., Ma, Y., & Lefsrud, L. 2019. *An Overview of Fuzzy Logic and its Application in Analyzing Incident Reports*. Center for Risk, Integrity and Safety Engineering Workshop / Symposium Conference Paper. Newfoundland, July 15-19, 2019.

Larkin, I., & Pierce, L. (2015). Compensation and employee misconduct: the inseparability of productive and counterproductive behavior in firms. In Palmer, D. (Ed.), *Organizational Wrongdoing: Key Perspectives and New Directions* (pp. 1-27). Cambridge University Press.

LaPorte, T.R. (1996). High reliability organizations: Unlikely, demanding, and at risk. *Journal of Contingencies and Crisis Management*, *4*(2), 60-71.

Lefsrud, L. M., Graves, H. & Phillips, N. (2016). Analyzing Visual Rhetoric in Organizational Research. In Elsbach, K. D. and Kramer, R. M. (Eds.), *Handbook of Qualitative Organizational Research: Innovative Pathways and Methods*. New York, NY: Routledge.

Lerner, J. S., & Keltner, D. (2001). Fear, anger, and risk. *Journal of personality and social psychology*, *81*(1), 146.

Leveson, N. G., & Stephanopoulos, G. (2014). A system-theoretic, control-inspired view and approach to process safety. *AIChE Journal*, *60*(1), 2-14.

Levitt, S. D., & Dubner, S. J. (2014). *Freakonomics*. New York, NY: HarperCollins Publishers.

Li, Z., Cao, Z., & Zhao, Y. (2010). Safety case and PDCA based safety assurance system for mine tailings facilities. *Systems Engineering- Theory & Practice*, *30*, 932-944.

Lok, J., & De Rond, M. (2013). On the plasticity of institutions: Containing and restoring practice breakdowns at the Cambridge University Boat Club. *Academy of Management Journal*, *56*(1), 185-207.

Ludwig, T. D. (2017). Process safety: Another opportunity to translate behavior analysis into evidence-based practices of grave societal value. *Journal of Organizational Behaviour Management, 37*(3-4), 221-223.

Lundgren, R. E., & McMakin, A. H. (2013). *Risk Communication: A Handbook for Communicating Environmental, Safety, and Health Risks*. Hoboken, New Jersey: John Wiley & Sons.

Mannan, M. S., Sachdeva, S., Chen, H., Reyes-Valdes, O., Liu, Y., & Laboureur, D. M. (2015). Trends and challenges in process safety. *AIChE Journal, 61*(11), 3558-3569.

Mannion, R. & Braithwaite, J. (2017). False dawns and new horizons in patient safety research and practice. *International Journal of Health Policy and Management*, *6*(12), 685-689.

Marasi, S., Bennett, R. J., & Budden, H. (2018). The structure of an organization: Does it influence workplace deviance and its dimensions? And to what extent?. *Journal of Managerial Issues*, *30*(1), 8-27.

March, J.G. & Simon, H.A. (1958). *Organizations*. New York, NY: Wiley.

March, J. G. (1999). *Pursuit of Organizational Intelligence*. Oxford, UK: Blackwell.

Marion, R., & Uhl-Bien, M. (2011). Implications of complexity science for the study of leadership. In P. Allen, S. Maguire, & McKelvey (Eds.), *The SAGE handbook of complexity and management* (pp. 391). London, UK: SAGE.

Marks, N. 2011. Navigating Risk Management. *Internal Auditor*, *68*(3), 26-33.

Mecza, M. (2008, September). *A Canadian perspective of the history of process safety management legislation*. In Proceedings of the 8th International Symposium Programmable Electronic System in Safety-Related Applications (pp. 2-3).

Mikulsen, M., & Diduck, A. P. (2013). A fresh perspective on food safety in Canada: risk communication, public involvement, and the impact of the 2008 listeriosis outbreak. *Environmental Hazards, 12*(2), 148-165.

Mining Association of Canada. (2011). *A Guide to the Management of Tailings Facilities*. Ottawa, ON: Mining Association of Canada.

Morgan, M.G. & Lave, L. (1990). Ethical considerations in risk communication practice and research. *Risk Analysis 10*(3), 355-358.

Morgenstern, N. R., Vick, S. G., & van Zyl, D. (2015). *Report on Mount Polley Tailings Storage Facility Breach*. Province of British Columbia.

Namian, M., Zuluaga, C. M., & Albert, A. (2016). *Critical factors that impact construction workers' hazard recognition performance.* In Construction Research Congress 2016, pp. 2762-2772.

Nolke, A., & May, C. (2018). *Handbook of the International Political Economy of the Corporation*. Northampton, MA: Edward Elgar Publishing.

Occupational Health and Safety (OHS). (2009). *Occupational Heath and Safety Code*. Alberta Queen's Printer. Edmonton, AB.

Occupational Health and Safety (OHS). (2015). *Hazard Assessment and Control: a handbook for Alberta employers and workers.* Retrieved from https://open.alberta.ca/dataset/d15fd819-4bce-413e-9333-709928546337/resource/53f61081-0e58-4b3f-82e5-5f368d327b9a/download/2015-03-ohs-best-practices-bp018.pdf

Occupational Health and Safety (OHS). (2017a). *Investigation Report: Fatality-Worker drowned in tailings pond January 19, 2014, F-OHS-056980-A5B24*. Occupational Health and Safety, Government of Alberta, Edmonton, AB.

Occupational Health and Safety (OHS). (2017b, December 31). *Workplace incident fatalities accepted by the workers' compensation board in 2017*. Retrieved from https://open.alberta.ca/dataset/9e1c554c-4c3e-453a-aaed-51be3af4c82a/resource/ce2dfb82-e3aa-439f-860e-e064e77a4c5b/download/2017-workplace-fatalities-accepted-wcb.pdf

Oxford Dictionary. (2018). *Definition of Creative Sentencing*. Retrieved from https://en.oxforddictionaries.com/definition/creative_sentencing

Palmer, D. (2012). *Normal Organizational Wrongdoing: A Critical Analysis of Theories of Misconduct in and by Organizations.* Oxford, UK: Oxford University Press on Demand.

Paltrinieri, N., Scarponi, G. E., Khan, F. I., & Hauge, S. (2014). Addressing dynamic risk in the petroleum industry by means of innovative analysis solutions. *Chemical Engineering Transactions*, *36*, 451-456.

Perlman, A., Sacks, R., & Barak, R. (2014). Hazard recognition and risk perception in construction. *Safety Science*, *64*, 22-31.

Perri, F. S. (2011). White-collar criminals: the 'kinder, gentler offender?'. *Journal of Investigative Psychology and Offender Profiling*, *8*(3), 217-241.

Perrow, C. (1979). *Normal Accidents: Living with High-Risk Technologies*. Princeton, NJ: Princeton Press.

Power, M., Scheytt, T., Soin, K. & Sahlin, K. (2009). Reputational Risk as a Logic of Organizing in Late Modernity. *Organization Studies*, *30* (2-3), 301-324.

Power, M. (2016). *Riskwork: Essays on the Organizational Life of Risk Management*. Oxford, UK: Oxford University Press.

Probst, T. M., Petitta, L., Barbaranelli, C., & Austin, C. (2018). Safety-Related Moral Disengagement in Response to Job Insecurity: Counterintuitive Effects of Perceived Organizational and Supervisor Support. *Journal of Business Ethics*, 1-16. https://doi.org/10.1007/s10551-018-4002-3

Process Safety and Reliability Group (PSRG). (2018). *Prevention of Loss of Containment (PSM: 314)*. Retrieved from http://www.psrgroup.com/blog/psm-314-prevention-loss-containment/

Project Management Institute (PMBOK). (2017*) A guide to the project management body of knowledge*. (PMBOK Guide – Sixth Edition). Newtown Square, Pa: Project Management Institute.

Pryor, P. R. (2012). The Generalist OHS professional in Australia. In SIA*, In the Core Body of Knowledge for Generalist OHS Professionals*. Tullamarine: Safety Institute of Australia.

Qader, S. A., & Hill, G. R. (1969). Hydrocracking of petroleum and coal oils. I*ndustrial & Engineering Chemistry Process Design and Development, 8*(4), 462-469.

QSR International. (2018). NVivo (Version 12.1.1.256, Plus Edition) [Text analysis software]. Retrieved from https://www.qsrinternational.com/

Ramo, S. (1973). The Systems Approach. In R.F. Miles Jr (Ed.), *Systems Concepts: Lectures on Contemporary approaches to systems.* New York, NY: John Wiley & Sons.

Ramsay, J., Denny, F., Szirotnyak, K., Thomas, J., Corneliuson, E., & Paxton, K. L. (2006). Identifying nursing hazards in the emergency department: A new approach to nursing job hazard analysis. *Journal of Safety Research*, *37*(1), 63-74.

Reason, J. (1990). The contribution of latent human failures to the breakdown of complex systems. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *327*(1241), 475-484.

Reason, J. (1998). Achieving a safe culture: theory and practice. *Work & Stress*, *12*(3), 293-306.

Register M., & Larkin, J, (2005). *Risk issues and crisis management: A casebook of best practice*. Sterling, VA: Korgan Page US.

Reinecke, J., & Ansari, S. (2015). When times collide: Temporal brokerage at the intersection of markets and developments. *Academy of Management Journal*, *58*(2), 618-648.

Renn, O. (2010). Risk communication: Insights and requirements for designing successful communication programs on health and environmental hazards. In R.L. Heath & H.D. O'Hair (Eds), *Handbook of Risk and Crisis Communication* (pp. 92-110). New York, NY: Routledge.

Riggio, R. E. (2017). *Introduction to industrial/organizational psychology*. 7th Edition. New York, NY: Routledge.

Sandman, P. M. (1987). Risk communication: facing public outrage. *EPA Journal*, *13*, 21.

Sandman, P. (2012). *Managing Risk Familiarity*. Retrieved from http://www.psandman.com/col/familiarity.htm

Schulte, P. A., Boal, W. L., Friedland, J. M., Walker, J. T., Connally, L. B., Mazzuckelli, L. F., & Fine, L. J. (1993). Methodologic issues in risk communications to workers. *American Journal of Industrial Medicine, 23(*1), 3-9.

