A MINING PROJECT IS A FIELD OF RISKS: A SYSTEMATIC AND PRELIMINARY PORTRAIT OF MINING RISKS

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ABSTRACT

Due to the current economic situation and the growth in world demand, the mining industry is undergoing a period of spectacular development. The current need to increase production at mine sites coincides with the development of managerial capacities, the use of new industrial methods and equipment, and increased use of skilled workforce. Despite such developments, a number of researchers view the mining sector among the world's most uncertain and hazardous industries. Although the sector utilizes risk management tools appropriately, several large-scale mining projects have failed as a result of neglect or underestimation of hazards. Total risk management of a new project remains a goal to be attained so as to enhance reliability of decisions and make mining organizations safer and more secure.

The intent of this paper is to provide researchers and practitioners a preliminary portrait of the risks related to new mining projects. To attain this objective, the authors have primarily used results from research undertaken in the field. They completed this portrait using the results of hazard identification studies that they conducted in an open-pit mining project in Quebec. During this study, a number of data-gathering techniques were used, including documentation analysis, collaborative field observations, and interviews with managers and workers.

This work demonstrates the possibility of identifying a number of categories of known risks and uncertainties not recently taken into account in any systemic or systematic way in mining project risk management. In this paper, identified risks are categorized hierarchically to show the impact and possibility of occurrence of each for every project phase. Despite having a number of limitations, this study enables construction of a risks portrait indispensable for completing a reliable and rapid assessment of mining project hazards.

Keywords: mining industry, project life cycle, risk management, risks portrait.

1 INTRODUCTION

The mining industry is among the largest sectors of a number of countries' economies [1]. In the commercial production phase, the mining process is generally divided into two stages: mining extraction (of underground or open-cut deposits) and ore processing (in plants). In general, researchers distinguish mines based on type of material extracted: coal, metals (gold, copper, diamond, iron, etc.), and non-metals (potash, salt, asbestos, sulfur, and gypsum). Mining projects are highly complex and often require very large investments [2]. Cooperation of several investors is becoming the rule to defray costs.

The global mining industry has been through a number of periods of cyclical economic growth and decline. For example, the mining boom of the 1960s and 1970s was a feature of the economies of both North America and Australia. And, according to Ric Battelino, Deputy Governor of the Reserve Bank of Australia, the current mining boom is set to last at least 10 years in view of intense growth in demand from industries in China and India [3]. Currently, a number of banking and stock market studies support Ric Battelino's forecast and act as encouragement to invest in the mining sector. Investors are targeting ongoing project expansions as well as the launch of a number of new mines of various sizes in different countries.

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According to the Institut de la statistique du Québec, Quebec mining investments attained the record sum of $2.5 billion in 2010 [4].

Canada, Australia, South Africa, China, and several other countries have begun to encourage investors to exploit mining deposits. Several changes to specific regulations and aspects of law are being undertaken by governments to promote development of mineral resources and greater social acceptability of mining development (e.g. Bill 14 in Quebec). Currently, government incentives take several forms and begin with initiation of negotiations with local populations and infrastructure preparations in the target regions, up to and including help with or contribution to capital development of new projects. In this context, Quebec has put in place the 'Plan Nord' program, considered to be '*one of the biggest economic, social and environmental projects in our time*' devoted primarily to the mining sector [5]. According to the Quebec Government [5], this program will lead to an $80 billion in investment over 25 years and will create 20,000 jobs a year.

Despite its economic success, the mining industry is still held back by certain problems and difficulties that slow its development and damage its image. A number of projects, which have received unprecedented publicity, have been abandoned for many reasons (e.g. economic, geological, geotechnical, financial, etc.) after several years [6]. As an example, Agnico-Eagle Mines recently decided to close Goldex Mine (Val d'Or, Quebec) in full commercial production for unexpected geological stability issues. This premature closure will result in loss of $190 million for the company [7]. The mining industry is often accused of creating various environmental problems [8] and a large number of work-related accidents [9,10]. Across the world, mines are also the cause of quite a few occupational diseases [11]. A significant number of miners suffer from severely poor work conditions and some mines are embroiled in corruption [12]. In short, the mining industry still has a long way to go to eliminate its problems and cope with unknown quantities, so as to no longer be considered an uncertain and hazardous undertaking [2,13]. Rapid adaptation to changes in regulations and laws and improvement of technologies, methods, and attitudes are necessary to address risks present throughout the life cycle of a mining project [14].

A mining project is invariably threatened by a number of hazards and uncertainties of varying nature (e.g. occupational health and safety [OHS], environment, operations, regulations, politics, finance, and economy). A mining company is a socio-technical system, presenting complex interactions between humans and various technical processes. These interactions further complicate the setup of a risk management policy, especially at the level of hazard identification and assessment. The intent of this paper is to construct a preliminary portrait of mining project risks. To facilitate management of such mining risks, this paper presents an overview of potential hazards that might threaten a project. Based on in-field analysis and a number of published case studies, this portrait also encompasses information concerning possible influences between hazards, the occurrence of each during various project phases, and the consequences for the industrial activity of the company as a whole.

The paper is organized as follows: The second section presents an overview of mining project risk management and demonstrates the importance of identifying and assessing mining risks. In the same section, the authors present in detail the phases of a mining project. The third section explains the methodology used to attain the study's goals. The fourth section shows how a risks portrait is constructed for a mining project. In this section, the authors also track influence relations between the different risk categories and their occurrence during each mining project phase. The fifth section discusses results, limitations of the research, and recommendations for future development. Finally, section six comprises the paper's conclusion.

