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## Addressing specific safety and occupational health challenges for the Canadian mines located in remote areas where extreme weather conditions dominate

Author(s) ORCID Identifier:

Rachid Halabi:  0000-0002-9552-3490

Mustafa Kumral:  0000-0003-1370-7446

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## Abstract

The number of mining operations is increasing in the Canadian North, where extreme weather conditions govern. Currently, many mine development projects are also in progress in this region. These mines' working atmosphere and employment circumstances are highly different from regular mines. One of the main differences is the special safety issues of the Canadian North. The primary sources of these special issues are: the difficulty of finding skilled employees; high employee turnover rate; insufficient training and certification requirements; delicate employment circumstances affecting the psychological well-being of employees; permafrost; mine inspection challenges; inventory and logistic hardship; and the legislative and regulative necessities corresponding to the particular working environment. This paper aims to set forth specific safety cases in the mines located in the Canadian North. Then, it argues the characteristics of safety organizations and management required to deal with these cases. Furthermore, how the current frameworks can be improved is discussed. Safety issues stemming from cold weather conditions and location remoteness of mines add further challenges to the viability and implementation of projects. The paper underlines that mining operations need certain safety organizations, management approaches, and specific regulations for the mines operated in remote areas and under severe weather conditions.

## Keywords

mine safety, remote mine sites, extreme weather conditions, health and safety legislation frameworks, mines in the Canadian North

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# Addressing Specific Safety and Occupational Health Challenges for the Canadian Mines Located in Remote Areas Where Extreme Weather Conditions Dominate

Rachid Halabi, Mustafa Kumral\*

McGill University, Mining and Materials Engineering Department, Montreal, Quebec, Canada

## Abstract

The number of mining operations is increasing in the Canadian North, where extreme weather conditions govern. Currently, many mine development projects are also in progress in this region. These mines' working atmosphere and employment circumstances are highly different from regular mines. One of the main differences is the special safety issues of the Canadian North. The primary sources of these special issues are: the difficulty of finding skilled employees; high employee turnover rate; insufficient training and certification requirements; delicate employment circumstances affecting the psychological well-being of employees; permafrost; mine inspection challenges; inventory and logistic hardship; and the legislative and regulative necessities corresponding to the particular working environment. This paper aims to set forth specific safety cases in the mines located in the Canadian North. Then, it argues the characteristics of safety organizations and management required to deal with these cases. Furthermore, how the current frameworks can be improved is discussed. Safety issues stemming from cold weather conditions and location remoteness of mines add further challenges to the viability and implementation of projects. The paper underlines that mining operations need certain safety organizations, management approaches, and specific regulations for the mines operated in remote areas and under severe weather conditions.

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## 1. Introduction

Canada has a strong record in mining and is among the top five global producers of numerous minerals and metals. The mining industry is also critical to the economic prosperity of local and indigenous communities. According to the Mining Association of Canada (MAC), mining activity is responsible for the prosperity and economic growth of up to 115 communities in different rural or remote regions of Canada [1]. Most Canadian mines are in the far North of the country's ten provinces and three territories. This is owing, in part, to the Canadian Shield, considered the country's biggest and most important geological formation, extending from the Northwest Territories to

Labrador. If we compare mining activities in Northern Canada by accounting for mining output in the real Gross domestic product (GDP), Northern Ontario is by far the strongest of all. The Northwest Territories comes in the second position, followed by Newfoundland and Labrador, and Quebec. Canada's North is becoming a mining powerhouse by the abundance of natural resources. The overall northern mineral output grew remarkably during the last decade. According to The Future of Mining in Canada's North, it was forecasted that mining-based production will increase by 7.5% annually, totalling 91% until 2020 [1]. The list of large mining operations in the Canadian North is given in Table 1. Also, there are development projects as of late 2021 that may come into operation in the future

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\* Corresponding author at:  
E-mail address: [Mustafa.Kumral@mcgill.ca](mailto:Mustafa.Kumral@mcgill.ca) (M. Kumral).

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Table 1. Mines located in the Canadian North [27].

Province	Operating mine	Commodity
Nunavut	Hope Bay	Au
	Mary River	Fe
	Meadowbank	Au
	Meliadine	Au
	Amaruq	Au
Yukon	Minto	Cu, Ag, Au
	Eagle Gold	Au
Northwest Territories	Diavik	Diamond
	Ekati	Diamond
	Gahcho Kue	Diamond

Abbreviations	
MAC	Mining Association of Canada
GDP	Gross Domestic Product
FIFO	Fly-in/Fly-out
TSM	Towards Sustainable Mining

(Table 2). In addition, there are also a large number of exploration projects.

