ÉCOLE DE TECHNOLOGIE SUPÉRIEURE
UNIVERSITÉ DU QUÉBEC

THÈSE PAR ARTICLES PRÉSENTÉE À
L'ÉCOLE DE TECHNOLOGIE SUPÉRIEURE

COMME EXIGENCE PARTIELLE
À L'OBTENTION DU
DOCTORAT EN GÉNIE
Ph. D.

PAR
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POUR UNE MEILLEURE PRISE EN CHARGE DE LA SST : UNE NOUVELLE DÉMARCHE PRATIQUE DE GESTION DES RISQUES DE PROJETS MINIERS

MONTRÉAL, LE 14 JUIN 2012

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ELLE A FAIT L'OBJET D'UNE SOUTENANCE DEVANT JURY ET PUBLIC

LE 5 JUIN 2012

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AVANT-PROPOS

Nous avons privilégié le format de thèse par articles de revues intégrés dans le corps du document. Nous avons clarifié les différents liens entre les articles (publiés, acceptés ou soumis), présentés sous forme de chapitres, de manière à démontrer la continuité des travaux et garantir une fluidité dans la lecture.

Les pages préliminaires, l'introduction, les deux premiers chapitres, la conclusion générale et les recommandations sont rédigés en français. Les chapitres consacrés aux résultats sont constitués d'articles de revues scientifiques publiés en langue anglaise. Nous sommes conscients du caractère problématique de l'utilisation de deux langues dans un même document. Dans la même veine, une thèse composée de plusieurs articles entraîne une dispersion des informations. Nous considérons malgré tout que la diffusion des résultats par le biais d'articles de revues est une excellente opportunité de partager ces résultats et d'en discuter avec une grande partie de la communauté scientifique.

Ainsi, les résultats de cette recherche ont fait l'objet de plusieurs publications. Leur diffusion a principalement été réalisée par des articles de revues avec comité de lecture. Elle a également été complétée par des conférences arbitrées nationales et internationales, des affiches et un article de vulgarisation scientifique. De plus, d'autres conférences sans comité de lecture ont été tenues dans la communauté de pratique en sécurité du travail et contrôle des risques industriels.

« Se sacrifier au service de la vie équivaut à une grâce. » *Albert Einstein*

REMERCIEMENTS

La décision de poursuivre mes études doctorales est parmi les plus importantes que j'ai eu à prendre dans ma vie. Bien que ce projet soit le fruit d'un travail individuel, il a impliqué de nombreuses personnes et a demandé des sacrifices tout au long de ces années de recherche. Malgré les quelques difficultés rencontrées, ces années de thèse resteront celles d'une expérience très agréable. C'est grâce à ce projet que j'ai rencontré des personnes très aimables et autour de lui que j'ai commencé tranquillement ma vie au Québec.

Les travaux présentés dans cette thèse sont les résultats d'une recherche qui s'est déroulée au sein de l'Équipe de recherche en sécurité du travail (ÉREST) du département de génie mécanique à l'École de technologie supérieure (ÉTS).

Je tiens à remercier profondément ma directrice Sylvie Nadeau et mon codirecteur André Gbodossou de m'avoir encadré tout au long de cette recherche. Je leur suis très reconnaissant pour le temps et les efforts qu'ils ont pu me consacrer depuis notre première rencontre. C'est grâce à ces personnes, avec qui il a été agréable et fructueux de travailler, ainsi qu'à leur qualité d'encadrement que j'ai pu mener à terme mes travaux. En plus de leur accompagnement dans mes études, ils m'ont accordé une attention particulière en me fournissant des conseils pertinents qui m'ont permis de développer plusieurs compétences essentielles à la réussite de ma future carrière de chercheur.

J'adresse mes sincères remerciements aux membres du jury : M. Daniel Forgues (ÉTS), Mme Françoise Marchand (ÉTS) et M. Laurent Giraud (IRSST). Je tiens à remercier chaleureusement les professeurs Daniel Forgues et Françoise Marchand pour leur disponibilité depuis mes premiers examens doctoraux. Leurs remarques et leurs rétroactions ont été très constructives et m'ont poussé à clarifier davantage plusieurs de mes pensées. Mes remerciements vont également à M. Laurent Giraud d'avoir accepté de participer à mon jury de thèse comme examinateur externe.

Cette thèse a été appuyée financièrement par plusieurs organismes, sous forme de bourses au mérite et de subventions. Je tiens à remercier le Fonds de recherche du Québec — Nature et technologies (FRQNT), l'Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), le Fonds de la recherche en santé (FRSQ), le Fonds québécois de la recherche sur la société et la culture (FQRSC), l'ÉTS, l'UQAT, l'ÉREST et la Fondation de l'Association québécoise pour l'hygiène, la santé et la sécurité du travail (AQHSST) pour leur soutien financier.

Mes remerciements vont également aux travailleurs et aux gestionnaires des deux entreprises minières pour leur implication active tout au long de ces travaux et leur détermination appréciable à améliorer les conditions de travail. Je tiens à remercier également mes collègues, mes amis et le personnel de l'ÉTS sans exception. J'ai toujours été bien accueilli, avec le sourire, dans tous les services et les départements. J'ai beaucoup apprécié et admiré votre professionnalisme !

Je n'ai pas trouvé les mots justes pour remercier ma meilleure amie, ma collègue d'université et mon épouse Sihem qui a fait preuve d'une compréhension exceptionnelle et qui m'a aidé et encouragé à terminer mes travaux. Enfin et comme nous en avons tous les deux discuté, nous voyons la lumière au bout du tunnel !

Mes petites filles Tesnim, Hosnelmael et Ilef ont également dû sacrifier de bons moments en ma compagnie et elles ont toujours essayé de garder le calme à la maison. Je vous dirais que vous êtes le soleil de ma vie. Mes remerciements vont également à ma famille en Tunisie et en France pour leurs encouragements constants.

Enfin, je dédie ultimement ce travail à ma mère qui m'a appris à prononcer et écrire les lettres et les mots, ainsi qu'à mon père, mon enseignant au primaire, qui m'a soutenu pour que je mène à bien mes études. C'est grâce à vous que je progresse…

POUR UNE MEILLEURE PRISE EN CHARGE DE LA SST :
UNE NOUVELLE DÉMARCHE PRATIQUE DE GESTION DES RISQUES DE PROJETS MINIERS

Adel BADRI

RÉSUMÉ

Bien que l'industrie minière utilise convenablement les outils de gestion des risques, certains projets miniers d'envergure ont rencontré de nombreux problèmes dus à un manquement de prise en considération de la santé et de la sécurité du travail (SST). Malgré le degré élevé des risques et des incertitudes relié à l'exploitation d'un projet minier, il n'existe qu'un nombre limité de recherches proposant de gérer tous les risques identifiés de façon systématique. Cette insuffisance est parfois expliquée par le manque de fiabilité des données et les carences relatives à l'expertise permettant d'identifier et d'évaluer convenablement tous les risques miniers.

Dans un contexte économique en pleine effervescence, l'industrie minière doit relever plusieurs défis en lien avec le démarrage de nombreux projets. Dans un environnement très complexe et incertain, une gestion rigoureuse des risques demeure une composante indispensable pour contourner plusieurs menaces. Étant donné la complexité de ces projets, plusieurs entreprises minières cherchent continuellement à améliorer et créer des démarches intégrées de gestion des risques.

Dans cette thèse, nous proposons une nouvelle démarche par facteurs de risques pour intégrer la SST, de façon systématique et systémique, dans la gestion des risques de projets miniers. Cette démarche est appuyée sur un nouveau concept, la « concentration des sources de dangers », et sur la méthode d'analyse multicritère AHP (Analytical Hierarchy Process). Les travaux de recherche ont pour finalité la généralisation progressive de l'utilisation de cette démarche dans le secteur des mines d'or au Québec.

En plus de la démarche proposée, de ses outils et de ses nouveaux concepts, nous fournissons à la communauté scientifique et aux praticiens un portrait préliminaire des risques associés aux projets miniers. Ce portrait de risques est indispensable pour compléter une évaluation fiable et rapide des risques de projets miniers. Nous partageons également deux bases de données évolutives comportant chacune plus de 200 sources de dangers élaborées relativement à deux mines d'or (à ciel ouvert et souterraine). Ces bases de données servent comme bases de connaissances évolutives et potentiellement adaptables et transférables à d'autres entreprises, de même qu'à d'autres nouveaux projets miniers.

Les travaux de recherche ont permis à nos partenaires industriels d'identifier et de prioriser les risques potentiels afin qu'ils puissent choisir la meilleure stratégie de contrôle. Plusieurs équipes interdisciplinaires ont été impliquées dans cette recherche, favorisant ainsi un partage

du savoir-faire industriel. Enfin, cette recherche a permis une prise en considération de la SST dans toutes les activités opérationnelles des mines impliquées.

Malgré ces efforts, cette thèse présente plusieurs limites parmi lesquelles on retrouve certaines que nous envisageons de résoudre dans un avenir rapproché. En premier lieu, nous nous proposons d'utiliser la méthode Delphi en vue d'atteindre un consensus entre les experts, dans le but de valider une échelle de conversion des « concentrations des sources de dangers » en probabilités. Nous envisageons également d'explorer les possibilités d'ajout d'autres techniques de collecte de données mieux adaptées aux problématiques et risques étudiés. Seulement deux entreprises minières au Québec ont mis en œuvre la démarche de gestion des risques proposée. L'influence de la culture des organisations sur la démarche proposée reste un obstacle important quant à la généralisation des résultats de la thèse. Nous essayons de remédier à cette contrainte par une présence plus étendue dans le secteur, ainsi que par le suivi de nos partenaires industriels.

Mots-clés : gestion de projet industriel, gestion des risques, santé et sécurité du travail (SST), recherche-action, analyse multicritère (Analytical Hierarchy Process), concentration des sources de dangers, mine d'or.

TOWARDS MORE EFFECTIVE CONSIDERATION OF OCCUPATIONAL HEALTH AND SAFETY: A NEW PRACTICAL APPROACH TO RISK MANAGEMENT IN MINING PROJECTS

Adel BADRI

ABSTRACT

Although the mining industry is known for proper use of risk management tools, companies continue to encounter difficulties with the incorporation of occupational health and safety (OHS) into major mining projects. In spite of the level of risk and uncertainty associated with mining projects, little research has focused on the systematic management of all risks including OHS. This limitation has been attributed to a lack of reliable data and a shortage of expertise for proper identification and evaluation of risks.