Searle, R.H., Rice, C., & McConnell, A.A. (2017). *Bad apples? Bad barrels? Or bad cellars? Antecedents and processes of professional misconduct in UK health and social care: Insights into sexual misconduct and dishonesty*. Coventry, UK: Professional Standards Authority. Retrieved from https://www.professionalstandards.org.uk/docs/default-source/publications/research-paper/antecedents-and-processes-of-professional-misconduct-in-uk-health-and-social-care.pdf

Seucharan, C. (2017). Mount Polley mine disaster: 3 years later concerns still remain. *CBC News.* Retrieved from https://www.cbc.ca/news/canada/british-columbia/mount-polley-mining-fears-1.4235913

Sigmann, B. (2018). Playing with fire: Chemical safety expertise required. *Journal of Chemical Education, 95,* 1736-1746.

Simon, H.A., 1972. Theories of bounded rationality. *Decision and organization*, *1*(1), pp.161-176.

Slovic, P. (1987). Perception of risk. *Science*, *236*(4799), 280-285.

Slovic, P., Peters, E., Finucane, M. L., & MacGregor, D. G. (2005). Affect, risk, and decision making. *Health Psychology, 24*(4S), S35.

Sorensen, J. (2018). *Alberta OHS Legislation expands options for creative sentencing*. Council of construction associations. Retrieved from http://cocabc.ca/alberta-ohs-legislation-expands-options-for-creative-sentencing/

Stackhouse, M. R., & Stewart, R. (2017). Failing to Fix What is Found: Risk Accommodation in the Oil and Gas Industry. *Risk Analysis*, *37*(1), 130-146.

Stranks, J. (2007). *Human Factors and Behavioural Safety*. Routledge.

Stoop, J., de Kroes, J., & Hale, A. (2017). Safety science, a founding fathers' retrospection. Safety *Science, 94,* 103-115.

Suddaby, R. (2006). From the editors: What grounded theory is not. *Academy of Management Journal*, *49*(4), 633-642.

Summers, A. E. (2003). Introduction to layers of protection analysis. *Journal of Hazardous Materials, 104*(1-3), 163-168.

Sylvester, C. (2017). *The Neuroscience of Personal Safety*. Retrieved from http://thesafestep.com.au/the-neuroscence-of-personal-safety/2872/

Takala, J., Hamalainen, P., Saarela, K.L., Yun, L.Y., Manickam, K., Jin, T.W., Heng, P., Tjong, C., Kheng, L.G., Lim, S., & Lin, G.S. (2014). Global estimates of the burden of injury and illness at work in 2012. *Journal of Occupational and Environmental Hygiene*, *11* (5), 326-337. DOI: 15459624.2013.863131.

Tamuz, M., & Harrison, M. I. (2006). Improving patient safety in hospitals: contributions of high-reliability theory and normal accident theory. *Health services research, 4*1(4p2), 1654-1676.

Tang, L., Li, Z., Zhao, Y., Qin, J., & Lin, L. (2012). Life cycle oriented hazards identification for tailings facility. *Procedia Engineering*, *43*, 282-287.

Tarrant, C., Leslie, M., Bion, J., & Dixon-Woods, M. (2017). A qualitative study of speaking out about patient safety concerns in intensive care units. *Social Science and Medicine, 193*, 8-15.

Teck Resources. (2018). *Learning from Loss.* Retrieved from https://www.teck.com/news/connect/issue/volume-23,-2018/table-of-contents/learning--from-loss

Tixier, A. J. P., Albert, A., & Hallowell, M. R. (2017). Proposing and validating a new way of construction hazard recognition training in academia: mixed-method approach. *Practice Periodical on Structural Design and Construction, 23*(1), 04017027.

U.S. Department of Labor, Bureau of Labor Statistics. (2016). *Comparison of fatal and non fatal injury data, 1993-2011.* Retrieved from https://www.bls.gov/iif/oshcfoi1.htm

Van Halderen, R.C., & Kolthoff, E.W. (2016). Noble cause corruption and task – related rule breaking behavior. In A. Farazmand (Eds), *Global Encyclopedia of Public Administration, Public Policy and Governance*. New York, NY: Springer.

Vardi, Y, & Weitz, E. (2016). Misbehavior in organizations: A dynamic approach. (2nd Ed). Series in *Applied Psychology*. New York, NY: Routledge Taylor and Francis Group.

Vaughan, D. (1996). *The Challenger launch decision: Risky technology, culture, and deviance at NASA*. University of Chicago Press.

Vaughan, D. (1999). The dark side of organizations: mistake, misconduct, and disaster. *Annual Review of Psychology, 25*, pp 271-305.

Vesa, M., Hond, F., & Harviainen, J. (2018). On the Possibility of a Paratelic Initiation of Organizational Wrongdoing. *Journal of Business Ethics*, *148*, 1-15. DOI:10.1007/s10551-018-3852-z

Venkatasubramanian, V. (2011). Systemic failures: challenges and opportunities in risk management in complex systems. *AIChE Journal, 57*(1), 2-9.

Venkatasubramanian, V., & Zhang, Z. (2016). TeCSMART: A hierarchical framework for modeling and analyzing systemic risk in sociotechnical systems. *AIChE Journal, 62*(9), 3065-3084.

Villeret, B. (2008, May). The social organization of a mistake. Interview: Diane Vaughan. *Consulting News Line.* Retrieved from http://www.consultingnewsline.com/Info/Vie%20du%20Conseil/Le%20Consultant%20du%20mois/Diane%20Vaughan%20(English).html

Watzman, S. (2002). Visual design principles for usable interfaces. In J.A. Jacko (Ed.), *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications* (pp. 263-285). Boca Raton, FL: Taylor & Francis Group.

Wei, Z. A., Shen, L. Y., & Li, W. D. (2003). Study on problems facing the design of tailing dam. *China Mining Magazine*, *12*, 60-65.

Weick, K.E. 1991, Organizational culture as a source of high reliability, *California Management Review*, *29*(2),112-127.

Winkel, G., Cocchio, J. R., Nibber, N., & Lefsrud, L. (2017). *The Handbook for Engineering Safety and Risk Management*. Edmonton, AB: University of Alberta, Custom Course-ware.

Wirth, O. (2017). COMMENTARY: Process Safety: Look Looking Beyond Personal Safety to Address Occupational Hazards and Risks. *Journal of Organizational Behavior Management*, *37*(3-4), 347-355.

Zinn, J. (2008). Heading into the unknown: Everyday strategies for managing risk and uncertainty. *Health, Risk & Society*, *10*(5), 439–450. doi:10.1080/13698570802380891

Zuber-Skerritt, O. (2001). Action learning and action research: paradigm, praxis and programs. *Effective Change Management Through Action Research and Action Learning: Concepts, Perspectives, Processes and Applications*, *1*, 20.

Appendices

APPENDIX A: Occupational Health and Safety Report

Investigation Report

Fatality – Worker Drowned in Tailings Pond

January 19, 2014

Report No-F-OHS-056980-A5B24
June 2017

Contents of this report

This document reports Occupational Health and Safety's (OHS) investigation of a fatal incident on January 19, 2014. It begins with a short summary of what happened. The rest of the report covers this same information in greater detail.

Incident summary

During a night shift, a worker noticed water flowing from an unknown source at the base of a tailings pond area in a large oil sands project. The worker parked the company truck and followed the water stream on foot back to the source of the water flow. A leak in a pipeline was the cause, and the leak had undercut the ground under an elbow in the pipeline creating a considerable hole filled with a slurry mixture of sand and water covered by a thin layer of ice and snow. The worker approached the source of the leak and fell through the ice into the slurry mixture and subsequently drowned.

Background information

Suncor Energy Inc. (Suncor) is a Canadian energy company based in Calgary, Alberta (AB) that extracts and upgrades oil sands material into bitumen products for further refining and processing. The deceased worker was an employee of Suncor.

The incident occurred at approximately 5:30 a.m. on January 19, 2014, in a location identified as Sand Dump 8 at Suncor - East Tailings Millennium Mine facility approximately 50 kilometres (km) north of Fort McMurray, AB.

Worker 1 – the deceased worker had worked as an upgrade supervisor for Suncor and had approximately 13 years' experience, as well as several years' experience working specifically as a tailings operator.

Suncor had provided numerous training courses, including the Line Patrol course, to worker 1 over the 13 year period.

Equipment and materials

Suncor - East Tailings area – Sand Dump 8 – Millennium Mine area consisted of coarse tailings produced as a result of the bitumen extraction process (approximately 250 feet deep of sand granular type material)

Pipeline "Line 16" was a 28 inch carbon steel pipeline which transported water mixed with tailings (fine and coarse granular sand type material) from Plant 300, approximately 10km, to Sand Dump 8 area where the tailings material was deposited.

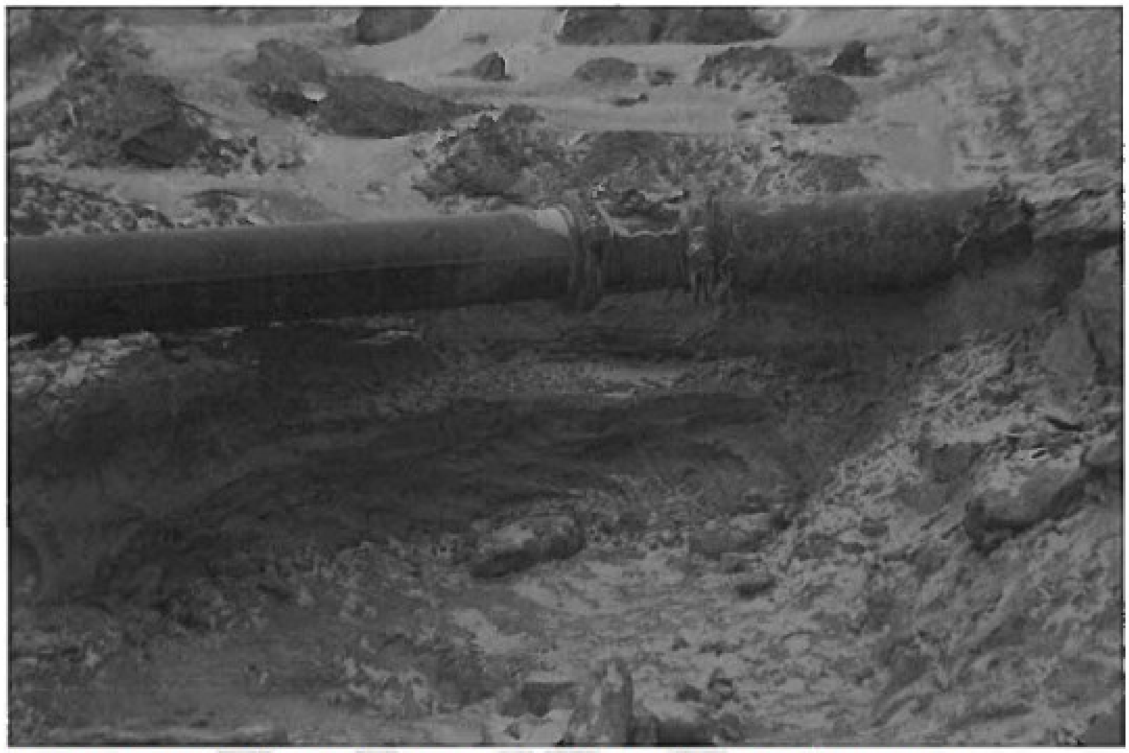


Figure 1. Location of undercut at Line 16 where the body of worker 1 was located.