The resources in northern Canada present opportunities and challenges. The justification of a mining project is complex. Mining in the Canadian North, including the Arctic, has three particular challenges: (1) climate change [19], (2) local and indigenous community's rights [20], and (3) safety and occupational health. The mining operations must conceive these issues as an ethical responsibility as well as a technical issue. These special characteristics require different management, organization, and culture models to generate real value from the operations. The development and finance of infrastructure, social acceptance, access to skilled labor and high levels of staff turnover, weak legislative framework, extreme weather conditions, high costs of roads maintenance, transportation fees related to fly-in and fly-out schedule to remote sites, logistics, and inventory are further issues. All these challenges are closely related to health and safety. In the 20th century, mine safety became a critical aspect of successful and productive mining operations. According to the U.S. Geological Survey [30], 22% of the world's recoverable resources of oil and gas is

placed in the Arctic region. Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the United States have parts in the Arctic. The other mineral resources are not different from this figure. Canadian Centre for Occupational Health and Safety (CCOHS) identifies temperature, humidity, and wind speed as the factors affecting work in a cold environment [29]. Personal protective equipment (PPE), work and rest schedules, and physical activity are proposed as solution approaches. Cold stress is observed when the skin temperature and the internal body temperature reduces. Hypothermia, chilblains, trench foot, and frostbite are prevailing health problems. Special training programs including emergency management and supervision, monitoring, and mentoring are needed for these operations. The mining industry's efforts to deal with cold weather comply with these proposals. Taarup-Esbensen [22] highlighted growing safety issues due to increasing mining activities in the Arctic region. Focusing on four projects in Greenland, he concluded that there is a need for new business continuity models such that organizational structures can mitigate risks associated with the Arctic operations. Jaroslawska-Sobór [23] emphasized that a mining corporation's successful occupational safety management adds value. Recruiting qualified people is another challenge in the projects of the North. Nadeau et al. [28] noted that the average age of employees is higher than regular mine. Aging people are more prone to safety issues. Noble and Bronson [24] proposed the incorporation of human health concerns into environmental impact assessment (EIA) in the context of the mining activities of the Canadian North. They ascertained that social health is ignored in the EIA. Only physical health is considered for environmental compliance. This trend, to a large extent, continues. Safety, including mental and physical wellness, should be seen as a complementary part of sustainability. More importantly, it is vital to consider the Northern communities' health as well as employees' health. Gendler and Prokhorova [25] pointed out that the climate conditions of the Arctic make safety a more sensitive topic. Therefore, there would be more detailed risk assessment approaches for managing safety risks in the Arctic. Climate change is a factor

Table 2. Mining projects in the Canadian North in 2021 (adapted from [31]).

Province	Project	Commodity
Nunavut	Backriver	Au
	Qilalugaq	Diamond
	Ferguson Lake	Pd, Pl, Rh, Cu, Ni, Co
Yukon	Coffee Creek	Gold
	Wellgreen	Pl, Ni, Cu
	Kudz Ze Kayah	Zn, Ag, Cu, Au, Pb
	Casino Mine	Cu, Au, Mo, Ag
	Skukum Gold	Au
	Keno Hill	Ag
Northwest Territories	Macmillan Pass	Zn, Pb, Ag
	Nico mine	Co, Au, Bi, Cu,
	Nechalacho	Rare earth elements
	Pine Point	Pb, Zn
	Prairie	Zn, Pb, Ag

threatening mine safety [26]. If the current trends continue, the effects of climate change will be visible in the near future in the Canadian North. Permafrost, increasing precipitation, and wind speeds will be observable. These effects cause more safety issues.

The contribution of this paper lies in discerning specific safety-related issues encountered in the mining operations in the Canadian North. We also discuss the safety organizations and management procedures required to deal with these cases. The research inputs were collected through interviews with the employees working in this region and the authors' observations. Furthermore, legislative frameworks are reviewed to discuss how they can be improved to ensure better occupational health and safety results.