Under economic boom conditions, the mining industry must meet several challenges associated with new project start-ups in environments marked by complexity and uncertainty. Rigorous management of risk remains indispensable for monitoring and controlling the various threats that loom over growing mining companies. Numerous companies thus seek to improve or devise integrated approaches to risk management.

In the present thesis, a new risk-factor-based systemic and systematic approach to integrating OHS into mining project risk management is proposed. This approach uses a new concept called "hazard concentration" as well as the multi-criteria analysis method known as the analytical hierarchy process. The aim of this work is to promote the utilization of this approach throughout the goldmine sector in Quebec.

In addition to the proposed approach, its tools and new concepts, we provide the scientific community and mining sector practitioners with a preliminary portrait of risk in mining projects. Such a portrait is indispensable for the timely production of complete and reliable evaluations of mining risks. We also share two adaptable databases each compiling over 200 hazards identified in the course of studies carried out in two goldmines, one open-pit and one underground. These databases constitute a body of knowledge that is potentially adaptable and transferable to other types of mining company as well as to other new mining projects.

In summary, this study enabled our industrial partners to identify and rank potential risks in order to choose the monitoring and control strategy best suited to their corporate goals. The study involved action research with inter-disciplinary teams over the duration of several phases of mining project and promoted sharing of industrial know-how. The effort allowed us to gather well-founded and consistent opinions and to benefit from a wealth of experience gained in the mining sector. Finally, our work could make a substantial contribution to the consideration of OHS in all operational activities in the mines involved in the study.

The work described in this thesis nevertheless has several limitations, a few of which we expect to address in the future. To begin with, we shall examine the use of the Delphi method as a means of reaching an expert consensus on establishing a scale for the conversion of hazard concentration to probability. We also recommend exploring the possibility of including other data gathering techniques that might be better suited to studying the challenges and risks. The proposed approach to risk management has been implemented in only two mining companies in Quebec. Its influence by organizational culture remains an impediment to the broader application of the results obtained. We hope to address this limitation through increased presence in the sector and by follow-up at the two companies that have participated so far in our studies.

Keywords: industrial project management; risk management; occupational health and safety; action research; multi-criteria analysis, analytical hierarchy process (AHP); hazard concentration; goldmine.

TABLE DES MATIÈRES

Page

LISTE DES TABLEAUX

Page

LISTE DES FIGURES

Page

LISTE DES ABRÉVIATIONS, SIGLES ET ACRONYMES

SST	Santé et sécurité du travail
ÉREST	Équipe de recherche en sécurité du travail
ÉTS	École de technologie supérieure
UQAT	Université du Québec en Abitibi-Témiscamingue
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
FRQNT	Fonds de recherche du Québec — Nature et technologies
FRSQ	Fonds de la recherche en santé
FQRSC	Fonds québécois de la recherche sur la société et la culture
AQHSST	Association québécoise pour l'hygiène, la santé et la sécurité du travail
AHP	Analytic Hierarchy Process
PMI®	Project Management Institute
IPMA®	International Project Management Association
PMBOK®	The Project Management Body of Knowledge
SEI	The Software Engineering Institute
LSST	Loi sur la santé et la sécurité du travail
OIQ	Ordre des ingénieurs du Québec
OHS	Occupational Health and Safety
INRS	Institut National de Recherche et de Sécurité (France)
ISO	International Organization for Standardization
OHSAS	Occupational Health and Safety Assessment Series
MADS	Methodology for Analysis of System Dysfunction

MOSAR	Méthode Organisée Systémique d'Analyse des risques
RAM	Risk Assessment Model
SEM	Structural equation model
CSE	Cognitive systems engineering
SPC	Safety planning and control model
PHA	Preliminary Hazard Analysis
PSW	Percentage of Safe Work Packages
QM	Quality Management
EM	Environmental Management
DMS	Drilling Management System
CPM	Critical Path Method
HSE	Health and Safety Executive (Great Britain)
MSD	Musculo-skeletal disorders
EMS	Environmental Management System
QMS	Quality Management System
TQM	Total Quality Management
FMECA	Failure Mode, Effects and Criticality Analysis
FTA	Fault Tree Analysis
ET	Event Tree
HRA	Human Reliability Analysis
HAZOP	Hazard and Operability Study
NIOSH	The National Institute for Occupational Safety and Health (USA)
ECSC	European Coal and Steel Community

MACBETH	Measuring Attractiveness by a Categorical Based Evaluation TecHnique
ELECTRE	Élimination Et Choix Traduisant la RÉalité
MAC	The Mining Association of Canada
QMA	Quebec Mining Association
QMEA	The Quebec Mineral Exploration Association
HRSDC	Human Resources and Skills Development Canada
GDP	Gross domestic product
IIR	Injury Incidence Rate
CSST	Commission de la santé et de la sécurité du travail (Québec)
CI	Consistency Index (AHP)
EAWS	European Assembly Worksheet (ergonomics)
OWAS	The Ovako Working posture Analysis System (ergonomics)
ETE	Estimate-Talk-Estimate method
MSHA	Mine Safety and Health Administration (USA)
MRNF	Ministère des Ressources Naturelles et de la Faunes
CSMOM	Comité sectoriel de main d'œuvre de l'industrie des mines
BM	Binary Matrices
CBA	Cost Benefit Analysis
FMEA	Fault Modes and Effects Analysis
HEA	Human error Analysis
MORT	Management Oversight and Risk Tree Analysis
SSM	Soft Systems Methodology
CTA	Causal Tree Analysis

INTRODUCTION

La santé et la sécurité du travail (SST) gagnent de plus en plus de terrain dans la gestion des risques de projets industriels. Plusieurs facteurs permettent de poser ce constat dont : l'évolution des législations, l'amélioration des référentiels de gestion, le développement de la culture de sécurité et l'apparition de plusieurs outils d'aide à la décision (Gambatese, 2000b ; Gibb et al., 2006 ; Hare et al., 2006 ; Cameron et Hare, 2008 ; Fung et al., 2010). Actuellement, travailler dans des milieux sécuritaires est devenu fortement souhaitable, que ce soit pour garantir l'efficacité opérationnelle ou rester compétitif. Les entreprises industrielles commencent à considérer la SST comme étant un élément de promotion, d'attraction et de rétention de la main-d'œuvre qualifiée.

Malheureusement, le niveau d'intégration de la SST diffère d'un secteur industriel à un autre (Hermanus, 2007). La façon de faire et les critères de mesure de cette intégration ne font pas consensus entre les différents secteurs. Si nous prenons l'exemple des industries pétrochimiques, minières, manufacturières, ou celle de la construction, nous remarquons des écarts significatifs dans les niveaux de cette intégration (Foster et al., 2008 ; Badri et al., 2012a). En général, ces écarts sont expliqués par plusieurs facteurs dont : le niveau des exigences présents dans les règlements et les lois, la nature des activités industrielles, la tolérance aux risques, la capacité d'investir en SST, la pression du public et la compétence des équipes de projets en matière de SST (Hallowell et Gambatese, 2009).

De nombreux travaux de recherche visant à intégrer la SST ont pu bénéficier à différents secteurs industriels. Certains chercheurs (Makin et Winder, 2008 ; Hallowell et Gambatese, 2009 ; Li et al., 2009) ont confirmé que, malgré le développement des outils et des approches et le niveau élevé de cette intégration, plusieurs de ces industries souffrent toujours de certains manquements en SST. Différentes causes sont à l'origine de ces problèmes, dont la négligence de plusieurs facteurs tels que la formation, la communication et les aspects organisationnels (Choudhry et al., 2007 ; Molenaar et al., 2009 ; Pellicer et Molenaar, 2009).

Les problèmes d'intégration de la SST dans les organisations, l'insuffisance des mesures prises pour promouvoir la SST, certains facteurs exogènes et endogènes aux entreprises et les contraintes d'identification des risques figurent parmi les causes fréquentes des accidents industriels.

En partant des secteurs industriels les plus développés en matière d'intégration de la SST, notre objectif est de profiter des approches et des techniques qui y ont démontré leur efficacité, de manière à les améliorer et les adapter au secteur minier aurifère du Québec (Badri et al., 2011a,b ; Badri et al., 2012a,b,c). Dans cette thèse, nous nous intéressons essentiellement à l'identification et l'évaluation des risques, car ces phases sont celles où l'impact sur le contrôle des dangers est le plus important (Hagigi et Sivakumar, 2009 ; Liu et Guo, 2009; Fung et al., 2010). Dans cette thèse, nous proposons une nouvelle démarche par facteurs de risques visant à intégrer la SST, de façon systématique et systémique, dans la gestion des risques de projets miniers. Cette démarche est appuyée sur un nouveau concept, la « concentration des sources de dangers », et sur la méthode d'analyse multicritère AHP (Analytical Hierarchy Process). Les travaux ont pour but de généraliser progressivement l'utilisation de cette démarche dans le secteur des mines d'or au Québec.

En plus de la démarche proposée, de ses outils et de ses nouveaux concepts, nous souhaitons fournir à la communauté scientifique et aux praticiens du secteur minier un portrait préliminaire des risques de projets miniers. Ce portrait est composé de plusieurs catégories de risques et d'incertitudes connues, qui ne sont cependant pas prises en compte de façon systématique dans la gestion des risques de projets miniers. Il s'agit d'un portrait de risques indispensable pour compléter une évaluation fiable et rapide des risques miniers. Nous partageons également deux bases de données évolutives comportant chacune plus de 200 sources de dangers élaborées relativement à deux mines d'or (à ciel ouvert et souterraine). Ces bases de données servent comme bases de connaissances évolutives et potentiellement adaptables et transférables à d'autres entreprises, de même qu'à d'autres nouveaux projets miniers.

Les travaux de recherche ont permis à nos partenaires industriels d'identifier et de prioriser les risques potentiels afin qu'ils puissent choisir la meilleure stratégie de contrôle. Cette recherche a impliqué plusieurs équipes interdisciplinaires durant différentes phases de projets miniers et elle a favorisé le partage du savoir-faire industriel. Cet effort a permis de recueillir des opinions fondées et cohérentes et de profiter d'un cumul d'expériences diverses dans le secteur minier. Enfin, cette recherche a favorisé une convergence vers la prise en considération de la SST dans toutes les activités opérationnelles des mines impliquées.

Les résultats de recherche de cette thèse ont été diffusés dans cinq articles de revues avec comité de lecture : deux articles publiés (Badri et al., 2011b et Badri et al., 2012a), un sous presse (Badri et al., 2011a), un accepté (Badri et al., 2012b) et un soumis (Badri et al., 2012c) ; huit conférences nationales et internationales et un article de vulgarisation scientifique (Badri et al., 2011c) (Appendice D). La section 2.5 (chapitre 2) présentera un résumé des articles inclus et détaillera la structure de la thèse afin de montrer et de clarifier la continuité des différents travaux. Par la suite, un bilan des travaux et des perspectives de recherche sera dressé sous forme de conclusion générale et de recommandations. Enfin, la dernière partie de la thèse, constituée d'annexes (I à VII) et d'appendices (A, B et C), sera consacrée à des informations complémentaires regroupées par thèmes.