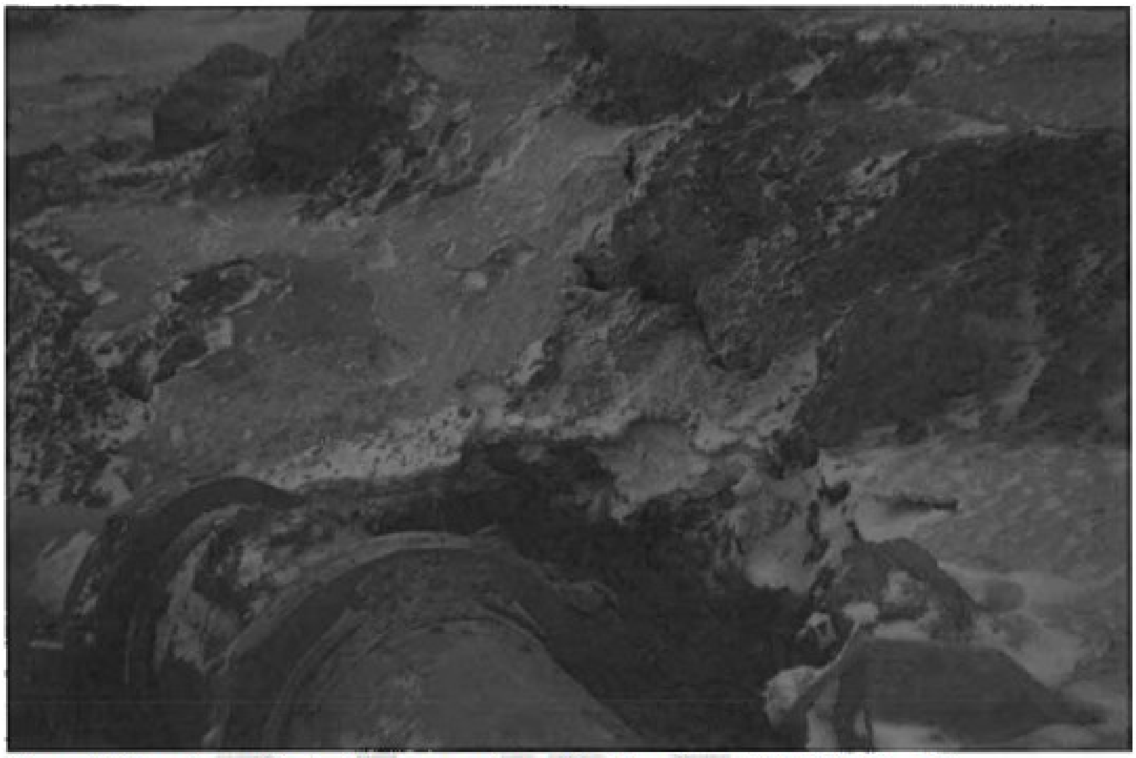


Figure 2. Location of footprints in snow above the elbow (spool 3890) in Line 16.

Sequence of events

On January 19, 2014, worker 1 performed job duties as an upgrade supervisor on the night shift rotation in the coarse tailings operations and operated a company pickup truck on a road within the area referred to as Sand Dump 8.

While driving the truck, worker 1 noticed a trail of water flowing below a tailings pond and suspected a breech in a nearby support dyke.

At about 5:10 a.m., worker 1 made a cell phone call to the shift supervisor to inform the shift supervisor of the flowing water and that worker 1 was going to follow the water to locate the source.

No further radio communication was heard from worker 1 after 5:10 a.m.

Between 5:45 a.m. and 6:00 a.m., several 2-way radio call attempts were made to contact worker 1.

Shortly after 6:00 a.m., Suncor's Line Patrol conducted a search for worker 1.

At 6:41 a.m., Suncor Emergency Services Department (ESD) received a dispatch call that worker 1 was missing.

An abandoned pickup truck with the driver's door open was found by Line Patrol parked off the road. Footprints in the snow were seen to lead away from the pickup truck towards the pipeline area of Line 16.

At 7:50 a.m., a 911 phone call was made by Suncor's onsite ESD for Royal Canadian Mounted Police (RCMP) assistance to locate missing worker 1.

Searchers followed footprints in the snow from the parked company truck which led up to Line 16 where a safety vest and a hooded jacket were located in the pipeline area under Line 16. The footprints in the snow, which led to Line 16, ended at the elbow in the pipe referred to as spool 3890.

Based on the footprints, vest and hoodie discovery, it was assumed by Suncor's Line Patrol that worker 1 may have fallen into an undercut in the dyke structure created by the water leak in Line 16.

Two excavators were called in from nearby operations to dig into the tailings material to drain the slurry tailings material and water under spool 3890. The body of worker 1 was not located at that time.

At 8:16 a.m., ESD called for vacuum trucks to come to Line 16, specifically to the elbow in the pipe (spool 3890). Vac trucks started to suck up the remaining pool of tailings and water.

At about 10:19 a.m., the body of worker 1 was located in the bottom of an undercut hole approximately 10 to 12 feet deep in the tailings sand under Line 16, spool 3890.

At 10:46 a.m., the RCMP searched the nearby abandoned company pickup truck and found a wallet inside the cab on the front seat which contained identification belonging to worker 1.

At about 11:09 a.m., the unresponsive body of worker 1 was recovered by Suncor's ESD personnel with RCMP present on site.

Worker 1 showed no vital signs of life upon removal from the hole.

The body of worker 1 was placed on a stretcher and taken to a nearby waiting Suncor ESD ambulance.

RCMP verified the identity of worker 1 from the identification found in the pickup truck that was parked by the road.

Worker 1 was taken by ambulance to Northern Lights Regional Hospital.

OHS was called and informed of the incident.

Completion
Occupational Health and Safety investigators completed the investigation and swore charges on January 13, 2016.

On April 24, 2017, Suncor Energy Inc. was convicted under Section 2(1)(a)(i) of the *Occupational Health and Safety Act*. At sentencing, Suncor Energy Inc. was fined $15,000 inclusive of a victim fine surcharge; a creative sentence was also levied against Suncor Energy Inc. under Section 41.1 of the *Occupational Health and Safety Act* in the amount of $285,000 in favour of the Lynch School of Engineering Safety University of Alberta to conduct a two year research project into tailings storage facilities in the oil sands.

This file was closed on April 26, 2017.

Signatures

ORIGINAL REPORT SIGNED	July 4, 2017
Lead Investigator	Date
ORIGINAL REPORT SIGNED	July 12, 2017
Manager	Date
ORIGINAL REPORT SIGNED	July 14, 2017
Director	Date

APPENDIX B: Semi-Structured Interview Questions and Detailed Interview Demographics Infographic

Frontline Workers

1. What is your role at your company, and how long have you been in this role?

2. What hazards do you see around tailings facilities, dykes, and transport systems?

3. If you could make one change with regards to tailings workplace safety practices, what would it be?

4. What are the barriers to implementing this change?

5. What do you think your supervisor's answer would be?

6. What do you deal with daily that you don't get support from management on?

7. Do you ever need to take shortcuts to get your work done? (Potential questions for elaboration: Please describe (what, when, how, why). If they answer "no"- Do you ever take short cuts? Does your supervisor know you take these short cuts? If they did, what do you think would happen?)

8. Knowing what you know now, what do you wish you were told on day 1 of your job (in regard to safety or operations with tailings facilities, dykes, and transport systems)?

Leadership

1. What is your role at your company, and how long have you been in this role?

2. What hazards do you see around tailings facilities, dykes, and transport systems?

3. In regards to tailings facilities, dykes, and transport systems safety, what keeps you up at night?

4. If you could make one change with regards to tailings workplace safety practices, what would it be?

5. What are the barriers to implementing this change?

6. If you had more resources for tailings safety and management, what would you ask for?

7. Knowing what you know now, what do you wish you were told on day 1 of your job (in regards to safety or operations with tailings facilities, dykes, and transport systems)?

Roving Contractors

1. What is your role at your company, and how long have you been in this role?

2. What hazards do you see around tailings facilities, dykes, and transport systems?

3. Are you treated differently compared to employees at your company? (Potential question for elaboration: In what ways?)

4. Are there additional demands on your time that employees don't have?

5. If you could make one change with regards to tailings workplace safety practices, what would it be?

6. What are the barriers to implementing this change?

7. Do you ever need to take shortcuts to get your work done? (Potential questions for elaboration: Please describe (what, when, how, why). If they answer “no”- Do you ever take short cuts? Does your supervisor know you take these short cuts? If they did, what do you think would happen?)

8. Knowing what you know now, what do you wish you were told on day 1 of your job (in regards to safety or operations with tailings facilities, dykes, and transport systems)?