## 2. Material and method

This paper takes into account specific safety and occupation health issues for the Canadian mines located in remote areas where cold weather conditions rule. The research method is based on the analysis of findings from the previous literature and employee interviews. Canadian North mining companies need a lot of effort and time to maintain high standards in health and safety values within their work environment. A large amount of resources is spent on preventing mine accidents and fatalities. The highest level of safety is a must for an operation. The remoteness of mine sites is a challenge if access to health care is needed in case of high-level emergencies. Northern mining operations attempt to control and manage a wide range of hazards associated with the mine life cycle. Indeed, mine safety is strongly valorized by Northern operations to reduce or eliminate risks associated with mining activities as much as possible. Zero tolerance for accidents is a top priority. The main goal is to operate a workplace without exposing an individual to injury and psychological traumas by implementing safe work systems. Strong safety culture has a beneficial impact on a business's quality, maintainability, competence, and productivity, so adhering to the Zero Accident Vision offers a competitive advantage for an organization. Zero Accident Vision advocates that (i) accidents are avoidable, (ii) safety innovation is a central commitment, (iii) there is a strong connection between safety and organization, (iv) safety is an essential component of a corporate's vision and mission, and (v) a positive safety culture is needed. Leaders that place a high priority on safety also place a high value on their workers' well-being.

There is no doubt that workers are reassured when management prioritizes safety. Another important aspect of adhering to the Zero Accident Vision is a resilient, proactive attitude, cooperation, and commitment to the safety of all levels within the company. One of the primary concepts is learning from previous mishaps and taking remedial steps to avoid similar incidents. Risk assessment and risk management in the workplace are critical to achieving a "zero injury" environment. With the same perspective, for Northern Canadian mines to reach the goal of "zero injury", it is important to identify the special safety concerns associated with their specific environment and unique conditions. In the following paragraphs, these different safety concerns will be explored.

Specific safety and health issues associated with mining operations located in remote areas, where extreme weather conditions rule, can be itemized as below:

- Fatigue-related to long working shifts and rotating day/night shifts
- Health emergency and emergency management infrastructure
- Employment models (e.g., fly-in and fly-out) and conditions affecting the psychological well-being of employees
- High employee turnover rate and difficulty in accessing skilled employees
- Extreme climate conditions (i.e., severe snow and wind)
- Lack of training and certification requirements and standards tailored to working conditions in the North
- Mine inspection challenges
- Inadequacy of legislation and regulative frameworks that ignore the specific characteristics of these mines
- Abrupt changes due to climate change (e.g., permafrost thawing, fluvial flood, erosion of coastal areas, wildfire intensity, extreme fog, and rainfall)
- Natural disasters, dangers, and zoonosis (e.g., avalanche, tsunami, animals, etc.)
- Poor maintained roads
- Poor logistics, procurement, and inventory
- Poor IT and telecommunication infrastructure
- Low reliability and maintainability of equipment
- Long dark hours and lack of light
- Adaptation difficulty to new safety-related technologies

The following section discusses these issues.

### 2.1. Mental health and psychological well-being of mine workers

Remote mines in Northern Canada have a particular employment arrangement commonly called fly-in/fly-out (FIFO). Workers are often transported to mine sites for specific lengths of time instead of relocating employees and their families permanently into established mining towns. The typical working length is two to three weeks, and the same amount of time is then spent at home. Various studies show that FIFO employees have higher incidences of mental health problems. FIFO can increase stresses in relationships and families along with sleeping disorders and risky behaviours, such as alcohol and substance abuse. Remote mines are susceptible to a wide range of stress factors that can affect miners' mental health and well-being. According to Wismer [2], isolation from home communities results in serious social and family issues due to the lack of community life and socialization. In other words, the benefit created by mineral production is returned to society as a cost. Isolation from family and friends, aside from the inability to leave the job site, all contribute to stress that can be detrimental to a miner's mental and physical health. Stress is also an important contributor to higher workplace injuries. Occupational health and safety research in remote mines environment has shown that shorter work cycles with a more homelike environment can lead to a considerable decrease in stress among fly-in workers. Furthermore, providing a good internet connection and optimal means of communication is a big challenge for mining companies in the North. Due to the remoteness of mining sites from rural telecommunication networks, these facilities are costly, and the connection's quality is often poor. Better forms of communication such as video calls can ensure constant contact with family and friends and certainly help the cause to reduce stress. Various employee and family aid programs are also established to help with mental health issues or the psychological well-being of mining workers. These programs are essential because one of the most potent predictors of significant psychological distress in remote sites is the stress connected with the stigma attached to mental health disorders. Growing awareness of mental health issues among workers is crucial to reduce any kind of stigma and improve psychological well-being prevention in the industry.