CHAPITRE 1

PROBLÉMATIQUE ET OBJECTIFS DE LA THÈSE

Ce chapitre présente la problématique de recherche et met en perspective le projet de thèse. La formulation du problème de recherche constitue l'objectif ultime de ce chapitre. En premier lieu (section 1.1), nous cernerons les quatre éléments principaux du problème général à traiter. Ces éléments seront tracés de manière systémique et macroscopique, de façon à souligner leurs interdépendances, interactions et influences. Cette étape permettra de repérer les dimensions et les angles possibles de notre étude. En second lieu (section 1.2), nous clarifierons le contexte général de la recherche et nous décrirons les grandes lignes qui orienteront nos travaux. Par la suite (section 1.3), nous formulerons les questions de recherche et à la fin (section 1.4), nous détaillerons les objectifs de la thèse.

1.1 Identification des éléments du problème

Dans le domaine de la gestion de projets industriels, plusieurs cas montrent l'insuffisance, voire l'absence d'une intégration formelle de l'évaluation et du suivi des risques de SST (Pal et Dewan, 2009 ; Fung et al., 2010 ; Badri et al., 2012a). Cette insuffisance se manifeste par des problèmes affectant la sécurité et la fiabilité des processus industriels. Elle est expliquée généralement par une carence de connaissances de la SST par les organisations et les membres des équipes de projets (Charvolin et Duchet, 2006).

Bien que plusieurs secteurs industriels utilisent convenablement les outils de gestion des risques, plusieurs projets d'envergure ont connu des échecs à cause des problèmes d'intégration de la SST (Tableau 1.1). Malgré le degré élevé des risques et des incertitudes de plusieurs projets industriels, le nombre de recherches portant sur la gestion des risques de façon systématique reste limité (Fung et al., 2010 ; Petrone et al., 2010 ; Badri et al., 2012a). Cette limite est parfois expliquée par le manque de données fiables et certaines carences en expertise qui pourraient contribuer à trouver et à évaluer convenablement tous les risques identifiés. La complexité de plusieurs projets ajoute d’autres contraintes à la prise en considération de la SST dans la gestion des risques potentiels de projets (Badri et al., 2011a,b ; Badri et al., 2012c).

Tableau 1.1 Exemples d’accidents industriels majeurs

Date	Localisation	Accident	Victimes
2010	Copiapó, Chili	Effondrement de la mine de cuivre et d'or de San José	33 mineurs bloqués sous terre et sauvés après 69 jours
2010	Golfe du Mexique, États-Unis	Explosion de la plateforme pétrolière Deepwater Horizon	11 morts
2010	Connecticut, États-Unis	Explosion d’une centrale électrique	5 morts et 12 blessés
2001	Toulouse, France	Explosion d'un site industriel	30 morts et plus de 2 000 blessés
1986	Tchernobyl	Explosion d’une centrale nucléaire	125 000 morts et plus de 200 000 invalides
1984	Mexico, Mexique	Explosion d'une citerne de gaz de pétrole liquéfié	Plus de 500 morts et 7 000 blessés
1984	Bhopal, Inde	Fuite d'un gaz toxique	Environ 2 500 morts et 250 000 blessés
1976	Seveso, Italie	Fuite de dioxine d'une usine chimique	37 000 personnes touchées
1974	Flixborough, Grande-Bretagne	Explosion d’un site industriel	28 morts
1966	Feyzin, France	Explosion d’une raffinerie	18 morts

Afin de clarifier davantage la problématique de recherche, il faut commencer par identifier les principaux éléments du problème (Figure 1.1). Cette étape est très importante vu le caractère interdisciplinaire du projet de recherche abordé. Pour ce faire, nous utilisons une approche systémique qui nous permet de montrer quels éléments sont à prendre en considération, de même que leurs interactions et interdépendances formant toutes les facettes de la problématique à étudier.

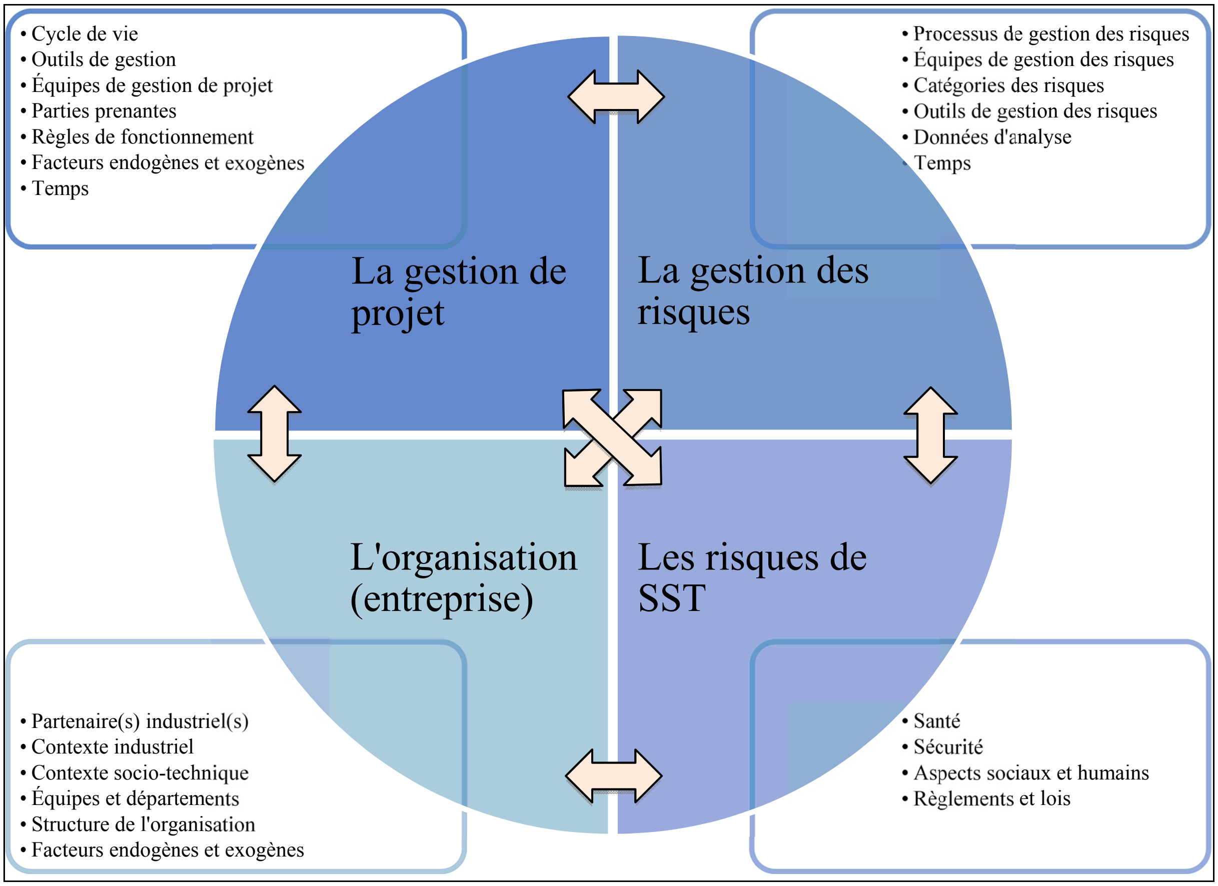

Figure 1.1 Les quatre éléments principaux de la problématique de recherche

Il est clair que la problématique d'intégration de la SST dans la gestion de projet dépend de plusieurs éléments issus de diverses disciplines (scientifique, sociologique et de gestion). Dans notre cas, il est important de souligner une influence possible entre les éléments « gestion de projet » et « SST ». Puisque nous nous occuperons de l'intégration des « risques de SST » dans la « gestion de projets industriels », il est important d'y ajouter la composante « gestion des risques » et de spécifier à quel type de « projets industriels » nous nous intéresserons. Pour ajouter plus de précisions relatives à l'étude et la formulation du problème, il est essentiel de prendre en considération la dimension « temps » pour étudier les contraintes d'intégration de la SST dans le « processus de gestion des risques de projets ». L'importance de cet aspect se manifeste par le caractère séquentiel et cyclique des approches « de gestion de projets » et des processus de « gestion des risques ». Finalement, l'intégration de la « SST » sera étudiée dans un « contexte industriel » impliquant des entreprises industrielles (ou des partenaires industriels). L'aspect « organisationnel » devient donc un autre élément à prendre en considération dans la description de la problématique étudiée.

La Figure 1.1 résume les quatre principaux éléments de la problématique d'intégration de la SST dans la gestion des risques de projets industriels. Les liens entre ces éléments décrivent les influences possibles, lesquelles représentent plusieurs contraintes quant à l'intégration de la SST. La Figure 1.1 présente, de façon systémique et macroscopique, les facettes dont nous tiendrons compte tout au long de la description de la problématique de recherche. Dans les prochaines sous-sections, nous tenterons de présenter et de clarifier ces principaux éléments afin d'énoncer les questions de recherche, déterminer les hypothèses générales de recherche, construire le cadre conceptuel et choisir les techniques de collecte et d'analyse des données.

1.1.1 La gestion de projet

Selon le Project Management Institute (PMI®) (2008a, p. 5), un projet est « *un effort temporaire exercé dans le but de créer un produit, un service ou un résultat unique. La nature temporaire des projets implique un commencement et une fin déterminés* ». La gestion de projet est une démarche permettant d'organiser et de faciliter l'exécution d'un travail complexe dans le but de fournir des livrables selon les objectifs fixés par un client. D'après Corriveau et Larose (2007, p. 20), la gestion de projet est « *une approche de gestion qui consiste à clarifier, à élaborer et à réaliser un projet dont le mandat est confié à une équipe de projet formée à cette fin et réunissant divers experts* ». Le PMI® (2008a) a défini le concept de base de la gestion du projet par l'utilisation de connaissances, de compétences, d'outils et de techniques pour organiser les activités afin de répondre aux exigences d'un projet. La gestion de projet est considérée comme un ensemble d'efforts temporaires réalisés par une ou plusieurs équipes dans le but de transformer une organisation (performance, processus, produit ou service) (Vidal et Marle, 2008).