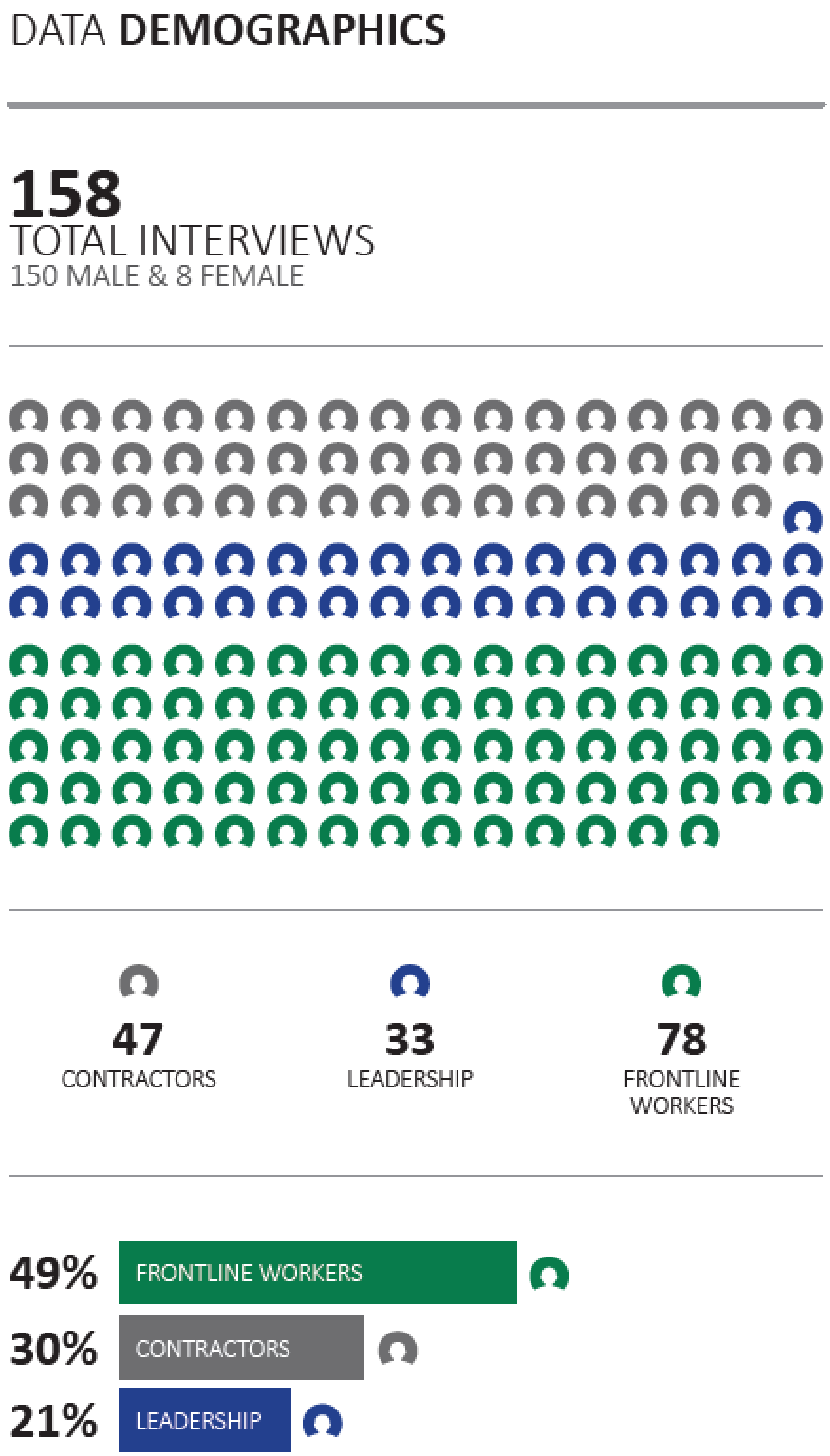


Figure 44. Detailed interview demographics for 158 interviewees.

APPENDIX C: Tailings Safety Symposium Flyer

Tailings Safety Symposium

WHERE: **Quality Hotel & Conference Centre**, Fort McMurray
WHEN: **November 29**, 2018
TIME: Breakfast **Starts At 7:30 am** | Day Will **Wrap Up At 4:30 pm**

Why Attend?

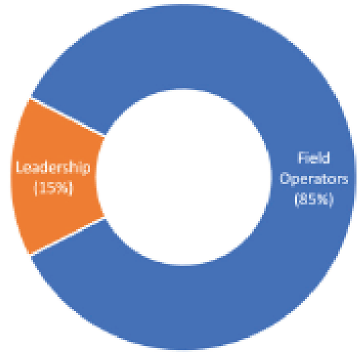
Influence the enhancement of tailings safety in the oil sands

A one – day symposium that will bring together frontline workers, contractors, safety professionals, leadership and academia to share their knowledge and expertise about working in or around the oil sands tailings operations.

University Of Alberta Research

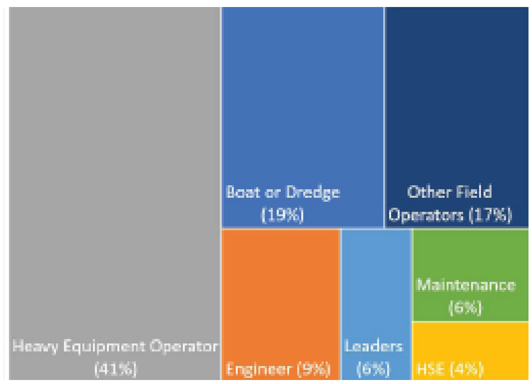
The University of Alberta has been conducting research with four key oil sands operators and ten regional contractors since August 2017. We have completed the following in the past year:

- Six site visits have been conducted in summer, winter and spring to assess the ground hazards and observe how the operations and risk drastically change with the seasons
- Over 140 frontline workers, safety professionals, contractors and people in leadership roles have been interviewed
- Key oil sands companies have provided us with their incident databases and we have analysed
- them to determine leading indicators of hazards in the tailings operations
- Energy Safety Canada provided us with a prioritized hazard list from their own site visits and we have created Bow Tie tools to help communicate the risks in the tailings operations



Findings

We have heard from many workers, leadership and safety professionals across the different organizations that there is a sense that the tailings operations are sometimes forgotten. We have found that people are aware of the hazards and risks in the tailings operations, but there appears to be some breakdown in the communication of these risks to workers who do not spend much time in tailings. There is also a disconnect between what is being reported in the incident databases and what workers and safety experts are identifying as high-risk activities in their working environment. Our goal is to bridge these gaps in communication. We want to provide recommendations to the oil sands operators that are useful, implementable and what the workers who interact with the tailings operations daily want to see. To do this, we need your help and input on this research project.



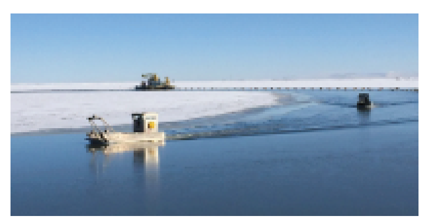
Benefits

The benefits to attend this one-day symposium are:

- You will be involved in a unique experience where workers from all levels and different companies are together in one space discussing issues, incidents, learnings and best practices and working together as an industry to make the tailings operations a safer place to work
- Your feedback over this day will be used to confirm findings and any identify gaps in our work to date
- This input will be used to identify next steps in enhancing tailings safety in the oil sands
- There will be the opportunity to network with people from different oil sands companies and regional contractors

Contact Information

- **Kathleen Baker**, EIT., kebaker@ualberta.ca, 403-969-6554
- **Dr. Lianne Lefsrud**, P.Eng., lefsrud@ualberta.ca, 780-951-3455
- **Tim Gondek**, tim.gondek@energysafetycanada.com, 780-715-3925



APPENDIX D: "8-1-2" Brainstorming sheet example

Table # __________

"8-1-2" Method – Structured Brainstorming

Problem Statement:
How do you eliminate or substitute for certain hazards in the _________ bow tie?

Name	Idea
Person 1	
Person 2	
Person 3	
Person 4	
Person 5	
Person 6	
Person 7	
Person 8	
Person 9	
Person 10	

APPENDIX E: Bow Tie Diagrams for the Top Seven Hazards in Tailings

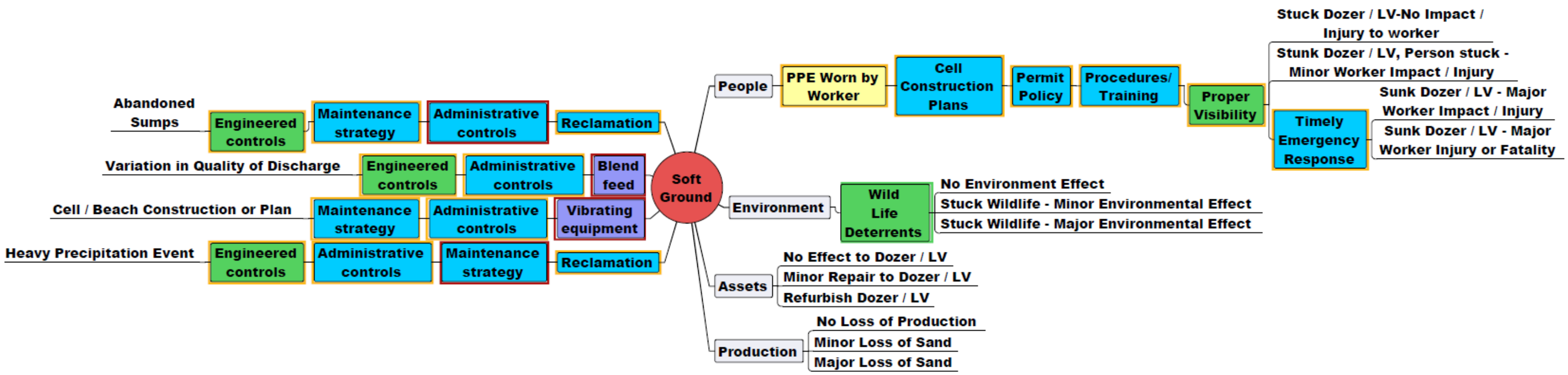


Figure 45. Soft ground bow tie diagram.

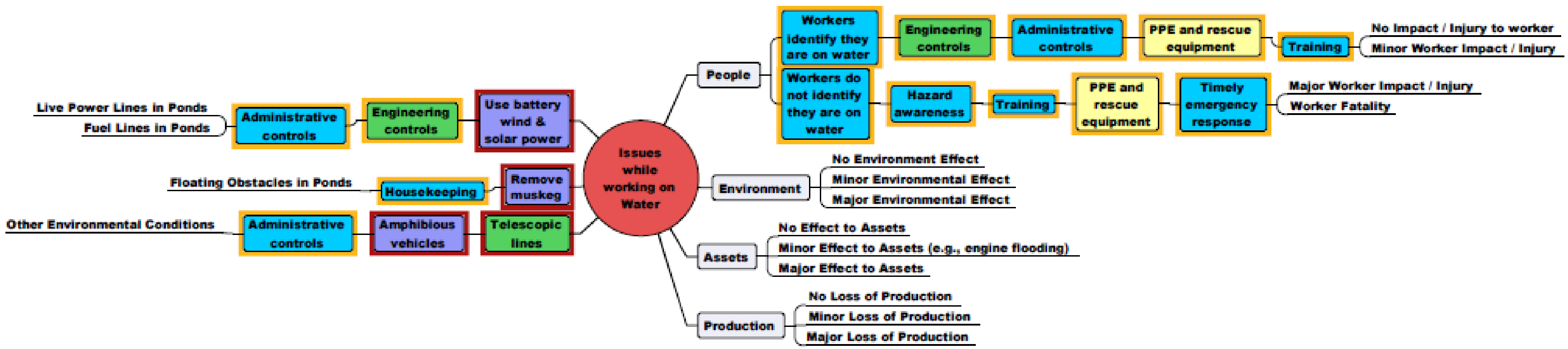


Figure 46. Working on water bow tie diagram.