### 2.2. Fatigue related to long working shifts and rotating day/night shifts

The mining sector faces several health and safety issues as a result of fatigue. Actually, the combination of long working hours and shift-work patterns of mining jobs leading to sleep disturbances is the leading cause of fatigue among mineworkers. Mining occupations can include a mix of labour-intensive activities with tedious and repetitive chores. According to Dembe and Erickson [3], working over 12 hours per day has been linked to a 37% increase in injury risk, while working more than 60 hours per week has been linked to a 23% increase. The mining industry is not the only one facing fatigue as a challenge in their day-to-day operations. However, remote sites in Northern Canada present multiple factors directly associated or not with the Nordic mining environment: darkness or low light; poor visual acuity because of underground mine environment or weather conditions; cold temperature; excessive redundant sounds; extremely repetitive, continuous, and tedious jobs; long travel time; rotation between day and night shifts; early morning awakenings and lousy sleeping habits [4]. The combination of these factors can make mineworkers more vulnerable to sleep disturbances and exhaustion than workers in other sectors or industries since these conditions are not always present simultaneously. FIFO arrangements also present the risk of fatigue and sleep deprivation. For example, workers who arrive on-site and are scheduled to work on night shifts must start work on the same day. They have little time to adjust their sleep schedule and rest from travelling, considering that many workers drive for a considerable number of hours to get to the airport before their flight to the mine site. Different alternations between day and night shifts can occur during the same rotation for different reasons such as lack of skilled workers, vacations, absenteeism, etc. Adjusting sleeping time according to the change in schedule is not easy and may take several days. Adjustment time is not always possible in FIFO arrangements since there is technically a limited number of days off when workers are on site. In fact, workers are allowed to have a specified number of days off per year, commonly called "pyjama days", to adjust their sleep or to rest on site. Mineworkers often report the amount of "pyjama days" as insufficient. Furthermore, when comparing reaction times between day and night workers, night workers face substantively slower reaction

times near the end of the shift [5]. That said, fatigue is slightly more present among night workers, and the main reason is more sleep disturbances among them. Workers sleeping fewer than 6 h per night are 1.79–2.65 times more likely to get injured than comparing to workers who sleep seven to 8 h each night [6]. On average, workers with sleep disorders were 1.62 times more likely to be injured, and sleep disturbances were responsible for nearly 13% of workplace injuries [7]. The actual level of understanding for dealing with fatigue in mining is nebulous. Researchers have dealt with the complexities of fatigue in complicated job environments such as mining.

### 2.3. Impact of extreme cold weather on working conditions

Severe cold in North Canadian mines endangers human health. The human body cannot withstand intense cold, and the consequences can range from frostbite to death [8]. The lower the temperature, the more difficult it is to retain body heat. Several disruptors work together: cold air, dreaded wind, contact with cold objects or cold water, and evaporation of sweat when the work is physically demanding. Frostbite inflames the nose, ears, cheeks, hands, and feet, always the first to be affected as extremities; the skin turns red and purple. Painful blisters may be formed, or the superficial tissues can necrotize and cause more pain if exposed for an extended time period [8]. Frostbite can progress to freezing when ice crystals are formed inside the tissues, which can lead to gangrene and loss of afflicted parts. At freezing temperatures, the risk of hypothermia emerges. The principal risks of hypothermia are reduced alertness and a loss of the capacity to make reasoned decisions. Extreme cold can induce the feeling of drowsiness and sleepiness, which can be problematic during work shifts and dangerous in certain labour work [8]. Furthermore, harsh cold weather comes with snow and ice, both of which endanger the safety of mineworkers. Many accidents/incidents such as slipping on ice or vehicle skidding off the road are reported every year. Blizzards and strong winds can also jeopardize the safety of workers on the roads. To address these problems, a strong supervisory system should be founded. PPE should not cause dense sweating. Training programs should avoid using standard corporate programs. They should address the specific conditions of cold weather. The programs should include re-warming techniques, the relationship between diet

habits and wellness, frostbite and hypothermia symptoms. Also, standard performance measures should not be used in this working environment for employee performance.