Dans le monde, plusieurs organismes encadrent les pratiques de la gestion de projet. Ces organismes veillent à la bonne application des principes de gestion et au développement de leurs communautés de praticiens (formations et certification). Parmi les organismes les plus connus, nous pouvons citer le PMI® et l'International Project Management Association (IPMA®). L'IPMA®, fondée en 1965, est la plus ancienne association de gestion de projet. Elle est présente dans plus de 50 pays (IPMA®, 2012). Le PMI® compte plus de 600 000 membres exerçant dans plus de 185 pays (PMI®, 2012). Les membres de ces organismes représentent plusieurs secteurs à savoir l'industrie manufacturière, la défense, les services financiers, l'industrie pharmaceutique, la télécommunication, les secteurs de la santé, l'industrie minière, les services-conseils en gestion et en organisation, les services-conseils en ingénierie, l'industrie pétrochimique et celle de la construction.

Le référentiel PMBOK® Guide (PMI®, 2008a) est généralement reconnu comme le recueil des meilleures pratiques dans le domaine de la gestion de projet. Il s'agit d'un corpus de connaissances essentielles pour gérer un projet quelle que soit sa nature et son domaine (PMI®, 2008a). Les domaines de connaissances du PMBOK® Guide (PMI®, 2008a) sont regroupés en neuf chapitres : (1) la gestion de l'intégration du projet ; (2) la gestion du contenu du projet ; (3) la gestion des délais du projet ; (4) la gestion des coûts du projet ; (5) la gestion de la qualité du projet ; (6) la gestion des ressources humaines du projet ; (7) la gestion de la communication du projet ; (8) la gestion des risques du projet et (9) la gestion des approvisionnements du projet.

Le cycle de vie d'un projet est « *un ensemble de phases, habituellement en séquence et parfois en chevauchement* » (PMI®, 2008a, p. 15). Selon le PMBOK® Guide (PMI®, 2008a), il existe plusieurs types de cycles de vie de projets conformes aux méthodes de gestion du PMI®. Cette variété dépend du domaine industriel, de la technologie utilisée et parfois de l'unicité du contexte de l'organisation. La Figure 1.2 détaille le cycle de vie d'un projet-type composé de quatre phases : (1) le démarrage ; (2) l'organisation et la préparation ; (3) l'exécution des activités planifiées et (4) la clôture.

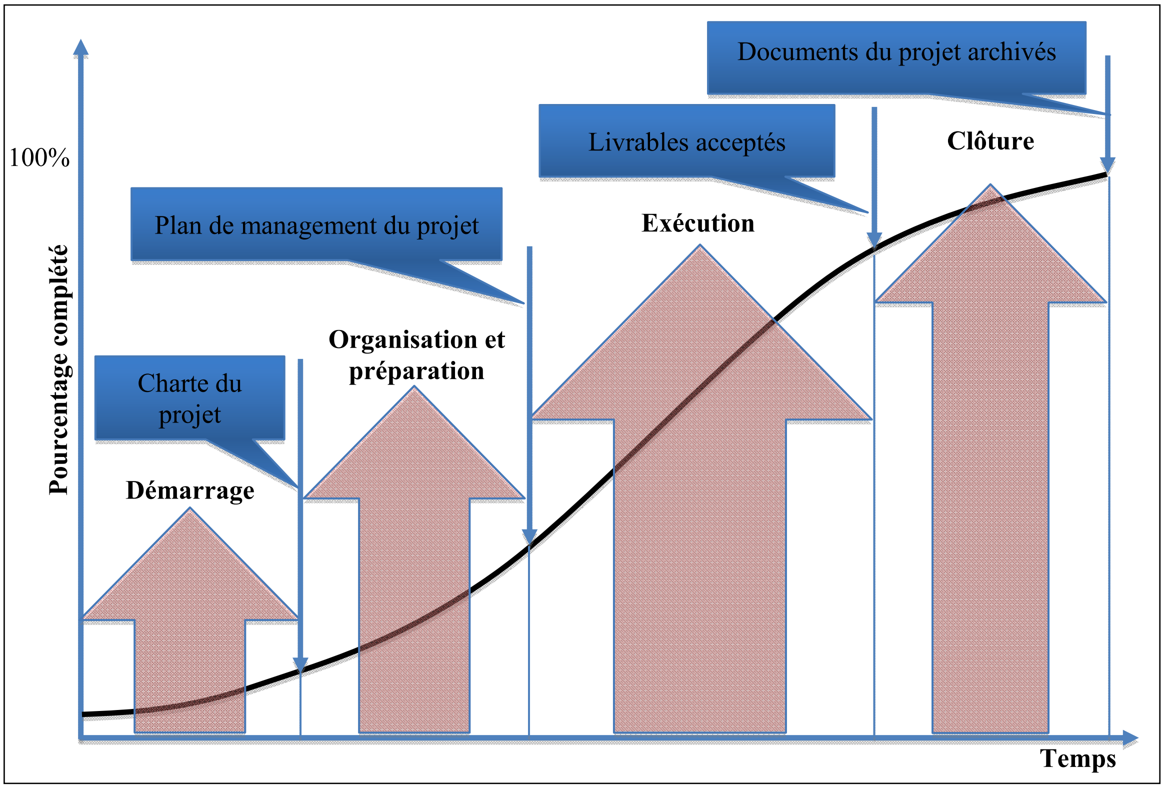

Figure 1.2 Cycle de vie d'un projet
Adaptée du PMBOK® Guide (PMI®, 2008a)

La gestion d'un projet est souvent influencée par plusieurs facteurs, endogènes (internes au projet) et exogènes (externes au projet). Ces facteurs rendent plus complexe l'atteinte des objectifs et ajoutent des contraintes à la gestion de plusieurs activités essentielles au projet (entre autres, la gestion des risques) tout au long de son cycle de vie. Parmi ces facteurs, nous soulignons (Hussain et Wearne, 2005 ; Vidal et Marle, 2008) :

- La complexité du projet (taille, durée, budget, nombre d'activités, nombre de fournisseurs ou sous-traitants, etc.).
- La variété dans le projet (diversité des équipes, expériences, compétences, localisation géographique des intervenants, méthodes et outils de gestion utilisés, etc.).
- Les interdépendances dans le projet (entre les intervenants, entre les équipes, relations, environnement organisationnel, etc.).

- Le contexte industriel (coopération, compétition, environnement du travail, lois et règlementations, culture, etc.).

La gestion de projet est également influencée par les incertitudes présentes tout au long de leur cycle de vie. En fonction des phases de projet, Atkinson et al. (1996) ont récapitulé plusieurs incertitudes dont nous évoquerons les erreurs d'estimation des ressources et la conformité des livrables (Badri et al. 2012b).

1.1.2 La gestion des risques[1]

La gestion des risques est « *l'adoption de mesures financières, technologiques et organisationnelles en vue de modifier la relation entre la turbulence dans l'environnement et la variabilité dans les résultats* » (Aubert et Bernard, 2004, p. 8). La gestion des risques est basée essentiellement sur l'analyse et l'évaluation de toutes les informations pertinentes et disponibles.

Un processus commun de gestion des risques est présenté à la Figure 1.3 selon le Software Engineering Institute (SEI) (Dorofee et al., 1996). Ce processus est généralement articulé autour de cinq phases : (1) l'identification des risques (trouver ou recenser les risques) ; (2) l'analyse des risques (évaluer les risques) ; (3) la planification (contrôler les risques) ; (4) le suivi (de la mise en place des actions décidées) et (5) le contrôle (d'efficacité des mesures prises). Il est important de noter que la communication reste un élément essentiel tout au long du processus de gestion des risques.

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[1] Tiré en partie et adapté de la publication des auteurs : Badri et al. (2011c)

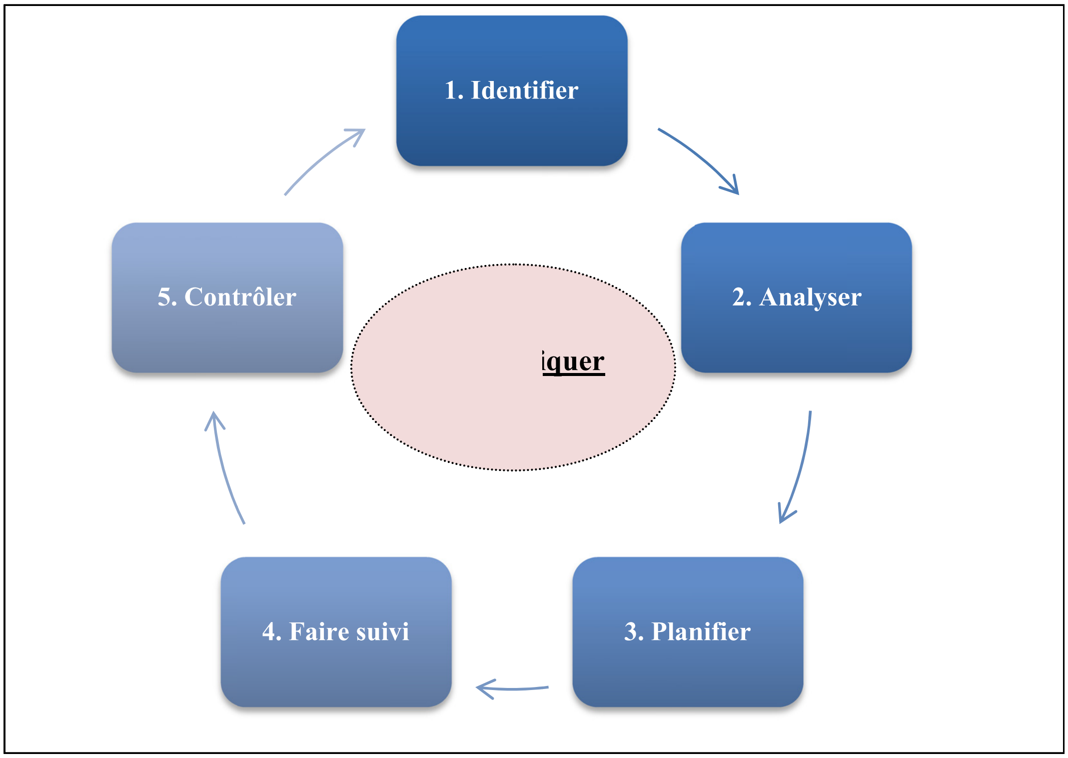

Figure 1.3 Processus de gestion des risques
Adaptée de Dorofee et al. (1996)

La gestion intégrée des risques est « *un ensemble d'activités coordonnées qui sont réalisées par une organisation de façon à identifier, mesurer, évaluer et modifier à la fois la probabilité d'occurrence de certains évènements pouvant avoir un impact sur une ou plusieurs entités, et l'impact de ces évènements sur ces entités* » (Aubert et Bernard, 2004, p. 15). La Figure 1.4 recense les facteurs de succès d'une gestion des risques de projet. Cette figure nous montre également les difficultés et les contraintes à prendre en considération lors de la mise en place d'une gestion des risques intégrée au processus de gestion d'un projet.