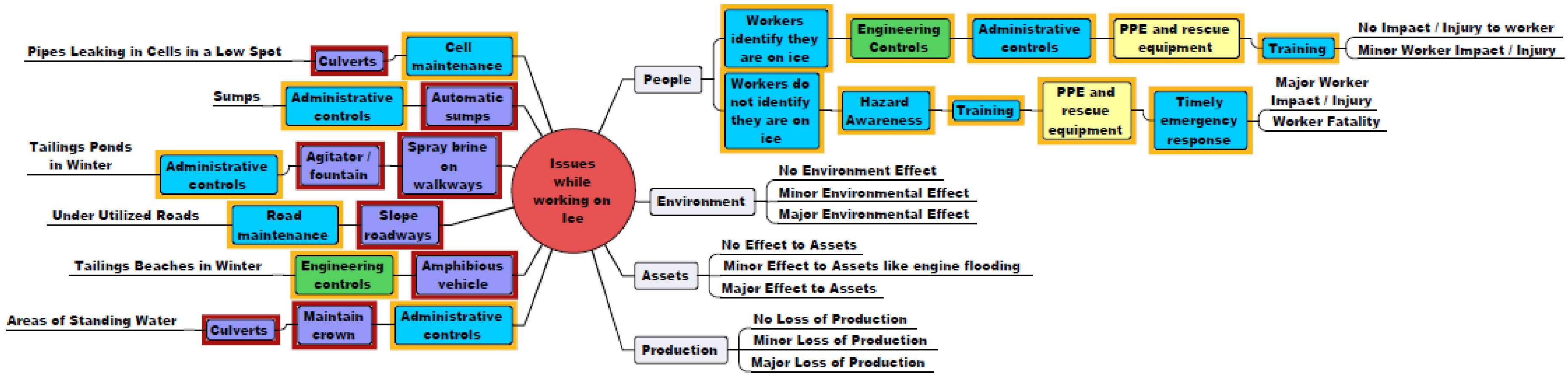


Figure 47. Working on ice bow tie diagram.

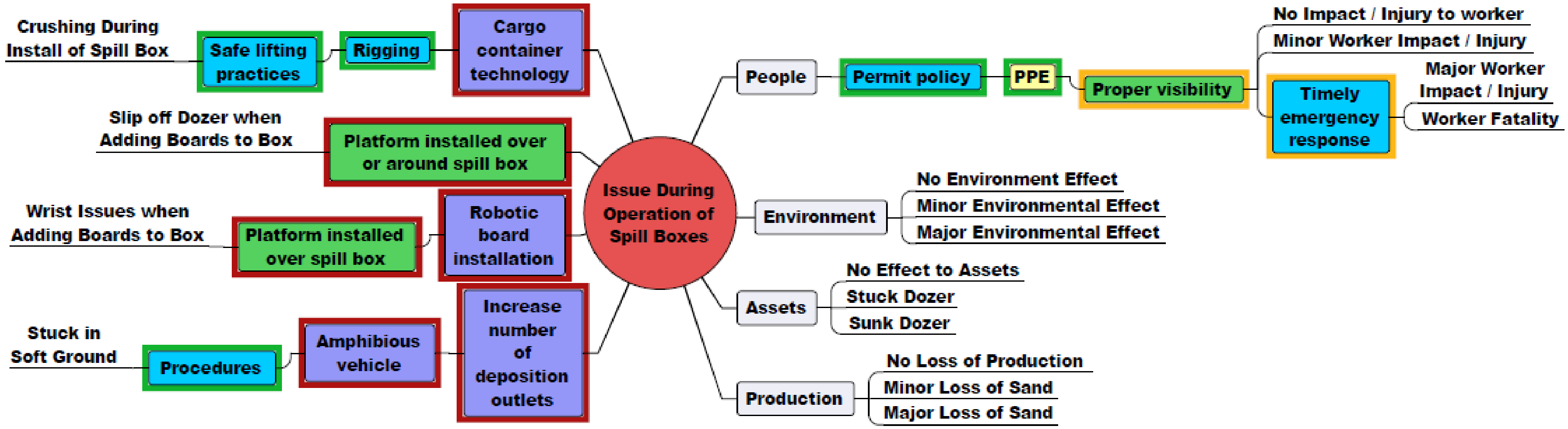


Figure 48. Spill box operation bow tie diagram.

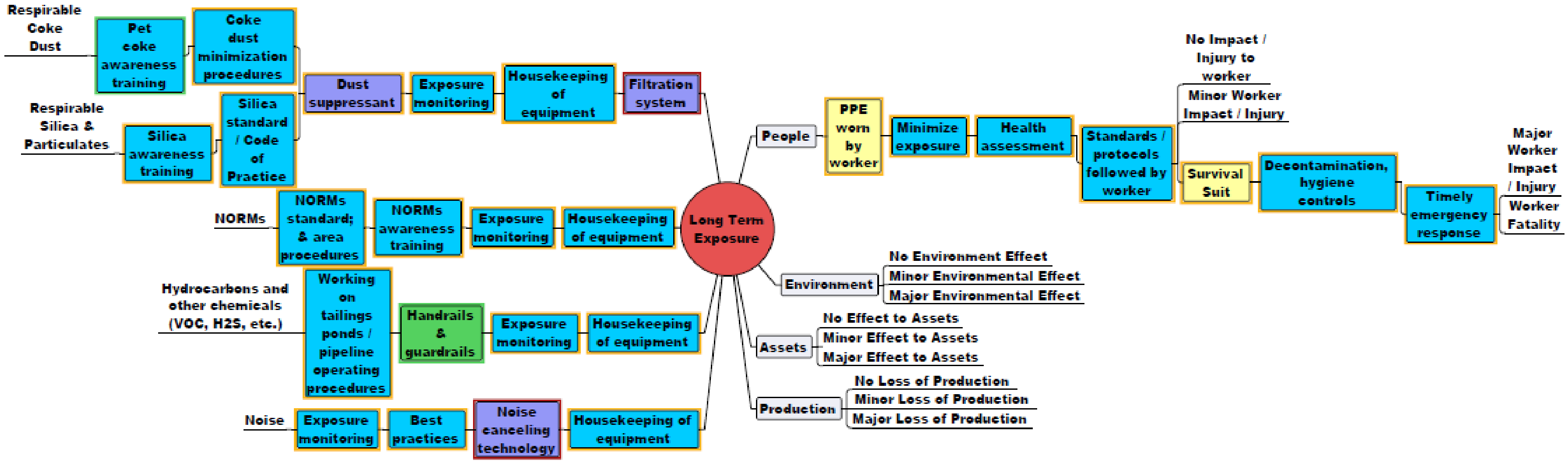


Figure 49. Long-term exposure bow tie diagram.

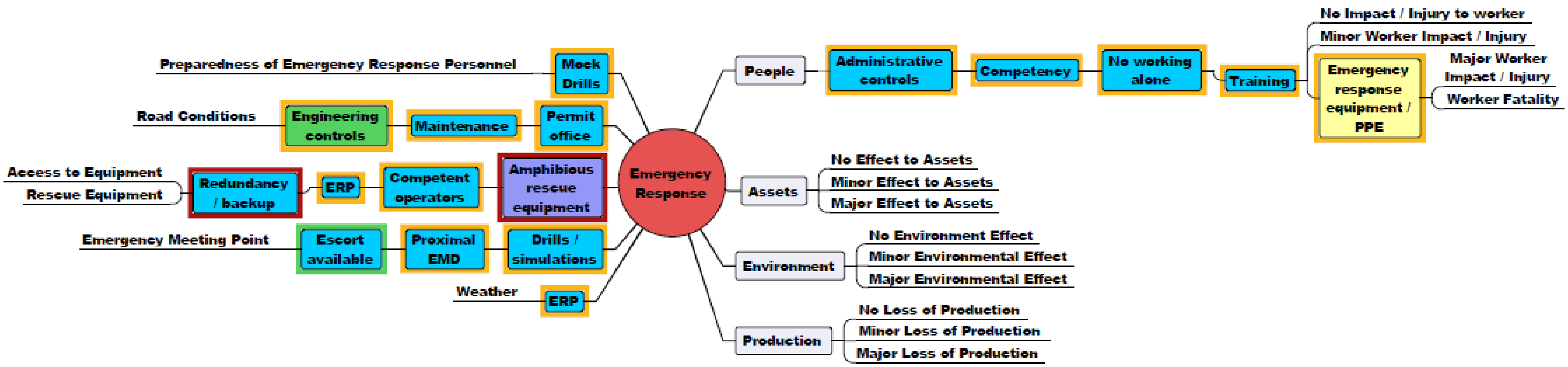


Figure 50. Emergency response bow tie diagram.