2 THE CURRENT SITUATION

2.1 A mining project is a field of risks

The life cycle of a mining project is principally divided into four phases and is briefly explained here [15] (Fig. 1). The first phase of exploration (7–10 years) encompasses research activities surrounding the materials to be extracted. These activities are completed using quantitative and qualitative analyses of mineral reserves. This phase involves several teams and specialists, including mining engineers, geologists, metallurgists, and environmental experts. This phase also involves simultaneous participation of several organizations. The exploration phase enables confirmation of the profitability of a mining project. It also includes creation of all documentation necessary for the establishment of the business plan and the engagement of subcontracted consultants and other social actors with a view to launch the new operation. During this phase, various methods and technologies are used to complete the exploration (e.g. drilling, map-making, and geostatic simulations).

The second phase of development (between five and ten years) begins with the planning of the various phases that follow exploration and the actions needed in order to set the deposit into commercial production. During this phase, the organization begins by setting up its teams and advancing in parallel infrastructure construction and installation activities. This phase is characterized by the start of interactions between teams of subcontractors and those

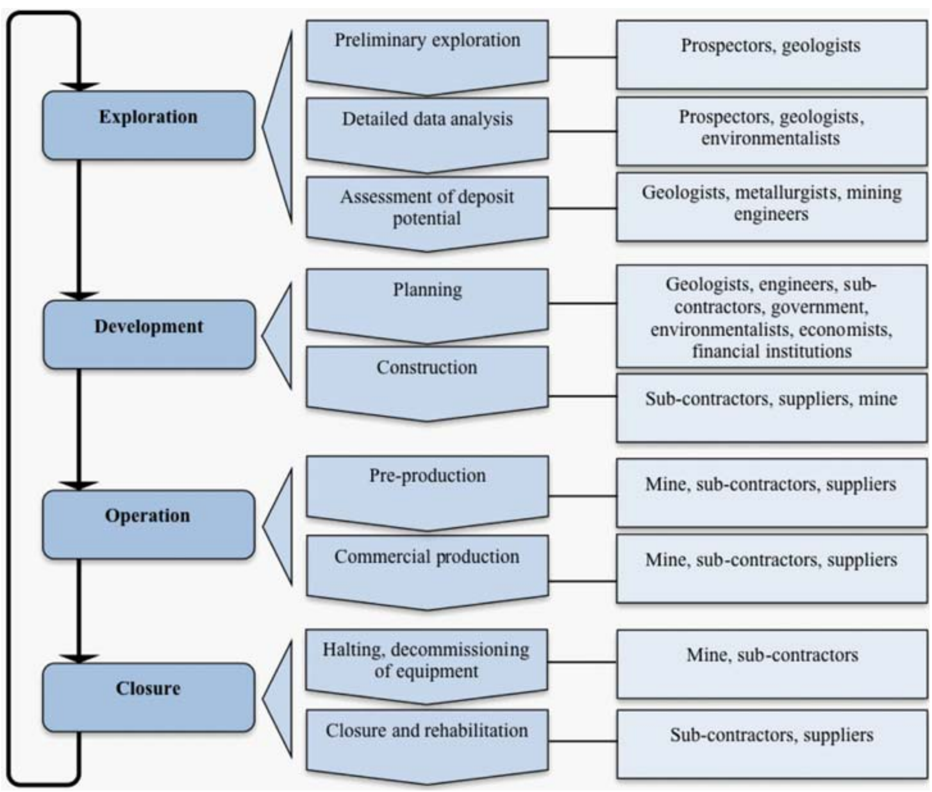

Figure 1: Life cycle of a mining project.

of the mine, the use of equipment and heavy machinery, and employment of a number of industrial disciplines all on the same site (e.g. civil engineers, mechanical engineers, electrical engineers, and geologists). This phase requires considerable investments and constitutes most of the project costs. Sometimes this phase is accompanied by preparation of urban infrastructure, such as roads, living accommodations, and services.

Once construction is complete and all installations are operational and set to standard requirements, the project moves into the third phase of operation (ranging from two to twenty years). This phase comprises primarily the commercial production stage and marks the beginning of profitability. This stage involves the mine teams taking over control of all mining operations. The operational teams, in particular those involved in production and maintenance, become the most sought-after entities. During this stage, some teams may be redirected toward other expansion activities or development of new exploration projects.

The final phase of a project is normally a long one (between two and ten years). This phase includes the dismantling stage and the reallocation of installations and equipment. The project closeout phase also includes a stage involving definitive project closure and rehabilitation of lands used and pits exploited.

As with any industrial project (petrochemical, manufacturing, nuclear, or construction), the life cycle of a mining project often contains hidden risks and uncertainties that can lead to poor decision-making [2]. The tools and means employed during all project phases contain hazard sources and uncertain factors; in short, hazards related to use of exploitation equipment (deep drilling, scraping with power shovels or explosives, etc.). Uncertainties estimating quantity or quality of mineral reserves are also present from the exploration phase on and engender poor project planning [16]. There are also risks related to the operation phase, such as the presence of various OHS hazards enumerated by both researchers and practitioners. These hazards are related to use of heavy equipment and interactions between differing energy sources [17–20]. Uncertainties of price, competition, regulation change, and financial and economic problems are also primary causes of premature closure of many mines (e.g. Lamaque Mine in Val d'Or, Quebec) [6, 21]. Briefly put, several types of risks exist, and these change in frequency and severity depending on the project phase in question. Management of these risks depends on several factors, including issues of responsibility, culture of prevention, and companies' and workers' risk tolerance levels [22].