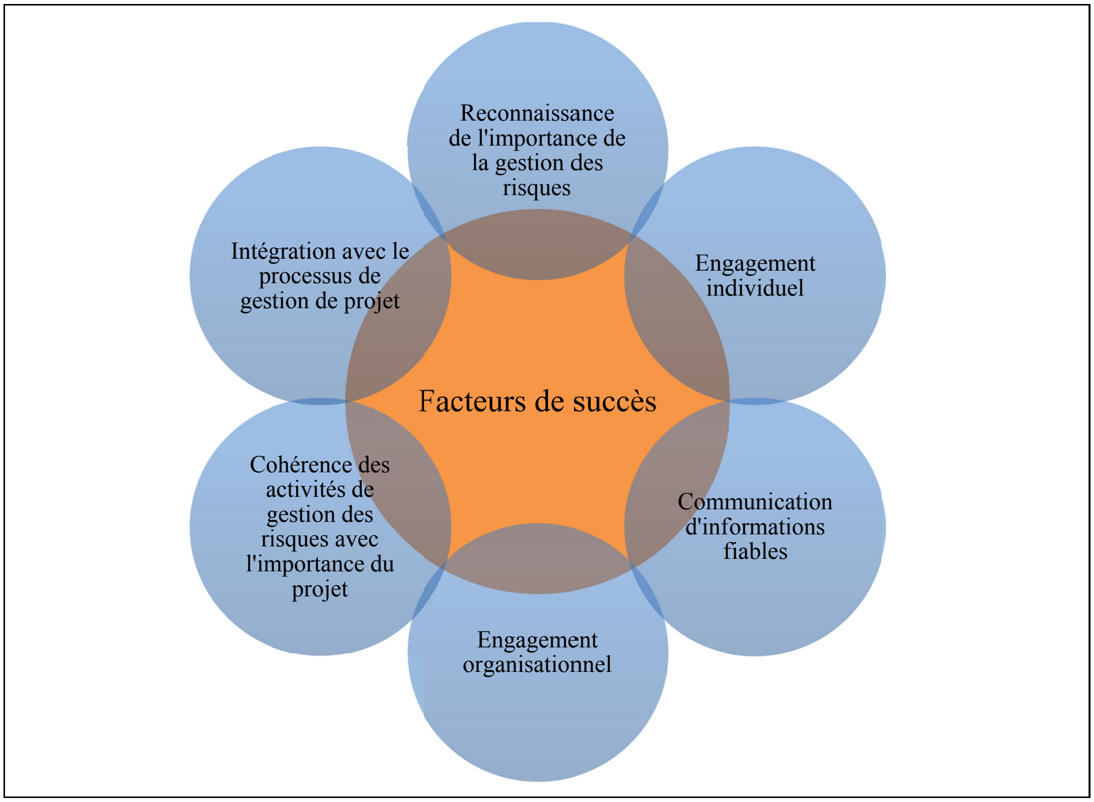

Figure 1.4 Les facteurs de succès d'une gestion des risques de projet
Inspirée de PMI® (2009)

La gestion des risques est basée sur l'évaluation et l'utilisation de toutes les informations disponibles dans l'organisation étudiée. Tout au long du processus de gestion des risques, il est nécessaire d'analyser l'ensemble de ces informations avant de prendre des décisions de correction ou de prévention. Une information réelle, bien fondée et non biaisée permettra d'éviter de prendre de mauvaises décisions et, en conséquence, de mettre la vie de l'humain en danger (Viau, 2009).

Pour engager une action préventive ou corrective, il faut identifier les sources de dangers à partir d'une analyse rigoureuse de l'information (ou des données). Cette analyse se confronte à la réalité et aux contraintes de sélection de plusieurs sources d'informations de différentes natures (financières, économiques, opérationnelles, etc.). De plus, la gestion des risques est souvent confiée à une équipe constituée de personnes de différentes spécialités et cultures (personnelle, organisationnelle, tolérance aux risques, etc.) qui doivent collaborer et atteindre des objectifs communs. Les membres de cette équipe ne possèdent pas nécessairement les mêmes expertises ni, le même vocabulaire et ont donc du mal à se comprendre (Boissières, 1999).

La gestion des projets industriels repose généralement sur des compétences purement techniques et scientifiques. Les gestionnaires de projets, les ingénieurs et les concepteurs se préoccupent des risques techniques connus (Kutsch et Hall, 2010). Ils négligent trop souvent certains risques (entre autres, la SST) à cause d'un manque de connaissances, des contraintes de délais ou encore des difficultés techniques et économiques.

Une gestion des risques est conduite par un humain qui engage des humains pour analyser les dangers provoqués par des systèmes, des processus ou des projets, impliquant eux-mêmes des humains. En ce sens, il est nécessaire d'améliorer les approches techniques utilisées dans la gestion des risques par l'introduction d'un aspect sociologique. L'aspect sociologique permet de tracer et de prendre en considération les interactions et l'influence des humains impliqués dans le processus de gestion des risques. La gestion des risques devient donc plus complexe et le recours à des équipes interdisciplinaires s'avère essentiel.

Finalement, d'autres contraintes de gestion des risques s'ajoutent comme les délais de réponse aux offres de services, la concurrence, les cycles de vie raccourcis des projets industriels et les ressources humaines et matérielles limitées. Ces contraintes obligent les équipes à simplifier à outrance les études afin de compléter, à l'intérieur des délais, les analyses de risques.

1.1.3 Les risques de SST[2]

Actuellement, la prise en compte de la SST est justifiée financièrement ; et sa négligence provoquera des ralentissements de la croissance économique (Agence européenne pour la

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[2] Tiré en partie et adapté de la publication des auteurs : Badri et al. (2011c)

sécurité et la santé au travail, 2011). Les diverses dispositions de lois (par exemple, la Loi sur la santé et la sécurité du travail [LSST], Québec, 2012) exigent la prise en considération de la SST et l'élimination, à la source, de toute forme de menace contre l'humain. Dans le monde, plusieurs mesures règlementaires ont permis l'amélioration de plusieurs référentiels de gestion de projets dans divers domaines. À titre d'exemple, citons la nouvelle intégration de la composante de SST dans la gestion des risques de projets de construction (PMI®, 2008b). Par l'application de différents codes de déontologie (par exemple, celui de l'Ordre des ingénieurs du Québec [OIQ]), les ingénieurs sont actuellement *« aux premières loges dans la lutte pour contenir et prévenir les risques. Ils ont même l'obligation éthique et légale de se préoccuper de la sécurité des installations, des procédés et des produits qu'ils conçoivent et utilisent »* (OIQ, 2004, p. 1).

Finalement, pour bien analyser les risques de SST d'un projet industriel, il est important de prendre en considération toutes les sources de dangers recensées. La nature complexe de ces risques impose l'utilisation d'outils sociologiques dans l'entreprise afin de les recenser et de les évaluer (par exemple, les observations, les entrevues et les sondages). Or, les organisations n'ont pas toujours les moyens de recruter des experts externes afin de bénéficier de leur évaluation à ce sujet. De plus, le choix et l'utilisation de ces outils présentent plusieurs contraintes et nécessitent des règles et des démarches rigoureuses parfois négligées par les praticiens.

1.1.4 L'organisation

Les objectifs à atteindre par un projet dérivent forcément de la stratégie de l'organisation. L'équipe de projet est désignée par l'organisation et reste influencée par la hiérarchie et les liens directs et indirects de ses membres avec les autres départements et services. L'organisation est donc le premier environnement qui touche directement l'univers d'un projet. D'après Corriveau et Larose (2007), il existe trois structures typiques d'organisations qui influencent la gestion de projet : la structure de type matricielle reste selon eux la plus adaptée et élimine les inconvénients des deux autres (c'est-à-dire, les structures fonctionnelle et par projets).

Plusieurs difficultés relatives à la qualité de la gestion de projet ou la gestion des risques peuvent être induites par le fait qu'une équipe de projet peut impliquer des intervenants ou des membres externes. La problématique de la sous-traitance soulignée par plusieurs chercheurs constitue un exemple de ces difficultés (Gambatese 2000b ; Badri et al., 2011b). Selon PMBOK® Guide (PMI®, 2008a), la culture organisationnelle, le style et la structure d'une entreprise influencent fortement l'atteinte des objectifs et la façon de gérer les projets.

Finalement, nous tenons à souligner que nous avons tenté de prendre en considération ces différentes facettes de la problématique de recherche dans l'élaboration du cadre conceptuel de la solution à proposer. Ces principaux éléments (Figure 1.1) feront l'objet de diverses discussions dans les prochains chapitres (chapitres 3 à 7) qui présenteront la recension des écrits et les résultats de la recherche.

1.2 Contexte général de la recherche : des précisions

Afin de mieux cerner notre sujet de recherche, nous avons procédé en premier lieu à l'identification des quatre éléments principaux du problème. Par la suite, nous avons jugé nécessaire de décrire les grandes lignes qui orienteront notre recherche, de clarifier certains termes du vocabulaire utilisé et de veiller à préciser le cadre préliminaire de ce travail. Ce cadre orientera les publications présentées aux chapitres 3 à 7. Il permettra également de préciser les définitions et certaines notions utilisées, délimitant ainsi notre travail, faisant partie d'une problématique assez complexe et diversifiée.

Nous utilisons souvent les expressions « industrie (s) » ou « industriel (s) » pour discuter de la « gestion de projet (s) industriel (s) », la « gestion des risques industriels », les « risques industriels », et les pratiques « industrielles » en matière de SST. Selon le Larousse (2011, p. 421), le terme « industrie » signifie : (1) « *l'ensemble des activités, des métiers qui* *produisent des richesses par la mise en œuvre des matières premières, par l'exploitation des mines, des sources d'énergie, etc.* » ; (2) « *Toute activité économique organisée sur une grande échelle (industrie du spectacle, industrie lourde, industrie légère, industrie automobile, industrie textile, etc.)* ». Dans le cas de notre projet de recherche, nous nous intéresserons essentiellement à l'intégration de la SST dans la gestion de projets miniers. Il est important de souligner que nous avons exploré, adapté et utilisé certaines contributions scientifiques issues de plusieurs secteurs industriels. Ces industries sont généralement issues des secteurs de la construction, pétrochimique, métallurgique, manufacturier, aérospatial, nucléaire, de l'ingénierie et de l'imprimerie.