APPENDIX F: Ground Hazard Database- Enlarged Photos

Summer Photo (a), View of the open pit (~30 m deep). Steep slopes (~55°) typical of mining operations. A failed slope can be seen (top) at an inactive pit area

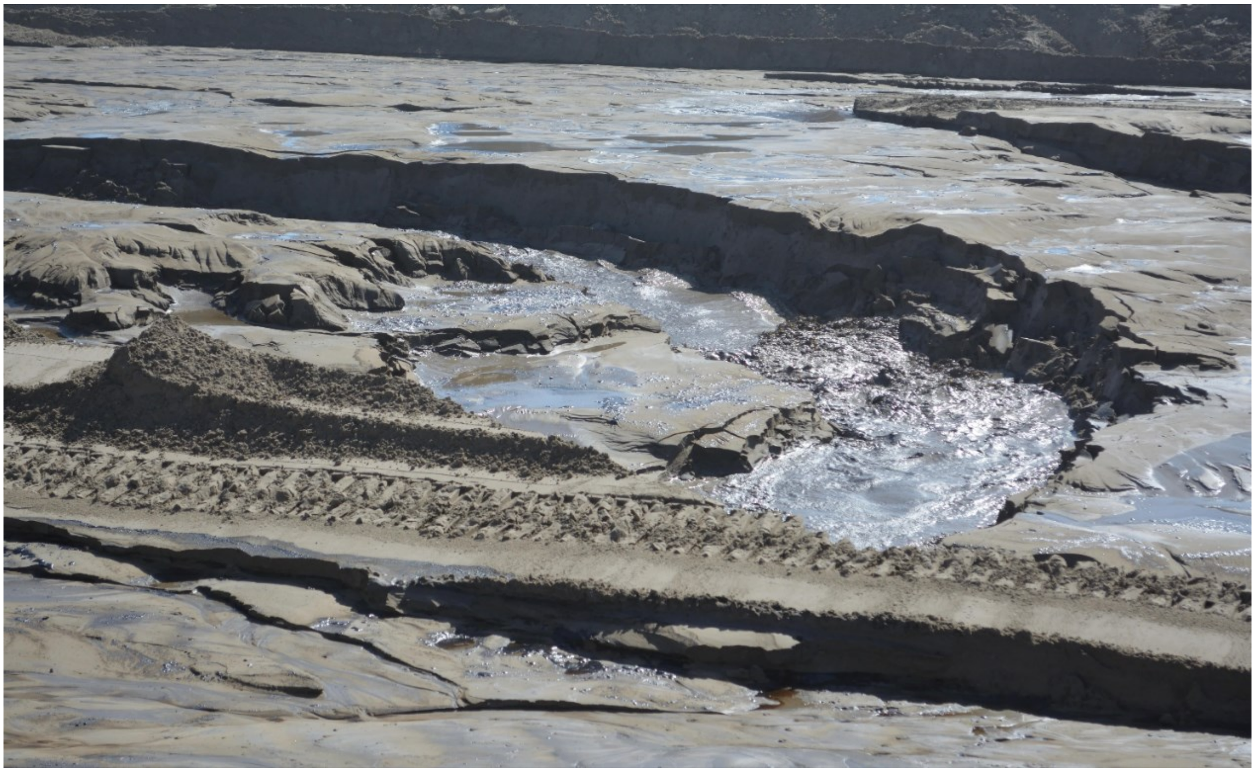
Summer Photo (b), Bulldozer creating steep cell walls in tailings discharge area.

Summer Photo (c), View of tailings discharge area and end of line device (dissipates kinetic energy).

Summer Photo (d), Pumps downslope of tailings dam. Pipes and associated structures in wet, soft ground conditions adjacent to slopes

Summer Photo (e), Bulldozer working in soft ground at tailings discharge area.

Summer Photo (f), Washout (width ~1.5 m) filled with water.



Summer Photo (g), Photo of a cut in the tailings discharge area.

Winter Photo (a), View of the open pit. Steep slopes (~55°) typical of mining operations and snow-covered benches.

Winter Photo (b), View of snow-covered eroded slopes of tailings dam.

Winter Photo (c), Steep slopes produced when pushing frozen soil and snow.

Winter Photo (d), Close-up of bulldozer in soft ground at tailings discharge area with steam from hot tailings discharge.

Winter Photo (e), Frozen tailings pond (not clear where beach ends and water begins).

Winter Photo (f), Frozen sump pump station.

Winter Photo (g), View of tailings discharge area and end of line device (right) while not in use; erosion on ground below end of line device.

Winter Photo (h), View of tailings discharge area with bulldozer operator working below an undercut slope.

Winter Photo (i), Open water at tailings pond recycled water inlet with a cut into the tailings material.

Spring Photo (a), Seepage at the toe of dyke with some unstable areas (middle) seen on the face.

Spring Photo (b), Seepage from face of dyke with ice and standing water at the toe.

Spring Photo (c), Water ponding (right) at the toe of loose sand.

Spring Photo (d), Truck stuck in mud and soft ground from spring melt.

Spring Photo (e), Standing water on road with ice melting on the side.

Spring Photo (f), Muddy and soft ground conditions between pipelines in working area.

Spring Photo (g), Slope in the tailings discharge area with pipeline and erosion features.

Spring Photo (h), View of pipeline that has fallen into an erosion feature next to a road.

APPENDIX G: Full List of Academic Presentations and Accepted Abstracts

Table 18. Summary of conference presentations, posters, and papers submitted as part of the creative sentencing project.

Authors	Title	Location	Date
Baker, K., and Lefsrud, L.	Update of Creative Sentencing Project and Tailings Safety Symposium Workshop	Tailings Safety Symposium Fort McMurray, AB	November 29, 2018
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.	Communicating risks across organizations and to contractors in the oil sands tailings operations	68th Canadian Chemical Engineering Conference Toronto, ON	October 29, 2018
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.	Using Process Safety Management tools to identify and assess oil sands tailings hazards	68th Canadian Chemical Engineering Conference Toronto, ON	October 29, 2018
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.	Leveraging of Incident Databases to Enable Best Practices in Safety and Risk Management	68th Canadian Chemical Engineering Conference Toronto, ON	October 31, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., & Lefsrud, L.	Protecting workers exposed to ground hazards through enhanced hazard identification and management tools	GeoEdmonton (Conference Paper) Edmonton, AB	September 24, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., & Lefsrud, L.	Protecting workers exposed to ground hazards through enhanced hazard identification tools (Paper)	Geohazards 7 (Conference Paper) Edmonton, AB	June 4, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., & Lefsrud, L.	Using Process Safety Management tools to identify and assess tailings hazards	Canadian Institute of Mining Convention 2018 Vancouver, 2018	May 8, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., & Lefsrud, L.	Leveraging of Incident Databases to Enable Best Practices in Safety Risk Management	Canadian Institute of Mining Convention 2018 Vancouver, 2018	May 8, 2018

Baker, K., Zettl, J., Macciotta, R., Hendry, M., & Lefsrud, L.	Communicating risks across organizations and to contractors	Canadian Institute of Mining Convention 2018 Vancouver, 2018	May 8, 2018
Baker, K., Zettl, J., & Lefsrud, L.	Workshop on Identifying Hidden Hazards	Petroleum Safety Conference Banff, AB	May 3, 2018
Baker, K., Zettl, J., Saksena, S, Macciotta, R., Lefsrud, L., & Hendry, M.	Protecting workers from ground hazards by enhancing hazard identification and management tools (Presentation)	Railway Ground Hazard Research Program Kingston, ON	December 13, 2017
Baker, K., Lefsrud, L., Macciotta, R., & Hendry, M.	Protecting worker safety by enhancing hazard identification and management tools (Presentation)	67th Canadian Chemical Engineering Conference Edmonton, AB	October 23, 2017
Baker, K. & Lefsrud, L.	Improving the sustainability of tailings operations: protecting worker safety by enhancing field level hazard assessment tools (Poster) *Received award for "Best Sustainable Research"	Faculty of Engineering Graduate Studies Research Symposium (FERGS) Edmonton, AB	June 26, 2017

Accepted Abstracts

1. **Center for Risk, Integrity and Safety Engineering (C-RISE 2019 Workshop), July 15-17, 2019**

Combining process safety and person safety to bring hazards into focus
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.

In the Canadian mining industry, from 2000 to 2014, there have been 49 dangerous occurrences associated with tailings facilities. Upon further investigation it was found that there is a dearth of information on worker safety around tailings storage and transport facilities. These incidents and the lack of literature illustrate the need for increased attention for worker safety in the oil sand tailings operations as well as enhancements to current hazard identification tools.

Workers in the oil sands tailings operations are exposed to hazards like loss of containment and line of fire, the difference between traditional process industries and the tailings operations are the pressures, volumes and temperatures. Process Safety Management tools like bowties can be applied to the tailings operations to visually identify unwanted events, potential threats, consequences and the controls to prevent incidents from occurring. They also serve as a tool for continuous improvement and show any over-reliance on one type of control such as administrative or personal protective equipment. In this research, seven hazardous activities have been selected for the bowtie analysis. This process has facilitated sharing of tailings safety best practices among oil sands operators and regional contractors.

2. **Center for Risk, Integrity and Safety Engineering (C-RISE 2019 Workshop), July 15-17, 2019**

Risk communication in the Athabasca oil sands tailings operations
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.

The oil sands operations consist of many working groups that can result in silos and can make effective risk communication challenging. Additionally, workers are exposing themselves to unidentified hazards without knowing the risk level. This has been illustrated with the fatalities in the oil sands related to unseen ground hazards at tailings storage and transport facilities. Thus, in this research we ask: How can we identify gaps in communication between different working groups and effectively disseminate information about risks to workers who interact with these facilities?

We are analyzing four datasets to identify areas for enhanced risk communication. The aim is to determine the hazards that workers see on the job site and compare their responses to tailings safety experts, geotechnical analysis and the recorded incidents. This will allow for the design of effective risk communication strategies in the oil sands tailings operations.

Traditional risk communication principles to disseminate information to external stakeholders will be applied to an internal audience like workers in the tailings operations. The aim is to enhance the dialogue regarding risks across the organization. This will be done by increasing the level of familiarity and decreasing the risk tolerance associated with hazards on the site.

3. **Society of Risk Analysis Benelux Conference, March 25-26, 2019**

Communicating risks across organizations and to contractors in the oil sands tailings operations
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.

The oil sands operations are made up of many working groups that each have an important role to play for the extraction and production of bitumen. Each of these operations are dynamic, demanding and required for oil sands companies to run an efficient operation and to be profitable. These qualities can lead to a very effective workforce, but they can also result in some silos between the different working groups on large sites like the oil sands tailings operations. These silos can cause breakdowns in communication across organizations and to contractors and can make effective risk communication challenging. Additionally, workers are voluntarily exposing themselves to unidentified hazards, potentially, without knowing the risk level. This has recently been illustrated with the fatalities in the oil sands tailings industry related to unseen and unknown ground hazards at tailings storage and transport facilities. Thus, in this research we ask: How can we identify gaps in communication between different working groups and effectively disseminate information about these risks not only to workers who interact with these facilities daily but also to contractors and other workers who are intermittently exposed?

We are analyzing four datasets to determine similarities and differences and to identify areas for enhanced risk communication. These four datasets include: (1) tailings safety expert hazard inventory, (2) interviews with frontline workers, safety advisors, supervisors, leadership and contractors, (3) ground hazard inventory and (4) company incident databases. The aim is to determine the hazards that workers see on the job site and compare these responses to the tailings safety experts, geotechnical analysis and the incidents that are being recorded. This will allow for the design of effective risk communication strategies in the oil sands operations, particularly in tailings

The traditional risk communication principles to disseminate information to external stakeholders will be applied to an internal audience like workers in the tailings operations. The aim is to enhance the dialogue regarding risks between workers, contractors and across the organization. This will be achieved by increasing the level of familiarity and decreasing the risk tolerance associated with the hazards on site through tailings specific training, formal mentorship programs and a visual ground hazard database. Additionally, increased communication should help to break down the silos to allow an easier flow of information between working groups in the oil sands.