### 2.4. High employee turnover rate and skills training challenges

Mining jobs are notoriously variable, making workforce recruitment and retention a challenging task. These challenges can contribute to a competitive labor market. Employers frequently find it difficult to recruit personnel back to mining after an economic crisis. Potential employees may be too pessimistic about mining job chances during a slump and quit the industry before fresh opportunities emerge. Remote mine locations face growing recruitment issues as well as a labor shortage. Furthermore, the scarcity of specialized labor, such as underground workers and mining engineers, leads to skill shortages. Due to the scarcity of diversified labor in mining, there is a restricted labor pool; as a result, mining companies may resort to recruiting unqualified applicants to fill positions during economic growth, which can raise operational expenses and impair performance [9].

Employee departures increase hiring constraints for companies attempting to replace departing employees, particularly if the departing employees have key skills, qualifications, and professional experience.

The three most common causes of employee turnover are [9]:

- Voluntary leave for personal reasons
- Involuntary turnover, such as layoffs and firing
- Retirement

Because operational professions in mining are primarily subject to physical material extraction, personnel in these occupations must be proficient in operating various types of heavy equipment or machinery. Companies are searching for problem solvers that can adapt to new technology, have technical and computer literacy abilities, and can fix equipment on the go. Employers also want someone who can communicate well and work well in groups. Managers also seek workers who are proactive, well-organized, value preventative maintenance, and can solve mechanical and electrical faults. Most businesses do not have a mechanism to quantify the turnover cost since it would need the collaboration of several departments. These departments may include Human Resources,

Administration, Operation management, and Technical Service [10]. Not only is it challenging for these disparate departments to collaborate, but the time required to gather pertinent information, evaluate it, and distribute it, the task becomes nearly impossible. It normally takes almost a year for new workers to feel sufficiently accustomed to their position and company culture. It may take them much longer to become efficient in a highly specialized technical function, as is particularly common in mining operations [10]. Strong company culture is difficult to build and much more challenging to sustain. High turnover rates can quickly damage it. Once turnover starts to influence the organizational culture, workers begin to be concerned about their employment, given that there are more tasks to be done and relatively fewer people to do them. This frequently results in an unhealthy culture of fatigued, stressed-out, dissatisfied workers who are on the point of abandoning their employment due to burnout. Some other unfavorable consequence of turnover issues is knowledge gaps. Each mine site functions differently for a variety of factors, including the mining process, geological aspects, and work culture. However, because each location is unique, the information staff gain on a daily basis is invaluable and particularly non-transferable. Whenever a worker leaves and carries their expertise with them, regardless of the context, it increases the cost of high turnover since it directly affects how someone else accomplishes their work [10].

### 2.5. Health and safety management in Canada's North mines

The sector's dedication to the highest health and safety standards, with the objective of achieving a zero-incident work environment, has resulted in increased safety. Mining businesses aggressively foster an entrenched workplace safety culture by training workers, managing risks, monitoring performance, rewarding accomplishment, sharing information, and implementing best practices. All accidents and occupational diseases may be avoided, and everyone has the right to work in a safe and healthy environment [11]. In this perspective and to help Canadian mining companies to achieve a zero-incident workplace, The Mining Association of Canada created the Safety and Health Protocol which includes five occupational health and safety management indicators. This protocol was established in the context of the Towards Sustainable Mining program, emphasizing companies' environmental and responsible mining practices and compatibility with the reporting standards [11].

These indicators are intended to verify whether facilities mining companies have put in place clear accountability for health and safety practices and performance, whether methods have been created to avoid the occurrence of accidents or incidents, whether all workers are committed to the adequate training to identify potential risks, whether performance is revealed both internally as well as externally, and whether mining companies set targets for continuous improvement in health and safety. A more detailed explanation for each of the 5 TSM Health and Safety Protocol indicators is presented as follows [11]:

1. Set explicit accountability for safety and health management and performance, as well as clear communication of safety and health obligations to workers.
2. Prevent mishaps by recognizing hazards, analyzing risks, and putting standard precautions and controls in place.
3. Employees should be trained to recognize dangers and avoid mishaps, and everyone should realize that safety and health are a collective responsibility.
4. Performance in terms of health and safety should be monitored and reported on.
5. Set goals for continuous progress toward a goal of "zero injury" with frequent evaluations of achievement against those goals.