2.2 Mining risk management

The literature is rich in work on industrial risk management in general, and for mining in particular. Researchers have backed their efforts with worrying statistics regarding work accidents and occupational sickness [23–25] and environmental, economic and social problems caused by mining [6,8]. Researchers and practitioners view the mining sector as among the world's most uncertain and dangerous industries [2,10,13]. If we consider the number of workers in the mining sector (351,000 people in Canada) and the share of GDP this industry occupies in several countries ($40 billion of GDP in Canada), we can understand the wide interest researchers and practitioners have in making projects more secure throughout their life cycle.

Despite the level of hazards and uncertainty of a mining project, and contrary to a number of other industrial sectors (e.g. construction and petrochemicals), the literature is not unanimous on the subject of risk management processes that mining enterprises should put in place. According to Chinbat and Takakuwa [2], there exist a limited number of studies focusing on management of all risks related to a mining project. This small number of studies is sometimes explained by a paucity of reliable and precise data and a lack of expertise enabling adequate identification and assessment of all risks present [26]. It is important to note that risk management is predominantly relevant to the mining construction stage [2]. Today, research on risk management goes beyond traditional parameters (i.e. the construction stage) to include other specific problem areas (e.g. ergonomic features of workstations, estimation of mineral reserves, use of equipment, working methods and conditions, and rehabilitation of closed mines).

Management of a mining project is multidisciplinary and complex [2]. Mine risk management requires significant efforts to identify various hazards or uncertainties [27]. Risk identification is no simple matter because of the presence in dynamic environments of a number of constraints of various characters. Of these constraints, we might list: (1) interactions and integration of teams with different cultures and perspectives in the same organization, and communication problems between companies involved in the same project, (2) disparity between regulations, laws, and requirements concerning risk from one country to another, (3) workforce retention and team renewal problems during a mining project's progress, leading to loss of knowledge capital and expertise necessary to facilitate risk identification, assessment, and control of a project. To address such constraints, appropriate methods and approaches need to be implemented [27]. These approaches must be adapted to mine type (underground or open-pit), to the type of material being extracted (coal, metals, non-metals), and to the country's regulations and laws. Mining risk management requires, above all, new systemic and systematic approaches that are able to continually resolve problems encountered [28, 29]. Systematic risk management permits implementation of a proactive prevention strategy [28].

According to Evans and Brereton [30], a mining project's risk assessment process must take ongoing account of social, cultural, OHS, environmental, and economical risks. This assessment is the task of a work team made up of operational personnel, with communication being an important means of ensuring high reliability of the risk management process [30]. Chinbat and Takakuwa [2] have attempted to identify causes of failure within the Mongolian mining industry. These researchers grouped risks together as a function of their consequences for a project (delays, loss of operating permits, and cost overruns). Chinbat and Takakuwa [2] identified risks related to financial difficulties, project management problems, bureaucracy, technical problems (dysfunctions and breakdowns), resource estimation errors (human and material), logistical constraints, occupational accidents (during construction and operation), and underestimation of environmental problems. In the same context, Ernst and Young [31] identified potential risks within the international mining industry that may be useful in identifying a mining risks portrait. Identified risks are: allocation of capital, skills shortage, cost control, social considerations, access to infrastructure, safe energy access, access to capital, exchange rates, and prices of material extracted. Ernst and Young [31] also added other risks such as use of new technology and changes in regulations and laws.

Sabour and Wood [21] and Heuberger [16] used modeling and simulation to highlight financial risks related to uncertainties in metal prices, exchange rates, and quantity and quality of mineral reserves. Li *et al.* [32] quantified uncertainties and geological risks with the aim of ensuring accuracy of resource and mineral reserve estimates before a project begins. Other researchers have oriented their research around technical risks so as to prevent problems during mine and mining equipment design, modification of existing equipment, or maintenance operations [29, 33-35]. Some researchers have focused their work on OHS hazards, such as fires, worker fatigue, thermal stresses, air quality, and noncompliance with

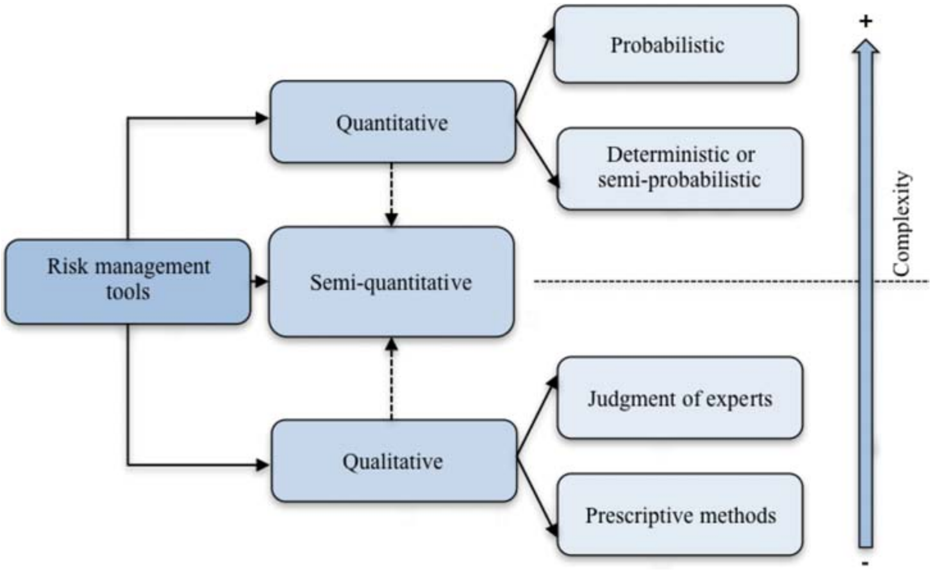

Figure 2: Classification of risk management tools. *Source*: Adapted from Rasche and Wooley [43].

safety instructions [9, 10, 36–39]. Several other studies have dealt with environmental problems (contamination, pollution, dust, noise, etc.) during mining projects' operational or closure phases [6, 8, 40, 41].