4. **Society of Risk Analysis Benelux Conference, March 25-26, 2019**

Using Process Safety Management tools to identify and assess oil sands tailings hazards
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.

In the Canadian mining industry, there have been 49 dangerous occurrences from 2000 to 2014 associated with tailings facilities (Hoekstra, 2014). At least two of these occurrences resulted in deaths at the oil sands tailings operations. Upon further investigation it was found that there is a dearth of information on worker safety around tailings storage and transport facilities. The majority of the research to date focuses on the potential for catastrophic failures and uncontrolled releases that could affect the public and the environment. However, this work and the mitigation strategies implemented are not preventing the occurrence of tragic worker fatalities and other incidents due to loss of containment events and other hazards near tailings storage or transport facilities. These incidents illustrate the need for increased attention for worker safety in the oil sand tailings operations as well as enhancements to current hazard identification tools.

Workers in the oil sands tailings operations are exposed to hazards like loss of containment and line of fire just like in any other refinery or upgrader. The difference between traditional process industries and oil sand tailings operations are the pressures, volumes and temperatures. Process Safety Management tools and principles like: Root Cause Analysis, Event Trees and bowties, are well used in the process industry to identify and manage hazards, but their application is not widely used in the oil sands tailings operations. In this research, bowties are being used to visually identify unwanted events, potential causes, consequences and the controls to prevent unwanted events from occurring. Seven unwanted events / hazardous activities in the tailings operations have been selected for the bowtie analysis. They include: (1) pipeline leak, (2) long term exposure, (3) soft ground, (4) emergency response, (5) issues while working on water, (6) issues while working on ice, and (7) operating spill boxes. These hazardous activities were selected based on a tailings safety expert hazard inventory, company incident databases and based on feedback from interviews with frontline workers, safety professionals, engineers and leadership at multiple oil sands operators and regional contractors.

Bowties illustrate the controls that are currently in place as well as areas for enhancement. They also serve as a tool for continuous improvement as companies have documentation of the controls in place to prevent an unwanted event and can revisit them to ensure the effectiveness of these controls. Additionally, they show any over-reliance on one type of control such as administrative or personal protective equipment. This process has helped to facilitate the sharing of tailings safety best practices among oil sands operators and regional contractors. Findings from this research will be used to create oil sands industry best practices for tailings safety and can be applied to the oil sands industry and mining industries more broadly.

5. **Canadian Society of Chemical Engineering Conference 2018, October 29-31, 2018**

Communicating risks across organizations and to contractors in the oil sands tailings operations
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.

The oil sands operations are made up of many working groups that each have an important role to play for the extraction and production of bitumen. Each of these operations are dynamic, demanding and required for oil sands companies to run an efficient operation and to be profitable. These qualities can lead to a very effective workforce, but they can also result in some silos between the different working groups on large sites like the oil sands tailings operations. These silos can cause breakdowns in communication across organizations and to contractors and can make effective risk communication challenging. Additionally, workers are voluntarily exposing themselves to unidentified hazards potentially, without knowing the risk level. This has recently been illustrated with the fatalities in the oil sands tailings industry related to unseen and unknown ground hazards at tailings storage and transport facilities. Thus, in this research we ask: How can we identify gaps in communication between different working groups and effectively disseminate information about these risks not only to workers who interact with these facilities daily but also to contractors and other workers who are intermittently exposed?

We are analyzing four datasets to determine similarities and differences and to identify areas for enhanced risk communication. These four datasets include: (1) tailings safety expert hazard inventory, (2) interviews with frontline workers, safety advisors, supervisors, leadership and contractors, (3) ground hazard inventory and (4) company incident databases. The aim is to determine the hazards that workers see on the job site and compare these responses to the tailings safety experts, geotechnical analysis and the incidents that are being recorded. This will allow for the design of effective risk communication strategies in the oil sands operations, particularly in tailings

The traditional risk communication principles to disseminate information to external stakeholders will be applied to an internal audience like workers in the tailings operations. The aim is to enhance the dialogue regarding risks between workers, contractors and across the organization. This will be achieved by increasing the level of familiarity and decreasing the risk tolerance associated with the hazards on site through tailings specific training, formal mentorship programs and a visual ground hazard database or an app. Additionally, increased communication should help to break down the silos to allow an easier flow of information between working groups in the oil sands.

6. **Canadian Society of Chemical Engineering Conference 2018, October 29-31, 2018**

Using Process Safety Management tools to identify and assess oil sands tailings hazards
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.

In the Canadian mining industry, there have been 49 dangerous occurrences from 2000 to 2014 associated with tailings facilities. At least two of these occurrences resulted in deaths at the oil sands tailings operations. Upon further investigation it was found that there is a dearth of information on worker safety around tailings storage and transport facilities. The majority of the research to date focuses on the potential for catastrophic failures and uncontrolled releases that could affect the public and the environment. However, this work and the mitigation strategies implemented are not preventing the occurrence of tragic worker fatalities and other incidents due to loss of containment events and other hazards near tailings storage or transport facilities. These incidents illustrate the need for increased attention for worker safety in the oil sand tailings operations as well as enhancements to current hazard identification tools.

Workers in the oil sands tailings operations ae exposed to hazards like loss of containment and line of fire just like in any other refinery or upgrader. The difference between traditional process industries and oil sand tailings operations are the pressures, volumes and temperatures. Process Safety Management tools and principles like: Root Cause Analysis, Event Trees and bowties, are well used in the process industry to identify and manage hazards, but their application has not yet been implemented into the oil sands tailings operations. In this research, bowties are being used to visually identify unwanted events, potential causes, consequences and the controls to prevent unwanted events from occurring. Seven unwanted events / hazardous activities in the tailings operations have been selected for the bowtie analysis. They include: (1) pipeline leak, (2) long term exposure, (3) soft ground, (4) emergency response, (5) issues while working on water, (6) issues while working on ice, and (7) operating spill boxes. These hazardous activities were selected based on a tailings safety expert hazard inventory, company incident databases and based on feedback from interviews with frontline workers, safety professionals, engineers and leadership at multiple oil sands operators and regional contractors.

Bow Ties illustrate the controls that are currently in place as well as areas for enhancement. They also serve as a tool for continuous improvement as companies have documentation of the controls in place to prevent an unwanted event and can revisit them to ensure the effectiveness of these controls. Additionally, they show any over-reliance on one type of control such as administrative or personal protective equipment. This process has also facilitated sharing of tailings safety best practices among oil sands operators and regional contractors. Findings from this research will be used to create oil sands industry best practices for tailings safety and can be applied to the oil sands industry and mining industries more broadly.

7. **Canadian Society of Chemical Engineering Conference 2018, October 29-31, 2018**

Leveraging of Incident Databases to Enable Best Practices in Safety and Risk Management
Baker, K., Macciotta, R., Hendry, M., & Lefsrud, L.

The old saying "what is measured gets managed" can be applied to many companies and operations and it is extremely relevant for hazards on industrial sites. On most sites, incidents are documented in a database that has information about the incident, investigation, risk level and corrective actions. In some cases, not much more done with this information aside from calculating metrics for management meetings or identifying lagging indicators. Incident databases can be used as much more than a metric, they can be used as a tool to identify, analyze and reduce risks thereby obtaining safe operating levels. Currently, oil sands companies tend to utilize tools like Field Level Hazard Assessments, Standard Operating Procedures, toolbox meetings etc. to ensure site and worker safety. These tools are effective to a certain extent but may fail to identify reoccurring incidents that could be prevented. High frequency, low consequence incidents can provide valuable information to workers and help to inform safety and risk management decisions. Thus, in research, we ask: How can we identify and control the low risk incidents to mitigate the occurrence of fatalities and enable better practices in safety and risk management?

We have been given access to multiple oil sands operators incident databases relating to tailings. Through analysis of these databases, we can identify low risk incidents that could be used as leading indicators. By investigating and remediating the root causes of these events, some catastrophic failures could be prevented. Additionally, we will be comparing the recorded incidents to our other datasets including tailings safety expert hazard inventory and interview responses from frontline workers, safety personnel and leadership to determine gaps and areas for enhancement in the incident recording process. There are also slight differences between how each company manages and utilizes these databases. Our goal is to create best practices for the tailings operations on how to leverage incident databases to enable optimized safety and risk management programs. These findings can be applied to the oil sands industry and other heavy industries more broadly.

8. GeoEdmonton 2018, September 23-26, 2018

Protecting workers exposed to ground hazards through enhanced hazard identification and management tools

Baker, K., Zettl, J., Macciotta, R., Hendry, M., & Lefsrud, L.

In Alberta, approximately 150,000 people are harmed at work annually (Jazayeri and Dadi, 2017). Industries, like the oil sands, see the importance of decreasing injuries on work sites and use tools like the Field Level Hazard Assessment (FLHA) to visually identify hazards that are known and visible, manage risks, and determine appropriate actions to ensure safe conditions. A challenge lies in some workplaces, including oil sands tailings storage and transport facilities (TSTF) where unexpected ground hazards exist making them invisible to workers that have not been trained to identify or mitigate ground hazards. Two recent deaths due to ground hazards in TSTF indicate the need for further work in this area. Ground hazards such as: soft ground, slope instability, erosion and sink holes have been identified at almost all the TSTF but these hazards manifest in different ways depending on the location, weather and operations.

A joint initiative with the Crown, industry and the University of Alberta has been undertaken to enhance tools used to identify and control ground hazards associated with tailings operations. Site visits were conducted to identify ground hazards at representative TSTF and employees were interviewed to determine their recognition of ground hazards associated with tailings operations. Suggestions to enhance current hazard identification and management tools like the FLHA and training to include ground hazards will be discussed. The aim of this research is to motivate change in best practices through dissemination of information to the oil sands industry, academics and other industries that are exposed to ground hazards. The methodologies developed to identify ground hazards and enhance controls will be discussed. An example of an enhanced FLHA tool based on a ground hazard database and interviews will be presented.

9. **Geohazards 7, June 3-6, 2018**

Protecting workers exposed to ground hazards through enhanced Field Level Hazard Assessment tools
Baker, K., Zettl, J., Macciotta, R., Hendry, M. & Lefsrud, L.