Below is a list of organizations that have worked on safety issues, including mining-specific entities, in Canada:

- Canadian Centre for Occupational Health and Safety
- Canadian Society for Safety Engineering
- Institute for Work & Health
- Institute for Research in Occupational Health and Safety
- Northern Safety Association
- Occupational Health & Safety Research Centre
- 62 Degrees North First Aid Training
- Arctic Response
- North American Occupational Health & Safety
- Mining Association of Quebec
- Mining Association of Canada
- Ontario Mining Association
- CNESST – Commission on workplace standards, fairness, health and safety
- Workplace Safety North
- NT WorkSafe
- Workplace Safety and Prevention Services

- Provincial Ministries of Labour
- Workers' Safety and Compensation Commission
- The Workplace Safety and Insurance Board – Ontario
- Infrastructure Health & Safety Association
- Public Services Health & Safety Association
- Mining Industry Human Resources Council

Canadian mines located in the North must establish a robust safety management system to ensure there is no accident/incident within their operations. Because of the remoteness of mine sites and harsh weather conditions, an accident can be very costly and significantly impact operations. Promoting zero-injury values has become rapidly crucial to be able to operate in the North. Being far from medical aid and isolated from governmental organizations and infrastructures, Canada's north mines have a greater responsibility towards their employees compared to other mines located in the south. They must put much more effort into ensuring the constant commitment of all employees and administration to health and safety values. Limited access to resources all year long and limited availability of skilled workers in Nordic conditions makes safety an important challenge for mines of the North. They must maintain high safety performances and keep track of their risk management for constant prevention of accidents.

A robust safety management system cannot be taken lightly and is necessary to ensure continuous improvement in health and safety. A safety management system may have a clear management framework to define the system and its limits in good safety practices. The system may have a framework for leadership and accountability to define who will be responsible and accountable for the mine safety management system, a performance and planning framework to specify the organization's plans, standards, and objectives in terms of safety performance [12]. Also, an implementation framework is needed to describe how the system should work, including important documentation, records management, and license needs. An operational risk control framework is needed to establish how the mine will handle the risks observed during operation, how innovation is managed, what technique will be used to identify and document hazards, and hazard assessment [12]. A framework for communication and consultation must describe how the mine would communicate dangers and consult with workers to enhance safety. Behavioral and skill framework is needed to evaluate what safety training is

necessary, what the site's stated minimum "safe behaviors" are, and how competency is tested and evaluated [12]. An incident management program is also needed to define how the site will examine and respond to mining safety events. An emergency strategic planning is needed to define how the mine will react to a variety of potential crises and how it will prepare and plan for emergencies and; finally, an audit and assurance program is needed to define how the mine objectively validates that it has taken preventive and systematic steps to mitigate dangers [12].

### *2.6. Safety regulations for Canada's mining industry*

Unless the subject matter of the activity comes within federal control, worker health and safety generally falls under provincial jurisdiction. In Canada, each province and territory has its own workers' compensation board or commission, with the exception of the Northwest Territories and Nunavut, which have a joint workers' compensation board [13]. These boards or commissions often serve a proactive purpose by enforcing occupational health and safety rules, as well as an administrative function by overseeing insurance programs for injured employees. The provinces have legislation and regulations that expressly relate to the mining sector. The Health, Safety, and Reclamation Code for Mines in British Columbia [21], for example, applies to both exploration and production mining sites in British Columbia. The Code requires owners to adopt a health and safety program and to form a combined management workforce health and safety committee. Furthermore, the Code specifies recordkeeping requirements for injuries, deaths, and harmful events, as well as the maximum number of work hours at a mining site. Owners, managers, and workers shall be subject to the health and safety regulations of the province or territory where the job is performed. While these requirements differ by province or territory, mine owners are required to ensure that applicable rules and regulations are obeyed, as well as to take all reasonable efforts to guarantee the health and safety of their personnel. Supervisors are responsible for ensuring that sufficient training is provided to staff on-site, as well as ensuring employee safety and well-being. Employees are required to notify managers of any possible hazards or risks on the job site, as well as to safeguard their own personal health and safety [13]. Except for regulations applied to territories, there are no specific safety regulations applied to Canada's North mines in each province. Health and