Finally, to manage different forms of risk identified, researchers and practitioners have employed methods adapted from a number of industries [16, 30]. In general, these methods use tools that are: (1) qualitative, such as HAZOP, FMECA, and FTA [1, 33], (2) quantitative, such as simulation (Arena® and Monte Carlo) and mathematical modeling [2, 21, 42], or (3) semi-quantitative, such as multicriteria analysis [34] (Fig. 2).

3 METHODOLOGY

The objective of this paper is to provide researchers and practitioners with a systemic and preliminary portrait of mining project risks. To attain this objective, the authors primarily employed results from research work conducted in the field. They completed this portrait using results of risk identification that they conducted in an open-pit mine in Quebec [44].

To review project hazards and risks comprehensively, this paper is based on consultation of research published in several scientific journals (publications referred by the databases Compendex and Inspec) and the work of several practitioners and specialists (referred by the Google search engine). A number of keywords, namely, risks, mine, underground, open-pit, project management, risk management, life cycle, financial, economic, operational, OHS, environment, political, legal, social, culture, planning, communication, organization, technical, tools, risks portrait, identification, assessment, prioritization, quantitative, qualitative were used. The research strategy combines two keywords using 'OR' or 'AND'.

The authors added to these results of hazard identification for a new open-pit mining project in Quebec the framework of an action-research project that they conducted at the end of 2010 [44]. During this action-research project, the authors used several data-gathering techniques to identify potential project hazards and risks. In the framework of this action-research project, semi-structured interviews, questionnaires, analysis of incident and accident reports, and collaborative field observations were used. The authors were present at the end of the development phase and the start of the operational phase. In short, more than 300 recorded incident and accident reports of the mining company and subcontractors involved were analyzed. The authors completed this analysis with 43 voluntary interviews and questionnaires with workers and managers (a participation rate of around 45%). They also used the results of 35 h of collaborative field observations at the operations sites, primarily at the principal pit, residue processing areas, and mechanical maintenance workshops.

4 RESULTS

4.1 Mining project risks

The methodology described above was followed to construct a mining project risks portrait. To the best of the knowledge, there is no consensus as to the choice of risk categories for mining risk management. In the present study, the authors employed and adapted primarily the risk categories of Ernst and Young [45] and Cameron and Raman [46]. When arranging these categories hierarchically, they took inspiration from the project risk breakdown structure of the PMBOK® Guide [47].

In each risk category, attempts were made to stimulate discussion using results from case studies identified in the literature and from the action-research project. In each risk category identified, the authors also listed project hazards to distinguish endogenous sources (internal and controllable by the company) from exogenous sources (external and not controllable by the company).

4.1.1 Operational risks

Operational risks are the cause of breakdowns in operations of internal processes (methods and work procedures), systems (technical, management, and organizational), and persons (within the organization or externally in interaction with the organization) [48]. According to Zhang *et al.* [49], we can classify operational risks into several categories: safety risks, planning risks, engineering risks, production risks, and technological risks. We might also add social risks related to the organization's functioning (socio-technical system) [30]. We can group together engineering risks (design, mechanical sizing, data analysis, assessment of quantity and quality of reserves, reliability and availability of equipment, etc.) and technological risks (new equipment, selection criteria for equipment, communication networks, etc.) into a single category analyzed as technical risks. Zhang *et al.* [49] classify risks of injury and mortality related to equipment hazards and energy-source use, in the category of safety risks, as operational risks. It is important to note that Zhang *et al.* [49] do not distinguish work accidents as OHS risks. In their cases, injury and mortality can lead to negative consequences for the organization's functioning. Problems of subcontracting and of partnership among several companies can also add to operational risks. The use of subcontracting constitutes a significant risk for safety of installations and the health of workers [50].

Among operational risks, the authors underscore problems related to design parameters and to mine operating conditions which cause, in general (partial or total), interruption of activities. For example, Lind [51] identifies technical risks related to pillar design (mechanical performance) of underground galleries and to work conditions (constrained work area, presence of water and gas, etc.) in coal mines. Najafi *et al.* [52] also deal with pillar design risks and use results of a probabilistic stability analysis as a decision aid for choice of their dimensions.

A number of researchers have studied risks from mining equipment inventory shortages [33, 53]. Such shortages are sometimes unavoidable and affect performance and progression of project activities [53]. Preventing risk of stoppages caused by critical spare parts inventory shortages becomes paramount. This risk may seem self-evident, but it presents difficulties related to a number of technical and economical parameters, such as choice and reliability of equipment, conditions of use (temperature, humidity, work methods, worker training, etc.), supply times, and parts quality [33].

Steering and management of processes (e.g. procedures for ore extraction and processing), teams (organization, skills, etc.), and operations [2] also present operational risks. These problems can lead to poor estimates of the need for resources and management cost overruns. Management problems can also influence the company's work climate. According to Radosavljevic *et al.* [29], technical risk management contributes to the reliability of functioning of mining processes and, as a consequence, bolsters project performance.

Availability of a qualified workforce is a non-negligible constituent in view of its importance and critical nature. Everywhere in the world, the mining sector suffers from a shortage of skilled labor [31]. The situation is becoming increasingly difficult in the face of the number of competitors locally and internationally. The worker recruitment and retention challenge is becoming a project risk to be reckoned with [31, 54, 55].