Dans cette thèse, l'expression « phase » est réservée à la description d'une période prédéterminée dans un processus. Cette notion est souvent mentionnée lors de la description des processus de gestion de projet ou de gestion des risques. L'expression « phase » indique « *des aspects successifs d'un phénomène ou d'une action en évolution* » (Larousse, 2011, p. 603). Les « étapes » indiquent des successions de plusieurs catégories d'activités (ou de tâches) dans la même « phase » du processus étudié.

Selon PMBOK® Guide (PMI®, 2008a), les influences des parties prenantes (clients, sous-traitants, fournisseurs, utilisateurs, public, gouvernement, etc.), les risques et les incertitudes sont assez importants au début du projet. Ces influences diminuent tout au long de l'avancement du projet (Figure 1.5). « *Un projet est nécessairement flou, inorganisé et dysfonctionnel à sa naissance* » (Corriveau et Larose, 2007, p. 36). Il est donc judicieux de s'intéresser à éliminer ou à contrôler le maximum des risques et d'incertitudes dès le « début d'un projet ».

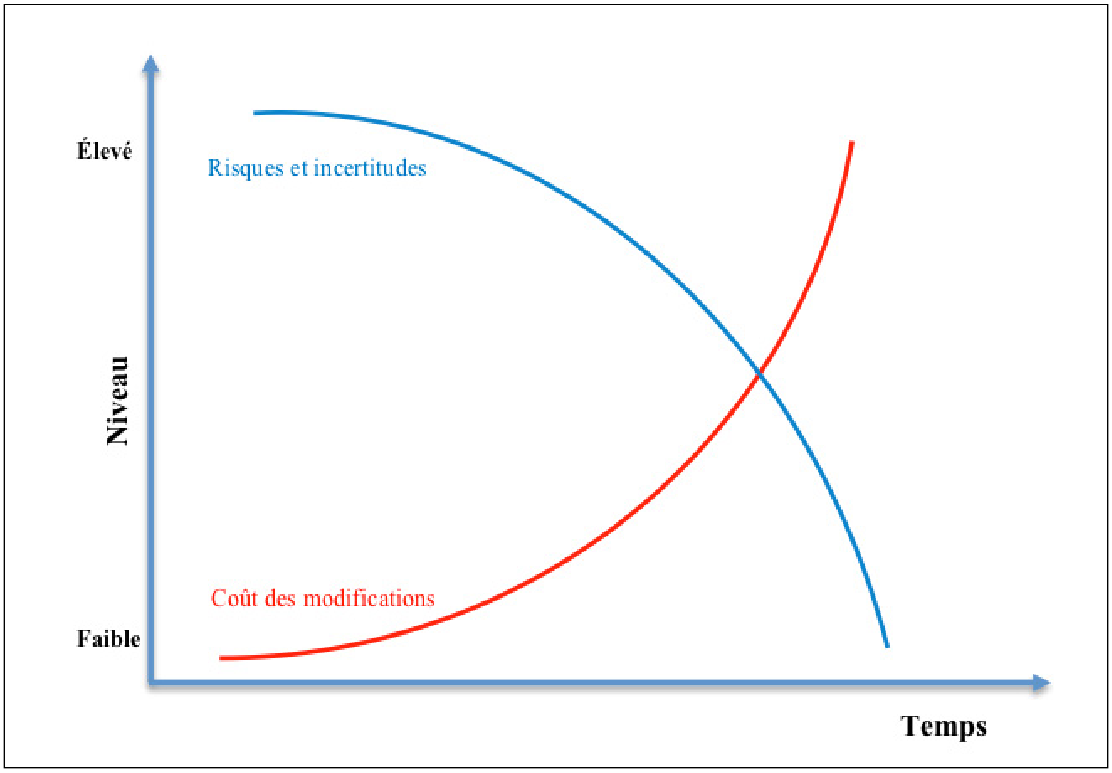

Figure 1.5 Progression des risques, incertitudes et coûts de modification
Selon le PMBOK® Guide (PMI®, 2008a)

La Figure 1.6 ajoute plus de précisions à notre discussion sur l'importance d'éliminer les risques dès le « début d'un projet ». Il devient important de définir le « début d'un projet » en fonction des phases prédéterminées d'un projet. Bien que la Figure 1.6 présente une légère différence dans la division et la désignation des phases par rapport à la Figure 1.2, elle reste intéressante étant donné qu'elle nous permet de clarifier ce que nous signifions par le terme « début de projet ». Durant la période d'évaluation (les phases de préplanification et de planification), il sera possible de réduire au maximum les coûts, les risques et les incertitudes. D'après Smith et al. (2006), une évaluation adéquate des risques durant cette période permet d'éviter des conséquences désastreuses. Nous définissons donc le « début de projet » par la période d'évaluation présentée dans la Figure 1.6. Il s'agit de l'ensemble des activités de clarification (cadre logique, études de préfaisabilité et de faisabilité et mémoire d'identification du projet) et de planification du projet.

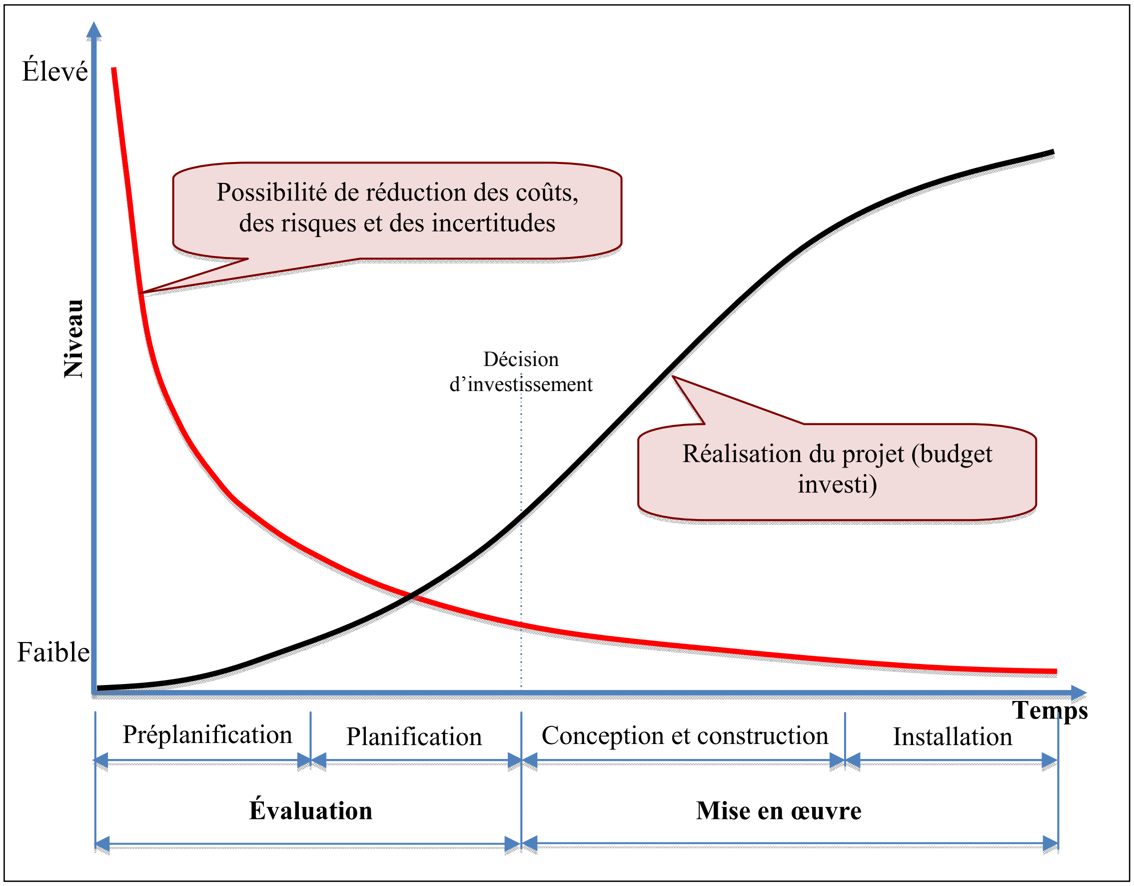

Figure 1.6 Maîtrise des facteurs de projet (coûts, risques et incertitudes)
Adaptée de Smith et al. (2006)

1.3 Questions de recherche

Dans le but de mieux orienter les travaux et à la suite de l'identification des quatre principaux éléments qui dérivent du thème central à étudier, nous énoncerons les questions de recherche. Nous devons justifier le besoin d'intégration de la SST dans la gestion de projets industriels en général et miniers, en particulier. La pertinence et l'importance d'une prise en compte de la SST découlent principalement des limites et des lacunes identifiées dans les travaux de recherche disponibles. L'identification des quatre principaux éléments du problème dans la première partie du présent chapitre est réalisée grâce à une lecture initiale et elle doit être complétée par une lecture attentive des textes bibliographiques recensés (Badri et al., 2011a,b ; Badri et al, 2012a,b,c). Les questions de recherche et la clarification des objectifs permettent de cerner les thèmes de l'étude et d'éviter de se disperser, vu l'ampleur de la problématique.

Finalement, plusieurs questions entourant le thème principal de notre recherche peuvent être énoncées :

- Comment intégrer la SST dans la gestion des risques de projets et remédier aux difficultés d'évaluer simultanément tous les risques identifiés ?
- Comment adapter et mettre à l'épreuve la nouvelle démarche de gestion des risques de projets dans le contexte d'un nouveau projet minier à ciel ouvert ?
- Est-il possible de bâtir une base de connaissances regroupant la majorité des menaces non prises en considération, de façon systématique, dans la gestion des risques de projets miniers ?
- Comment adapter, améliorer et mettre à l'épreuve la nouvelle démarche de gestion des risques de projets dans le contexte d'un projet minier souterrain ?

1.4 Objectifs de la thèse

La recherche vise ultimement à donner plus de considération à la SST dans la gestion des projets miniers. Ainsi, l'objectif principal de notre recherche est d'intégrer, d'une façon systématique et systémique, la SST dans la gestion des risques de projets miniers. Cette intégration doit se faire en minimisant les difficultés lors de l'évaluation de tous les risques potentiels identifiés (qui sont de différentes natures).

Cette intégration nécessite une adaptation et une transposition de certains outils existants (qui sont généralisables), de même qu'elle nécessite la création d'autres techniques d'évaluation des risques, techniques regroupées dans une démarche globale de gestion des risques miniers.