safety regulations for each province are applied to the whole province and are not specific to certain regions within the province. An important issue related to safety regulation in Canada is the lack of uniformity. Each province has its own legislation and regulations; some are stricter than others. This lack of uniformity is problematic for workers coming from different places across Canada and travelling for work in a different province or territory, such as in a FIFO work arrangement. The Health and safety experience or values of workers can differ according to under what specific safety regulations they are used to work. The regulatory framework has the potential to be a significant weapon in the fields of health, safety, and prevention. Each province's Occupational Health and Safety Act establishes particular occupational health and safety regulations for mine owners, employers, supervisors, and employees [13]. However, there are no specific regulations or Safety Act for mines operating in harsh weather conditions or under a FIFO arrangement. Risks associated with mines under these conditions are not fully covered and explored with the actual safety regulations. Risk assessments in remote Canadian mines have been managed by mining companies for many years now; however, there is no specific regulatory framework related to these risks that are specific to these operations. Creating a distinct Occupational Health and Safety Act for remote mines in the North of Canada can help mining companies reduce risks and improve their operations to become a safer workplace. Risks related to fatigue and psychological well-being of workers under a FIFO arrangement should also be regulated to support the mining workforce and eliminate or reduce risks of accidents, knowing that these workers under these conditions are highly skilled and rare to find.

### *2.7. Inadequacy of legislation and regulative frameworks that ignore the context of North Canadian mines*

Provincial governments are responsible for legislation regarding health and safety in mines in Canada. Each province has its own legislation. For example, in Quebec, the primary legislation is the Act Respecting Occupational Health And Safety, which covers all industries and activities. In the Act's words, the objective is to eliminate, “at the source, dangers to the health, safety, and physical and mental well-being of workers [16].” The essential chapters of this act are definitions, scope, rights and obligations, formation of health and safety committees, the establishment of representatives,

Union and employers' associations, occupational health, health programs, and the standard contract, etc. Under this act, “Regulation respecting occupational health and safety in mines” is the specific document focusing on the mining industry. It is conducted by the Ministère du Travail, de l'Emploi et de la Solidarité sociale of Quebec [16].

However, the requirements of each jurisdiction for compliance with health and safety regulations are not necessarily adequate to specific conditions associated with remote mine sites located in Canada's North with extremely difficult weather conditions. The legislation tackles mining-related health and safety problems, such as training, fire protection, explosives, mine-hoisting plants, and electrical and mechanical equipment [14]. In fact, the requirements or regulations are often too general. These regulations are meant to cover all mining activities all over the province in a “fit all” purpose framework. This lack of defined requirements or regulations for remote mining operations with distinctive challenges associated with the North is problematic. The fact that the actual regulations do not cover risks and dangers specifically related to Canada's North conditions demonstrates that there is currently an inadequacy of legislation frameworks. Here is a list of challenges or concerns that should be addressed in legislation frameworks and should not be taken lightly: harsh weather conditions, operations in permafrost, long working shifts, rotation of day and night shifts, constant travelling, remoteness of sites, and psychological well-being. These challenges, directly and indirectly, impact mining operations and the health and safety of remote mine workers. Harsh weather conditions have various effects on occupational health and safety. For example, aside from increasing the chance of accidents during extreme weather events because of poorly maintained roads or low visibility, adverse weather conditions can also impact employees' mental health, most notably in the manner of post-traumatic stress disorder [15]. Another unintended effect of quick changes in weather conditions is the increased risk of accidents caused by personnel rushing to complete their activities before a storm. Extreme weather events may also force employees in remote locations to stay on mine sites longer than intended before being substituted by other employees, extending their work hours and raising their accident risk owing to a lack of rest [15]. Furthermore, milder temperatures and melting permafrost appear to be causing considerable damage to road infrastructure and mine support systems. This damage can potentially interrupt transportation and raise the hazards in

underground mines, as well as the possibility of road accidents and drownings [15]. Melting permafrost can also present a danger of explosion associated with the release of methane in underground operations. There are no regulations about permafrost and the presence of methane in mining operations at the moment. Moreover, many workers complain about working hours or shifts that are heavily impacted by fatigue caused by travelling via plane to get on site. Many operations are expecting workers on night shifts to start working the day they arrive on site. It is important to consider that some employees must drive for multiple hours to get to the airport before flying to the remote mine site. The accumulation of fatigue from travelling can impact the workers' concentration and performance. Hence, it can have a direct impact on their health and safety at work.