4.1.2 Financial and economic risks

According to Nelsen *et al.* [56], growth of the mining sector permits creation of new jobs, reduces exodus of qualified workers, and maintains an acceptable economic level for local communities. Mine development thus has economic advantages for workers and the community. Accounting for financial and economic parameters will have a direct influence on choice of technologies and work methods in mines. Profitability requires a choice of technical solutions (equipment, processes, technologies, etc.) and indicators (efficiency, productivity, profitability, etc.) that often conceals risks and constraints of different natures. For example, focusing solely on productivity can slant choice of equipment and technologies to the detriment of other considerations, such as those of OHS. Mine mechanization has led to a number of hazards, including intoxication and respiratory impairment, fires, mechanical failure, slips or falls while accessing workstations, vibration, ergonomic problems, etc. [57].

In this category, it is important to highlight risks related to cost control and allocation of capital [31]. A project's high return on investment depends on a strategy for reducing and eliminating waste. Such a strategy limits resources allocated to a mining project in favor of cost–effectiveness improvement. Improvement of cost efficiency requires investment in training, communication, and optimization of processes sometimes difficult to pinpoint in advance. To control cost overruns, mining enterprises must continually revise their budgets, form partnerships with other companies, and favor subcontracting [31]. To estimate profitability of projects, mining project feasibility studies take into account several financial and economic parameters (price, exchange rates, budgets, etc.). Reliability of these studies depends on availability and accuracy of technical data (e.g., productivity expected, quantity and grade of mineral reserves, reliability of equipment, etc.) [16, 21, 58]. A number of researchers have proposed models for assessing risks and uncertainties related to financial, economic, and technical parameters [16, 21]. These single studies show their limitations for dealing with all facets of a mining project in view of its complexity.

Mining companies are also highly vulnerable to material extracted prices [16, 21, 42]. These prices are indexed on various exchanges and depend on global demand. These parameters render highly important dependence on (or vulnerability to) exchange rates and to market fluctuations (customers and competitors). These fluctuations are often taken into consideration in mining project feasibility studies [27]. Information on markets is uncertain and rests on aggregated data [59]. These constraints add uncertainty to mining project profitability studies. These studies are also vulnerable to availability of information on competition and corruption.

According to Ernst and Young [31], access to capital is also a significant risk to be taken into consideration by mines. This access to financing permits the companies to explore new deposits, set up new projects, and improve and renew equipments and means on a consistent basis.

4.1.3 Political and legal risks

Despite the significance of legal and political risks, the authors have identified few studies on the mining sector that deal with this sort of risk and discuss solutions. It is important to note that effective functioning of mining enterprises set up in a number of countries often have to combat political problems and difficulties of exchange between these countries.

Globalization has drawbacks that negatively affect the mining sector. Mines have operational problems in countries burdened by heavy bureaucracy, political instability, and societal insecurity [60–62]. Political instability is a determining factor when deciding to invest in mining exploitation in a number of countries. Recent political problems in North Africa and the Middle East show that developing countries present political and economic risks that limit investment flexibility and access to capital.

Mining companies must take into consideration the gaps and differences between regulations and laws framing their activities depending on the host region and country. Changes in regulations and law present risks by, sometimes, adding new measures potentially resulting in augmented exploitation costs and complicating company management. To give an example, modification of Polish water protection regulations in the 1980s led to excessive waste management and storage costs unforeseen in advance by copper producers [61]. These unavoidable cost increases can easily generate losses and can lead to ceasing of mining company activities. Another example is the bill introduced recently by the Government of Quebec entitled *Loi n° 14 sur la mise en valeur des ressources minérales dans le respect des principes du développement durable*. Once approved, this law will have significant financial consequences for mining companies, such as subsidy and tax holiday reductions.

4.1.4 Environmental risks

Several studies have dealt with environmental risks, whether during exploitation or after planned or premature closure of mines [6, 8, 40, 41]. It is important to note the preoccupation of researchers with environmental problems in operational phases (pollution of water reserves, excessive noise, mineral ore wastes, atmospheric pollution, dust, radiation, etc.) or closure phases (long-term effects of radiation, chemical products, mineral ore wastes, etc.). The negative consequences of mineral exploitation for the local community and the ecosystem make their presence known on a daily basis, even in the most regulated countries in this regard [63, 64].

The majority of work, excavating, processing, and utilizing mineral ores, creates environmental problems [65]. During the operational phase, mines use processes for ore processing that involve a number of chemical products. The newest equipment enables recuperation of the maximum amount of these products and evacuation of sterile residue. The new generation of equipment is unavailable to mines everywhere in the world, and thus, the debate remains open on the subject of chemical pollution generated by older processes.

The premature closure of several mines and abandonment of sites in deplorable condition show the negative consequences of failing to assess risks, of mining project planning problems, and of problems with laws governing mining activities [6, 8]. Generally the granting of operating licenses is done on the basis of feasibility studies, which show the profitability of a project and the measures taken by the organization to respond to governmental requirements. Granting of mining operating licenses does not preclude difficulties that may put the longevity of the company in the medium- and long-term in jeopardy. To remedy this problem, the government of Quebec has put in place a financial guarantee mechanism (70% of estimated costs of restoration work) so as to ensure restoration of abandoned sites independent of the financial situation of the mining company. This mechanism permits budget protection, beginning at company's startup, to ensure safe closure of a project's operations and avoid chaotic cessation thereof.

4.1.5 OHS risks

Recent statistics show a fall in accidents and occupational diseases in the mining sector of several developed countries like those of the United States and Canada [10, 23, 66]. This fall is generally explained by efforts deployed by the mining industry and governments aiming to keep workers safe. Despite these efforts, this improvement does not meet the expected level of legislators, workers, or researchers [23].