Il est important de souligner les trois orientations qui guideront la conceptualisation de nos idées :

- Une pensée multicritère permettant la prise en compte de l'ensemble des composantes des quatre éléments principaux de la problématique (l'approche de gestion de projet, le processus de gestion des risques, la SST et les aspects organisationnels).
- Une participation active des parties prenantes (partenaires industriels et sous-traitants) et des membres de l'équipe de projet (conception, construction, opération, SST, environnement et maintenance) : cette participation ne doit pas se limiter seulement aux gestionnaires et aux cadres techniques impliqués directement dans l'équipe de projet.
- Un cadre d'étude favorisant l'amélioration continue et compatible avec les référentiels de gestion. La convergence avec les référentiels, les lois et les règlements en vigueur est un volet important à prendre en considération.

Finalement et par l'intermédiaire de ces travaux, nous souhaitons améliorer les pratiques de gestion des risques de projets miniers par l'intégration de nouvelles composantes négligées jusqu'ici. Cet effort doit permettre de piloter les projets miniers non seulement en fonction des objectifs de coûts, d'échéancier et de fonctionnement technique, mais aussi en fonction des résultats que ces projets vont générer durant leur cycle de vie, d'un point de vue SST.

CHAPITRE 2

MÉTHODOLOGIE DE RECHERCHE

Ce chapitre présente la méthodologie de recherche adoptée et met en lumière la structure des prochains chapitres de la thèse. L'objectif ultime de ce chapitre est de montrer les étapes effectuées pour atteindre les objectifs de la thèse. Le chapitre montre les outils et la méthodologie de recherche utilisés tout au long de l'avancement des travaux. En premier lieu (section 2.1), nous détaillerons la démarche méthodologique adoptée pour la thèse. En second lieu (section 2.2), nous préciserons les dimensions de la solution à proposer pour remédier à la problématique d'intégration de la SST dans la gestion des risques de projets miniers. Par la suite, nous justifierons le choix d'une méthodologie de recherche-action (section 2.3) et nous préciserons les outils de collecte de données utilisés (section 2.4). À la fin (section 2.5), nous présenterons la structure des prochains chapitres pour clarifier le lien et la continuité des travaux présentés sous forme d'articles publiés, acceptés ou soumis à des revues scientifiques avec comité de lecture.

2.1 Démarche méthodologique de la thèse

La Figure 2.1 détaille la démarche méthodologique adoptée. Il s'agit des différentes étapes prévues pour mener notre recherche partenariale. En premier lieu, la démarche méthodologique met en évidence le cadre théorique formé par les étapes : (1) définition des questions de départ ; (2) exploration de la littérature ; (3) description de la problématique et (4) l'élaboration du modèle conceptuel. En second lieu, la démarche méthodologique nous expose le cadre pratique formé par les étapes : (5) collecte de données ; (6) analyse des données ; (7) mise en place du modèle conceptuel adapté et amélioré et (8) description des résultats et des changements. Enfin, l'étape 9 (conclusion et recommandations) permet de récapituler et d'évaluer les changements apportés par les solutions mises en place et d'ajuster le modèle conceptuel théorique pour des fins de généralisation future.

Pour situer la démarche de recherche dans son environnement, nous tenons compte des liens entre les quatre principaux éléments du problème cités au chapitre précédent. Le cadre pratique permet aux chercheurs d'évaluer le modèle conceptuel par sa mise en œuvre dans un contexte industriel précis et par l'appréciation des solutions qui y sont apportées. En contrepartie, l'entreprise impliquée profite des résultats de recherche pour améliorer des situations et éliminer des problèmes. Cette amélioration pourra influencer la culture, les pratiques de l'entreprise, de même que le comportement de ses gestionnaires et travailleurs.

Le modèle conceptuel doit comprendre un système formel et des systèmes de réflexion. Le système formel est composé d'ensembles fondamentaux (logiques et mathématiques). Dans notre cas, il s'agit d'évaluer les risques en fonction d'une probabilité d'occurrence (ou une concentration des sources de dangers) et d'un impact négatif (ou conséquence). Le système de réflexion comporte des pensées structurelles et autres comportementales. Le but est de ne pas négliger les aspects sociologiques dans la modélisation d'un concept à étudier dans un environnement sociotechnique et dynamique.

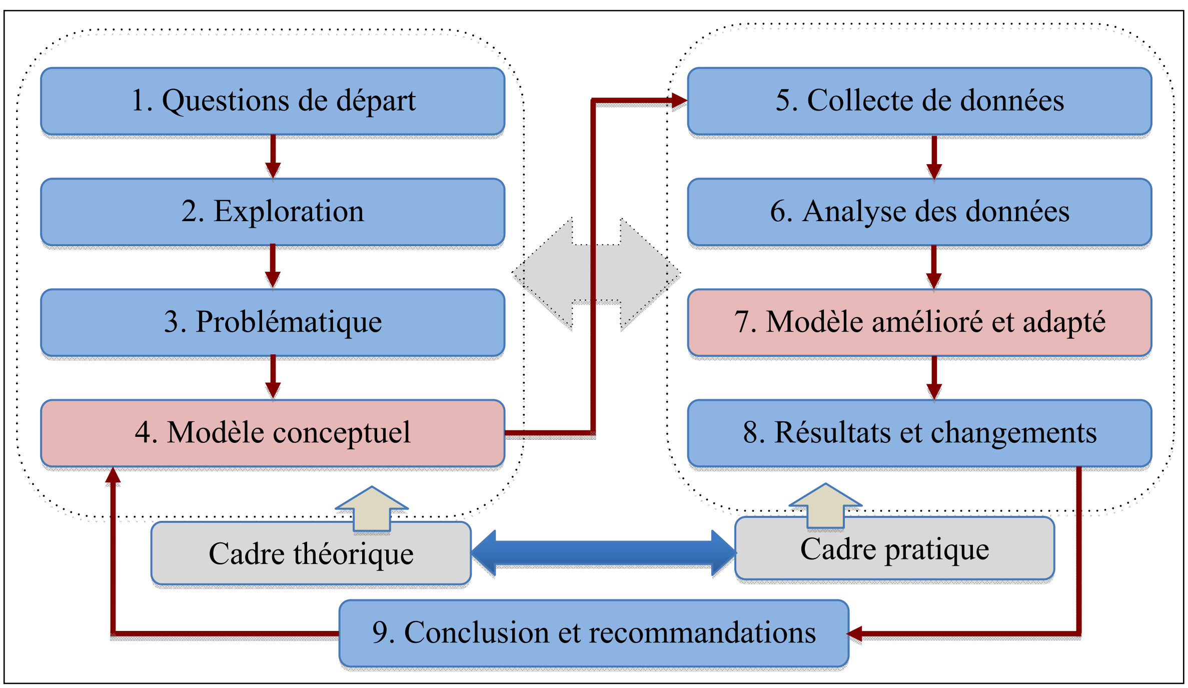

Figure 2.1 Démarche méthodologique de la thèse

2.2 De l’idée au concept : les dimensions de la solution

Notre travail se situe dans un cadre industriel précis : il s’agit de la gestion des risques de projets miniers. La recherche commence par un cadre théorique (la recension des écrits et l’élaboration du modèle conceptuel). Ce cadre théorique est basé essentiellement sur notre recension des écrits et l’exploration des pratiques de plusieurs industries structurées en matière d’intégration de la SST (entre autres, les industries de la construction et manufacturière). L’implication des partenaires industriels n’a débuté qu’après la construction du modèle conceptuel de la solution proposée. Durant la première partie de la recherche, nous tentons de comprendre l’état de l’intégration de la SST dans la gestion des risques de projets industriels pour pouvoir y proposer des améliorations. La deuxième partie de la recherche complète le cadre théorique par une compréhension du métier des partenaires industriels, de la nature de leurs activités et de leur contexte organisationnel. Il s’agit d’une proposition d’amélioration par la mise en place d’une ou plusieurs solutions adaptées en fonction de plusieurs contraintes du terrain.

Pour préciser l’étendue de la solution envisagée, nous pouvons la résumer en trois dimensions. La première dimension montre le cadre théorique qui regroupe notre recension des écrits et l’élaboration du modèle conceptuel. Ce cadre théorique repose sur des études de cas dans plusieurs industries. La deuxième dimension représente le cadre pratique d’implication des partenaires industriels. La troisième dimension regroupe les quatre éléments principaux, lesquels forment les interactions à prendre en considération dans l’étude du problème (la gestion de projet, la gestion des risques, la SST et l’organisation). La solution à proposer devra donc mettre en évidence les trois dimensions discutées ci-haut (Figure 2.2).

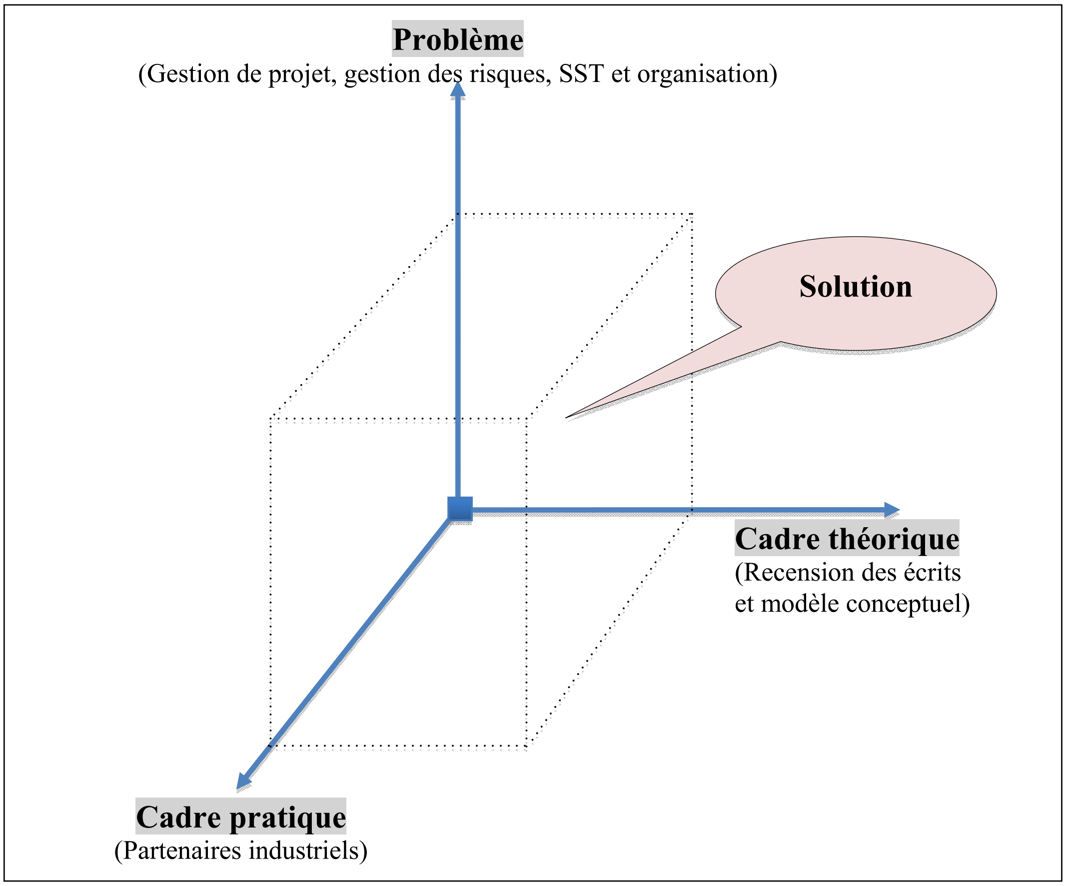

Figure 2.2 Dimensions de la solution

2.3 Du concept au terrain : une recherche-action

Le projet de recherche est conçu de façon à répondre à une problématique perçue dans un cadre théorique, mais aussi exprimée par des partenaires industriels. De plus, il nous est très rapidement apparu que notre présence sur le terrain ne serait pas sans effet sur les pratiques des entreprises impliquées. Le recours à une recherche-action a donc été discuté dès nos premières rencontres avec nos partenaires industriels.