### *2.8. Additional factors affecting safety and occupational health in remote mines*

The rate of accidental injuries is much higher than the rate of nationwide mean in the Canadian North [17]. Unfortunately, both mine's and the community's health services are insufficient for severe cases and emergencies. This insufficiency is not independent of the lack of skilled people in the North. Special incentives are needed from both the government and corporates to attract health service employees. Thus, health services, including preparedness, prevention, and response, can be provided. Vehicle accidents, asphyxiation, zoonosis, special diseases, more diverse natural disasters, and mental well-being needs specialized staff. Furthermore, logistics, procurement, and inventory systems disruptions create a work atmosphere prone to safety issues. Poor quality roads and not well-maintained equipment also have the potential for accidents.

There has been significant progress in safety analytics, automation, telematics, sensors, and wearables in the last two decades. These new technologies allow mining operations to harness their safety systems toward zero harm targets. For example, Aqueveque et al. [18] developed a safety system that continuously measures various variables (e.g., electrocardiogram, breathing action, body temperature, ambient temperature, and relative humidity). Wearables use non-invasive sensors to monitor workers. The system continuously generates information about heart and breath rate. Poor IT and internet connection is a challenge in installing such a system. Mining operations have a large amount of data related to inspections, audits, accidents, training, mine, and equipment

maintenance. New technologies abovementioned also enable mines to collect continuous data. Furthermore, external data, such as weather, climate change, geospatial, and labor and legislative-related, are available externally. The amalgamation of these big data provides opportunities to benefit from data analytics and machine learning approaches. Digitally connected employees in the workplace facilitate monitoring and predict safety incidents. To improve the employment atmosphere, existing safety management and monitoring systems should be continuously tracked. This process needs a strong change management organization that facilitates the adaptation of new technologies.

The inspection without notice is almost impossible for the mines in which access is provided by the corporate's transportation means. Even if mining corporates are sensitive to safety issues, external inspection is useful to avoid biases. There is a need for special items in the regulations on how these special mines are inspected.

## **3. Results and discussion**

Increasing population, the necessities of new e-mobility vehicles and renewables, and infrastructure requirements of emerging countries drive the demand for mineral resources. As a result, mining corporations expand their operations worldwide, including the Arctic, and to remote regions. In the Canadian context, remote areas are usually attached to the North. Climate change has shown its effects in the North over the years. This phenomenon is observed in growing permafrost, severe precipitation, high wind speed, and harsh fogs in this region. Specific characteristics of the Arctic, along with increasing climate change consequences, make additional and particular safety risks in mining operations arise. These risks can be classified into five groups: (i) Organization and management-related: FIFO system, training, certification, and high turnover rate, (ii) Extreme weather-related: Cold and wind, (iii) Climate change-related: Permafrost thawing, flood, intense wind speed, severe fog, and precipitation, (iv) The lack of infrastructure-related: Poor internet and logistic, and (v) The limitations of legislative framework-related: Inspection difficulties, ignoring special features of the North. The interviews showed that long working hours and mental wellness were identified as the key factors. Organization and culture are essential elements that should be considered in a safety system. The internal responsibility system is a core structure in an organization. Also, the formation of safety committees enforced by legislation is a critical aspect. The

difference between a management organization and a safety organization should be recognized. A flexible organization that reacts to changes should be established.

#### 4. Conclusions

Safety issues stemming from extreme weather conditions and location remoteness of mines add further challenges to the viability of mining projects. Mine safety is a key subject for Canadian North mines with the objective to reduce or eliminate risks associated with mining activities. This paper identifies mental and physical aspects affecting mine safety. Among others, the FIFO system, high turnover rate, fatigue related to long working shifts, and rotating day/night shifts are found as the dominant factors. The safety vision of mining corporate governs these factors. The vision can be enhanced through modernizing safety organizations and culture. A robust safety management system is also necessary to assure a continuous improvement in health and safety. This requires strengthening legislation, regulations, rules, and protocols, fitting special conditions of the North, in such a way as to assist mining businesses in lowering hazards specifically related to the difficult Nordic environment and enhancing operations to make the workplace safer. The training programs tailored to extreme weather conditions and the psychological well-being of employees should be developed by mining stakeholders. Also, these mines are more inclined to safety and health issues and accidents. Therefore, health service and emergency response systems should be stronger than regular mines. Mining operations should invest in more innovation to find safer and more environmentally friendly engineering practices. Countries with mining operations in the Arctic have different experiences, and exchanging these experiences will facilitate the development of safer operations. Finally, a safety program should also include the safety of local or indigenous communities, as well as the employees' safety.

#### Conflicts of interest

The authors declare no conflict of interest.

#### Ethical statement

The authors state that the research was conducted according to ethical standards.

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