Researchers and practitioners have concentrated their efforts on the control of OHS risks in mines in the operational phase. Saleh and Cummings [10] analyzed the constraints that hamper prevention of explosions and proposed a protection process to improve accident prevention. The same problem area of explosions and fires is dealt with by Larry Grayson *et al.* [9] using data recorded by the Mine Safety and Health Administration (MSHA, USA) to propose a systematic strategy for attenuating these hazards. Guo and Wu [38] construct an assessment model for fire hazards and recommend adjustments to prevention objectives as a function of constraints in the field. Several other OHS hazards are underscored in connection with the use of mining equipment [67], natural phenomena [13], mining operations [1], work conditions [36], and rockfall or gallery collapse events [68]. Problems surrounding the skills shortage are also studied from an OHS point of view. Researchers have proposed a number of solutions, including setup of integration and training programs for new recruits and ongoing improvement of work conditions [17, 54].

OHS risks are the cause of several hazards of different characters. Of the hazards identified, we can underline mechanical factors (equipment, vehicles, cleaning, and maintenance), electrical factors (electrical energy sources and electrical equipment), physical environments (thermal stresses, humidity, dust, noise, and vibration), human and social factors (unsafe behavior, fatigue, and competence), and work methods (team management, work organization, planning, and execution of work) [17, 37, 39, 69–71].

It is important to note that accidents and occupational diseases in the mining sector are caused, in large part, by human error [72, 73]. Human error is difficult to detect and difficult to estimate using traditional risk assessment tools. We have identified human error related to insufficient education, training or competence, risky behavior (noncompliance with rules and instructions, harassment, conflicts, etc.), and errors of perception in hostile environments (noise, dust, heat, etc.) [73, 74]. Simpson *et al.* [73] have demonstrated the influences between human error and other factors (that are sometimes considered to be independent risk categories): man–machine interfaces, work environment, methods and procedures, skills and training, team management, safety systems management, internal organization, and safety culture. These factors influence perception and risk-taking of workers and managers.

Ultimately, numerous studies have attempted to determine OHS risks, but the list remains non-exhaustive in view of the complexity of a number of interactions and latent phenomena, such as reinforcement between hazards.

4.2 Preliminary mining risks portrait

Identification of all risks related to a mining project is no easy task. Identification and assessment of these risks suffer from a number of difficulties, such as constraints on reinforcement effects assessment and difficulty of identification of several hazards (emerging factors, unknown phenomena, etc.). For example, it is difficult to identify all risks related to mining operations [51]. According to Lind [51], this difficulty persists due to the incoherence of the definition of operational risk and the unique character of the mining operations of each company.

Table 1 summarizes mining project risks identified in a number of research works and as a function of the interviews with workers, the observations in the field and the consultation of documentation of the mining company concerned. In Table 1, the authors have detailed hazards in terms of the above fixed categories. In this paper, the authors principally use and adapt the risk categories set out by Ernst and Young [45] and Cameron and Raman [46]. They also use the PMBOK® Guide [46] as a model for hierarchical breakdown of project risk categories. Subcategories are separated hierarchically so as to facilitate any risk assessment using industrial safety systems tools (FMECA, FTA, HAZOP, etc.) or multicriteria analysis methods (AHP, MACBETH, etc.).

Throughout the study, the authors identified possible influence links between risk categories. These links are identified by starting from the hypothesis of presence of an influence between two risk categories if there exists (at least) a possible interaction between their elements: hazards, undesirable event, or consequence (Fig. 3). To give an example, communication can generate a number of risks and problems of various natures. In the case of the mine concerned, communication problems generated accidents and injuries through lack of tasks coordination between workers. Costs reduction (to avoid financial problems) can also lead to violations of safety rules and a number of work accidents [75]. Use of subcontracting as means of costs reduction can also generate OHS problems [50]. It is important to note that 73% of incidents and accidents that the authors analyzed arose principally from subcontracting activities.

Possible influence links between different mining risk subcategories are detailed in Table 2. This table shows that a risk can develop and be transformed into a hazard or a negative consequence belonging to another risk category (Fig. 3). This modeling enables us to understand potential influence links and take note of possible interactions between risks. For example, we can confirm that organizational and human behavior problems generate OHS risks, promoting occurrence of accidents and occupational diseases [76].

It is also highly pertinent to identify periods of occurrence of these risks throughout the life cycle of a mining project. Such work allows for prioritization of necessary preventive action as it relates to a project's progress. This approach allows for setup of preventive action management as a function of periods of possible occurrence for each risk subcategory. Interventionists can thus add a new variable '*period of possible occurrence*' to risk assessment procedures to better prioritize prevention measures.

Our The authors presence in the mine was undertaken during the final phase of development and the beginning phase of operation. During this period, they confirmed the occurrence of a number of mining risks and completed the portrait with published case studies

Table 1: Summary of mining project risks.