Risk acceptability is often technically defined 'As Low as Reasonably Practicable' and companies utilize many tools and procedures to obtain these safe operating levels. One such engineering safety and risk management tool is the Field Level Hazard Assessment. This tool allows employees to efficiently assess a worksite for hazards to ensure the site's safety. This method is effective for hazards that are known and visible. A subset of workers and operators performing tasks around certain facilities (e.g. oil sands tailings storage and transport facilities) are not likely to be trained in assessing potential ground hazards, and these would be invisible and unexpected for them.

Much work has been focused on the safety and performance of tailings storage and transportation facilities, which has led to increasing safety against catastrophic failure and uncontrolled releases. However, there have been two recent deaths related to ground hazards near tailings storage and transport facilities, illustrating the need for improving worker safety in their day-to-day tasks in the vicinity of these facilities. This paper presents a recent initiative between the oil sands industry, the Province and the University of Alberta to enhance Field Level Hazard Assessment tools to recognize and better manage hazards associated with tailing storage and transport facilities. This research aims to increase the priority of worker safety by creating a usable and implementable hazard assessment tool.

10. **Canadian Institute of Mining Convention 2018, May 6-9, 2018**

Using Process Safety Management tools to identify and assess tailings hazards
Baker, K., Zettl, J., Macciotta, R., Hendry, M. & Lefsrud, L.

Oil sands tailings may not be the typical case study that comes to mind when thinking of Process Safety Management, but there are many aspects of tailings operations that could benefit from the use of these principles to identify and manage hazards. Much work has been focused on the safety and performance of tailings storage and transportation facilities, which has led to increasing safety against catastrophic failures and uncontrolled releases. However, despite this good work, tragic tailings related fatality incidents persist due to loss of containment events near tailings storage and transport facilities. These fatalities illustrate the need for improving hazard identification and management in the vicinity of these facilities.

This research uses Process Safety Management tools like Root Cause Analysis, Event Trees and Bow Ties to identify the hazards associated with oil sands tailings operations. These tools were used to analyze hazard inventories from three sources: oil sands tailings safety experts, employees and company incident data. The results were compared to determine common themes, hazards and gaps in controls. Findings from this research will allow for enhancements to the current safety management systems, the development of prioritized action lists and will ideally enhance industry standards.

11. Canadian Institute of Mining Convention 2018, May 6-9, 2018

Leveraging of Incident Databases to Enable Best Practices in Safety Risk Management
Baker, K., Zettl, J., Macciotta, R., Hendry, M. & Lefsrud, L.

Incident databases can be used as a tool to identify, analyze and reduce risks thereby obtaining safe operating levels. Currently, oil sands companies tend to utilize tools like Field Level Hazard Assessments, Standard Operating Procedures, toolbox meetings etc. to ensure site and worker safety. These tools are effective to a certain extent but may fail to identify reoccurring incidents that could be prevented.

Many companies use their incident databases to monitor high consequence, low probability events or lagging indicators. As a result, high frequency, low consequence incidents are often overlooked. These near miss or low risk incidents could be used as leading indicators and by investigating and remediating the root causes of these events, some catastrophic failures could be prevented. Thus, in research, we ask: How can we identify and control the low risk incidents to mitigate the occurrence of fatalities and enable better practices in safety risk management.

Analysis was completed using a company's incident database to determine the actual hazards encountered by the worker at the time of the incident. This research could help foster a continuous improvement safety culture where hazards are recognized and enhancements to controls are implemented prior to high consequence events occurring.

12. Canadian Institute of Mining Convention 2018, May 6-9, 2018

Communicating risks across organizations and to contractors
Baker, K., Zettl, J., Macciotta, R., Hendry, M. & Lefsrud, L.

Risk communication is the dissemination of information from an organization to its stakeholders. Typically, this is open two-way communication of known hazards from an organization to the public. However, we have identified a gap in the communication of risks within organizations to employees and contractors. Workers are voluntarily exposing themselves to unidentified hazards, sometimes without knowing the risk level. This has recently been illustrated in the oil sands industry after tragic fatalities related to unseen and unknown ground hazards at tailings storage and transport facilities. Thus, in research, we ask: How can we identify and communicate risks not only to workers who interact with these facilities daily but also to contractors who are intermittently exposed?

We have conducted interviews with frontline workers, safety advisors, supervisors, leadership and contractors to determine the hazards the workers see on the job site. Responses varied significantly across working groups and experience levels. We will be using traditional risk communication practices to enhance the dialogue regarding risks between workers, contractors and across the organization. We aim to increase the level of familiarity and decrease complacency with the hazards on site through tailings specific training, formal mentorship programs and geohazard databases.

13. Petroleum Safety Conference, May 1-3, 2018

Workshop on Identifying Hidden Hazards

Lefsrud, L., Baker, K., & Zettl, J.

The Petroleum Industry uses tools such as the Field Level Hazard Assessment to allow workers to visually identify hazards, mitigate risks or take corrective steps prior to beginning work. These tools work well for hazards that are known and visible, there are however, some workers who are exposed to hazards that are unknown and invisible such as ground hazards. Two recent deaths associated with ground hazards at tailings storage and transport facilities in the oil sands illustrate the need for enhanced ground hazard identification and controls.

The Crown, University of Alberta and oil sands industry are working together to enhance the current hazard identification tools and controls. Site visits identified ground hazards such as: soft ground, slope instability, erosion and sink holes at almost all of the tailings transport and storage facilities. All of these hazards manifest themselves in different ways depending on the operation, location and weather. Employees and contractors of all levels at multiple oil sands operators have been interviewed to determine the hazards workers are exposed to on a daily basis. Process Safety Management techniques like bow ties and event trees have been used to cluster hazards from a hazard inventory created by Energy Safety Canada tailings safety experts. Data from the above sources will be analysed together and used to enhance current field level hazard assessment, other hazard identification tools and controls. The aim of this research is to enhance the current best practices related to tailings operations and ground hazards.

Learning Objectives/ Takeaways

1. Ground hazards are well understood by geotechnical experts, but there is a gap in the communication of these risks to workers. Ground hazards can be seen in the conventional petroleum industry as well, the same gap could be present and these methods could be applied to other sites to increase ground hazard awareness.

2. Leading indicators like unsafe acts and substandard conditions that can inform maintenance and operations of potential hazards and allow workers take corrective action prior to a high consequence occurring.

3. Occupational Health and Safety and Process Safety are two distinct and important aspects of a safety program. However, techniques from both can be used to gain a holistic understanding of the hazards workers are exposed to during their daily operation opposed to worker safety being job task oriented.

Target Audience

Our target audience is diverse with representation from frontline workers, supervisors, safety representatives, upper management and leadership. We feel that it is important to facilitate discussion between these groups to increase awareness and enable enhanced risk communication between working groups. This presentation would be valuable not only to those working in the oil sands industry but also to those working in the conventional petroleum industry as ground hazards can be seen in both of these operations.

14. Canadian Chemical Engineering Conference 2017, October 22-25, 2017

Protecting Worker Safety by Enhancing Field Level Hazard Assessment Tools
Baker, K., Macciotta, R., Hendry, M. & Lefsrud, L.

Risk acceptability is often technically defined 'As Low as Reasonably Practicable' and companies utilize many tools and procedures to obtain these safe operating levels. One such engineering safety and risk management tool is the Field Level Hazard Assessment. This tool allows employees to efficiently assess a worksite for hazards to ensure the site's safety. This method is effective for hazards that are known and visible. Currently, there is no contingency built into the tool for invisible, unexpected hazards, like ground hazards associated with oil sands tailings storage and transport facilities. There have been two recent deaths related to ground hazards near these facilities, illustrating the need for the improvement of these tools. Companies tend to focus on catastrophic failures, posing risks to the public and environment (i.e., Mount Polley). As a result, worker safety during tailings operations is often overlooked. Thus, in this research, we ask: How can we enhance Field Level Hazard Assessment tools to recognize and better manage hazards associated with tailing storage and transport facilities. Data will be collected using a mixed methods approach. With input from workers, the current Field Level Hazed Assessment tools will be modified to include practical identifiers so operators can recognize and appropriately manage ground hazards prior to beginning work. This research aims to decrease the number of incidents associated with tailings facilities and protect workers from unseen and potentially unknown ground hazards.

15. Faculty of Engineering Graduate Studies Research Symposium, June 27-28,2017

Improving the Sustainability of Tailings Operations: Protecting Worker Safety by Enhancing Field Level Hazard Assessment Tools
Baker, K., & Lefsrud, L.

Risk acceptability is often technically defined ‘As Low as Reasonably Practicable’ and companies utilize many tools and procedures to obtain these safe operating levels. One such engineering safety and risk management tool is the Field Level Hazard Assessment. This tool allows employees to efficiently assess a worksite for hazards to ensure the site’s safety. This method is effective for hazards that are known and visible. Currently, there is no contingency built into the tool for invisible, unexpected hazards, like ground hazards associated with oil sands tailings storage and transport facilities. Recently, there has been two deaths related to ground hazards near tailings storage and transport facilities, illustrating the need for the improvement of these tools.

The sustainability of mine sites and tailings facilities tends to focus on catastrophic failures, posing risks to the public and environment (i.e., Mount Polley). As a result, worker safety during tailings operations is often overlooked. Thus, in this research, we ask: How can we enhance Field Level Hazard Assessment tools to recognize and better manage hazards associated with tailing storage and transport facilities.

To answer this question, we will collect data using a mixed methods approach: surveying ground hazards during field visits, semi structured interviews with various employees, and assessing their risk management techniques for oil sands companies with tailings facilities. With input from workers, the current Field Level Hazed Assessment tools will be modified to include practical identifiers so operators can recognize and appropriately manage ground hazards prior to beginning work. This research aims to increase the priority of worker safety by creating a usable and implementable hazard assessment tool.

Phase one of this research consists of gathering data on ground hazards, precursory events and current industry best practices. Interviews with employees will also be conducted in this phase to determine current operating conditions. Phase two will include the development of the Field Level Hazard Assessment tool with consultation from industry. Phase three will contain the implementation and optimization of the tool as well as industry sharing and education.

Most importantly, this work will help to decrease the number of incidents associated with tailings facilities and protect workers from unseen and potentially unknown ground hazards. This research will be applicable to all companies that operate tailings facilities and dams more generally. Our findings will be translated into training modules which will hopefully enhance industry standards.