1. Operational	2. Financial and economic	3. Legal and political	4. Environmental	5. Health and safety(OHS)
1.1. Technical Engineering and design (design processes and design quality); technological; availability of data, innovation and patents, reliability and availability of equipment and systems: Modifications, improvements and obsolescence of equipment; communication. 1.2. Organization and management Methods and procedures; planning, management of resources; management of contracts; partnership; communication.	2.1. Costs control Budget adherence; planning adherence; performance adherence indicators; wastage; contracts; systems breakdown; maintenance and spare parts. 2.2. Markets Demand; competition, exchange rates; prices and inflation; exchange standards; availability of data and reliability of analyses. 2.3. Capital Access to financing; liquidity and cash flow; credit rating; availability of data and reliability of analysis.	3.1. Legal Changes in laws; new legislation; pressure; discrepancies between countries; regulatory constraints. 3.2. Political Political instability; conflicts; bureaucracy: societal insecurity; corruption; operating licenses; restrictions on external exchange; public relations and reactions.	4.1. Internal Environmental policy; competence; organization and crisis management; reliability of data analysis; work conditions; communication. 4.2. External Pollution (chemical, radiation, noise, diesel, etc.); ecological damage; Illness.	5.1. Mechanical Equipment and vehicles; elements under constraint; moving parts; maintenance; handling; explosion and fire; rock falls and collapse. 5.2. Electrical Electrical energy sources; electrical equipment. 5.3. Physical Light environment; noise environment: vibration; dusty areas; restricted environments; climatic conditions. 5.4. Human and social Behavior; competence; fatigue; Interactions; conflicts; errors (decisions, skills, perceptual); communication.

(Continued)

Table 1: *Continued*

1.3. Supply chain Partnerships; sub-contracting, purchases; inventory management; transport; contracts; communication. 1.4. Internal social Company culture; conflicts; resistance and opposition; unions; communication. 1.5. Workforce Availability; qualification; retention 1.6. Production Procedures and processes; conditions of operation; access to energy sources.	5.5. Work methods Inappropriate methods; excessive effort; planning; execution; communication. 5.6. Natural Earthquakes; floods; gas; radiation: geology.

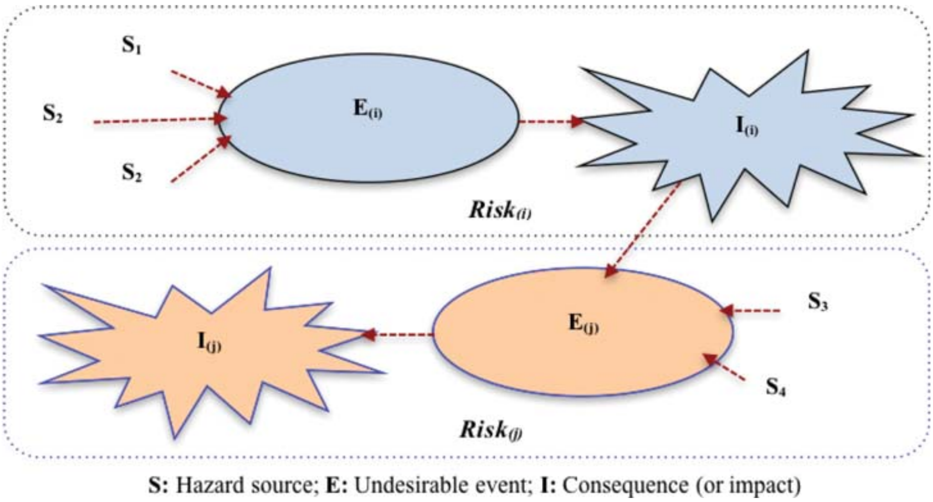

Figure 3: Possible influence between two risk categories.

[6, 8, 16, 21, 55]. Table 3 shows the possibility of occurrence of each subcategory as a function of project phases. A risk or a hazard can arise in several phases. To eliminate the risk at the source (e.g. LSST: *Loi sur la santé et la sécurité du travail*, Quebec), we must note its initial occurrence when prioritizing preventive action.

5 DISCUSSION

Management of all mining risks is not systemic and systematic, and it requires improvements so as to cover all problems that may arise throughout the project's life cycle. Researchers and experts have used a number of tools adapted from other industrial sectors to address frequently targeted problem areas during very limited time periods. Published work manages a number of risks as a function of the problem area identified and of the researcher's field of expertise. The majority of work has attempted to find solutions to problems encountered in development phases (construction stage) and operational phases of mining projects [2, 28]. This concentration of efforts on these phases is justified by the occurrence of a number of constraints and hazards related to intensive operations in the field.

Risk assessment tools require the know-how for data gathering which is difficult to accumulate. Several constraints on identification of all risks for the same project are taken into account, namely: (1) constraints on time allocated for project risk management, (2) gaps in knowledge and expertise covering the majority of mining activities, (3) difficulty in compiling multidisciplinary risk management teams, (4) intensive reliance on subcontracting and organizational problems stemming from this, (5) availability and sharing problems for data covering most potential risks in the mining sector, (6) the unique character of each mining activity and difficulties in generalizing results between mines, (7) limits to identifying emerging risks and latent phenomena, and (8) difficulties in assessing reinforcement effects between hazards.

The complexity of mining projects, the variety of hazards, the internal organizational interactions, and the dependence on several external factors of large-scale influence add to mining risk management constraints, even in the presence of qualified multidisciplinary teams and resource availability. In general, risks pinpointed during mine operations are of various

Table 2: Potential influences between mining project hazards.

Subcategory	Technical	Organizational	Logistical1	Internal social	Workforce	Production	Costs	Market	Capital	Legal	Political	Internal	External	Mechanical	Electrical	Physical	Human	Methods	Natural
Technical		S	S	—	S	S	S	—	—	—	—	S	S	S	S	S	—	S	—
Organizational	—		S	S	S	S	S	—	—	—	—	S	—	S	S	—	S	S	—
Logistical	S	S		—	—	S	S	—	—	—	—	—	S	S	S	—	S	S	—
Internal social	—	S	—		S	S	S	—	—	—	—	—	—	—	—	—	S	—	—
Workforce	S	S	S	S		S	S	—	—	—	—	S	—	S	S	—	S	S	—
Production	—	—	S	S	S		S	—	—	—	—	S	S	S	S	S	S	S	—
Costs	S	S	S	S	S	S		—	—	—	—	S	S	S	S	S	S	S	—
Market	S	—	S	—	S	S	S		S	—	—	—	—	—	—	—	—	—	—
Capital	S	—	S	—	S	S	S	—		—	—	S	S	—	—	—	—	—	—
Legal	S	S	S	S	—	S	S	—	—		S	S	S	S	S	S	—	—	—
Political	—	—	S	—	—	—	S	S	S	S		—	—	—	—	—	—	—	—
Internal	S	S	S	S	S	S	S	—	—	—	—		S	S	—	S	—	—	—
External	—	—	—	S	S	S	S	—	—	—	—	S		S	—	S	S	S	—
Mechanical	—	—	S	S	S	S	S	—	—	—	—	—	—		S	S	S	S	—
Electrical	—	—	S	S	S	S	S	—	—	—	—	—	—	S		—	S	S	—
Physical	S	—	S	S	S	S	S	—	—	—	—	—	—	S	—		S	S	—
Human	—	—	S	S	S	S	S	—	—	—	—	—	—	S	S	S		S	—
Methods	S	S	S	S	S	S	S	—	—	—	—	—	—	S	S	S	—		—
Natural	S	—	S	—	S	S	S	—	—	—	—	—	S	S	S	S	S	—	

S: Potential influence between risk(i) from row(i) and risk(j) from column(j).

Table 3: Possible occurrence of risks as a function of mining project phases.

Category	Subcategory	Exploration	Development	Operation	Closure
	Phase of project				
Operational	Technical	X	X	X	X
	Organizational		X	X	X
	Logistical	X	X	X	X
	Internal social		X	X	X
	Workforce		X	X	X
	Production			X	
Financial and economic	Costs		X	X	X
	Market			X	
	Capital		X	X	X
Legal and political	Legal	X	X	X	X
	Political	X	X	X	X
Environmental	Internal			X	X
	External		X	X	X
Health and Safety (OHS)	Mechanical	X	X	X	X
	Electrical	X	X	X	X
	Physical	X	X	X	X
	Human	X	X	X	X
	Methods	X	X	X	X
	Natural	X	X	X	X

X: Possibility of occurrence.

natures and with varying consequences capable of putting the company's entire activities in danger. Financial risks, uncertainties of the price of metal, mining resource estimate risks, technical risks, health issues, operational constraints, and environmental problem areas may show the readers the complexity of identifying the risks attached to a single mining project and the size of the work required to integrate these in a proactive manner.

This paper is the first part of a research project involving mining enterprises aimed at setting up a systematic approach to mining project risk management. To the best of the knowledge, the authors have identified no research work proposing a systematic approach to management of all mining project risks that does not neglect several risk categories. This initiative shows the importance of identifying all known project risks and their possible influences to clarify to the maximum degree their mechanism of occurrence and their negative consequences for the project and the organization.

The case studies analyzed and our presence in the field allowed us to collect a number of risk categories. The authors used a number of data-gathering techniques for obtaining information and enriching the mining risks portrait. This is a preliminary risks portrait, compiled and intended to be a checklist covering all risks that a new mining project might involve. The authors have created hierarchical categories and have systematically traced potential influences so as to be able to adapt to the majority of industrial risk assessment tools used in this sector.

5.1 Limitations and future research paths

This study presents a preliminary mining project risks portrait based on collection of known risks. The risks have been grouped together in categories and subcategories that may be discussed and readjusted as a function of each researcher's or practitioner's objective and discipline. This risks portrait is limited to presenting a global framework usable by any mine. It is important to note that realities change from one mining activity to another, from one mine to another, and from one organization to another. Each mine is a unique socio-technical system that presents constraints on the generalization of results. The authors have attempted to specify risks and hazards indicating each term without providing detail to allow specialists from any discipline the possibility of calibrating constraints as a function of the particular character of their project. For example, they have indicated design risks in the technical risks category. These risks bring together constraints on mine design, equipment, etc. The study of these risks requires attention of a number of specialists (engineers, designers, ergonomists, subcontractors, etc.) who can provide detail for this category as a function of their duties, the nature of their activities, and the constraints of their organization. This risks portrait will not replace the need for a multidisciplinary and qualified risk management team.

The publications to come will give details of project risk categories proper to each of the mining companies involved in the research. Details of each risk category as a function of the particular nature of each company would be provided. The authors will address the lack of systematic approaches to mining project risk management by providing an approach adapted to the constraints of each company to this industry.

6 CONCLUSION

Mining projects are fields of risk and uncertainty. Mines are dynamic environments and mining companies are exposed to a number of risks all throughout the lifecycle of their projects. The work of researchers enables management of a number of risks as a function of problem areas identified, and of their fields of expertise. The management of all mining risks is not systemic and systematic, and it requires improvements so as to cover problems that may arise throughout a project's progression to the maximum degree.

To attain the objective of providing a preliminary mining project risks portrait, the authors principally employed results from a number of published research works. They completed this portrait with results of risk identification that they conducted in an open-pit mine in Quebec [44]. The portrait established provides evidence for several project risk categories, namely: operational, financial, economical, legal, political, environmental, and OHS risks.

The present work shows the possibility of identifying several categories of known risks and uncertainties not systematically taken into account as a whole in the management of a mining project's risk. The risks identified are hierarchically categorized, showing their influences and their occurrence in terms of a mining project's phases. This study also shows influences between various identified risks and their possible occurrence, in terms of a mining project's phases. Despite its limitations, this study permits construction of a risks portrait indispensable for completing a reliable and rapid mining project risks assessment.

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