Notre démarche converge avec la définition de la recherche-action que donne Liu (1992), lequel précise qu'elle est une démarche de recherche fondamentale qui prend naissance dans la coïncidence entre une « *volonté de changement* » et une « *intention de recherche* ». Greenwood et Levin (1998, p. 251) ont défini la recherche-action comme une démarche qui

« *vise à résoudre des problèmes de la vraie vie. La recherche-action est une recherche où les participants et les chercheurs génèrent ensemble des connaissances à travers des processus collaboratifs* ». La recherche-action permet de construire une solution en tenant compte d'un monde interactif, perçu comme un ensemble d'objets dépendants avec des relations cohérentes (Rasmussen, 2004 ; Rasmussen et Garibald, 2004).

D'après Lavoie et al. (1996), la recherche-action comporte plusieurs regroupements. Le premier regroupement (Gélinas et Brière, 1985) est basé sur deux aspects : (1) le dosage de la recherche et de l'action et (2) la nature de l'intervention. Le deuxième regroupement (Hugon et Seibel, 1988) met en lumière trois types de recherche-action qui dépendent de plusieurs facteurs dont : (1) la proximité du terrain et (2) le nombre d'acteurs impliqués. Le troisième regroupement (Desroches, 1982) distingue les recherches-actions en fonction de la participation : (1) la recherche sur l'action, mais sans action ; (2) l'acteur expose le problème et le chercheur propose des solutions et (3) l'engagement total des acteurs dans la recherche. Le quatrième regroupement (Côté-Thibault, 1991) comporte cinq types de recherche-action dont nous citerons seulement la méthodologie des systèmes souples (Soft Systems Methodology).

Afin de s'assurer du bon emploi d'une méthodologie de recherche-action, il faut satisfaire simultanément les cinq critères cités ci-après (Dubost, 1987) : (1) une recherche s'inscrivant dans un monde réel ; (2) une recherche limitée sur une échelle restreinte ; (3) une recherche visant, par l'action, à changer des groupes et des environnements selon des objectifs fixés dès le début du projet ; (4) une recherche conçue dès son engagement pour permettre d'en dégager des résultats susceptibles de généralisation et (5) une recherche qui emprunte certains outils d'autres disciplines (règles, référentiels, outils de collecte de données, etc.).

Nous pouvons placer la recherche-action adoptée, dans notre thèse, au croisement des regroupements de Desroches (1982) et de Côté-Thibault (1991). Dans notre cas, l'acteur industriel expose le problème et les chercheurs proposent des solutions selon un modèle conceptuel construit autour d'un cadre théorique : il s'agit de la démarche par facteurs de risques d’intégration de la SST dans la gestion des risques de projets. Dans notre cas, le problème se manifeste par le manque d’un outil intégrant la SST dans la gestion des risques de projets miniers et l’absence des techniques d’évaluation des impacts des risques de SST sur le projet et l’organisation. Pour proposer des solutions, nous utilisons « la démarche par facteurs de risques » selon une méthodologie des systèmes souples (Checkland, 2000).

La méthodologie des systèmes souples est une approche composée de sept étapes (Checkland, 2000 ; Sandoval-Correa, 2006 ; Kinloch et al., 2009). Ces étapes font appel au concept des systèmes d’activités humaines afin de définir une situation problématique et de proposer des changements ou des transformations (Figure 2.3) :

- Étape 1 — observer la situation problématique : il s'agit d'observer le problème dans un contexte non structuré. À cette étape, nous cherchons à savoir et à comprendre les éléments en lien direct avec la problématique observée, dans le but de décrire l'ensemble de la situation problématique.
- Étape 2 — exprimer la situation problématique : il s'agit de décrire les connaissances acquises lors de l'observation de la situation problématique. La description doit être réalisée de manière compréhensible par la population visée.
- Étape 3 — définir les éléments pertinents : cette étape a pour objectif de définir et de conceptualiser un système de pensées susceptible de résoudre le problème. Nous devons choisir les perspectives qui serviront de points d'ancrage pour la conceptualisation.
- Étape 4 — élaborer le modèle conceptuel : nous construisons le modèle conceptuel à partir de ce qui est défini à l'étape précédente (image de la réalité). Ce modèle doit être conçu en se basant sur la situation problématique décrite à l’étape 2.
- Étape 5 — comparer l'étape 4 avec l'étape 2 : nous y comparons le modèle conceptuel (étape 4) avec la situation réelle (étape 2) afin de voir où ils diffèrent et se ressemblent. Il s'agit de trouver des lacunes dans la situation réelle qui sont comblées par le modèle conceptuel. À cette étape, nous pouvons adapter et améliorer le modèle conceptuel.
- Étape 6 — étudier la faisabilité des changements souhaitables : cette étape permet d'identifier les changements souhaitables et d’analyser leur faisabilité afin de corriger la situation problématique.

- Étape 7 — mettre en place les actions d'amélioration de la situation problématique : Cette étape permet la mise en œuvre des changements décrits à l'étape 6.

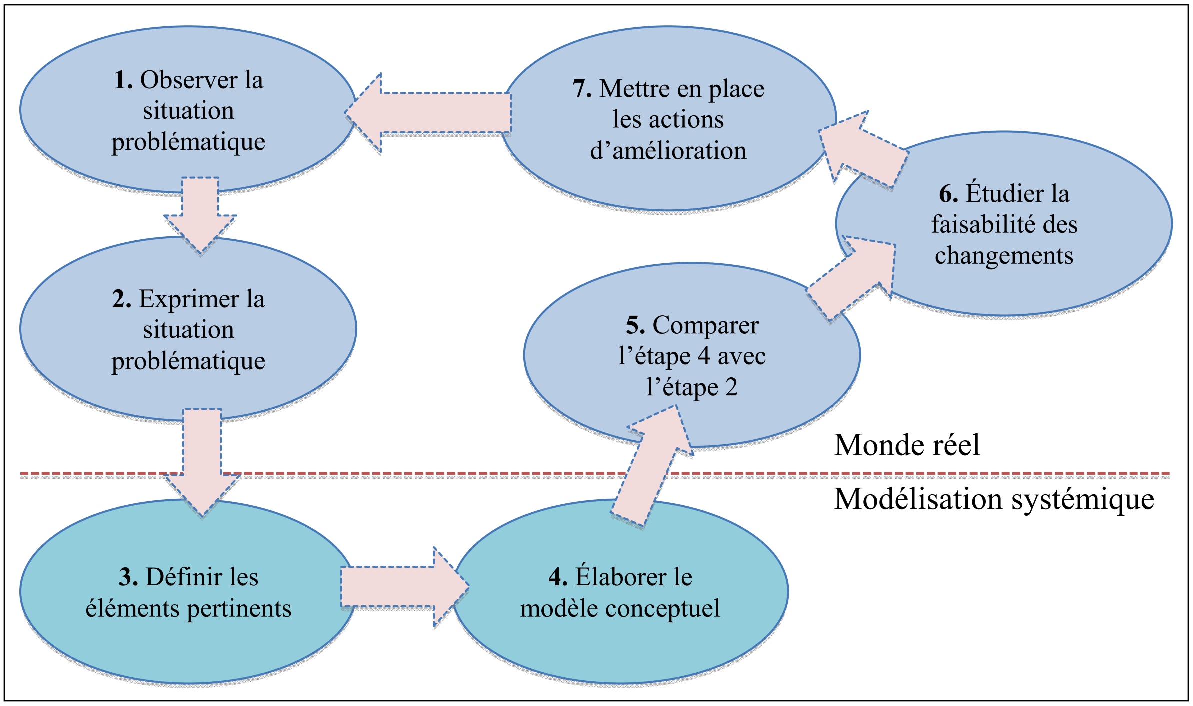

Figure 2.3 Les étapes de la Méthodologie des Systèmes Souples
Adaptée de Sandoval-Correa (2006)

La méthodologie des systèmes souples est une approche privilégiée grâce à son concept systémique où le système étudié est considéré comme un ensemble d'éléments en interaction dynamique et organisé en fonction d'un objectif (De Rosnay, 1975). D'après Gélinas et Gagnon (1983, p. 6), l'approche systémique « *vise à rassembler et à organiser des connaissances dans le but d'aider à résoudre des problèmes complexes de l'univers effectif* ». La méthodologie des systèmes souples nous permet, par sa flexibilité, de nous adapter en fonction des contraintes d'un environnement dynamique qui caractérise un système d'activités humaines.

2.4 La collecte de données : le coffre à outils

Dans la gestion des risques, l'importance d'une vision sociologique a été démontrée en particulier dans le contexte des études des organisations et des systèmes sociotechniques (Hassenzahl et Barr, 2004). Les accidents de grande envergure tels Bhopal (1984) et Tchernobyl (1986) ont montré l'insuffisance des seules stratégies scientifiques et techniques pour contrôler des systèmes sociotechniques complexes et prévenir des catastrophes industrielles. Ces accidents sont souvent causés par des évènements reliés à des comportements humains inhabituels (Simpson et al., 2009; Lan and Qiao, 2010). Ils sont toujours accompagnés d'un échec organisationnel (Pidgeon et O'Leary, 2000). Ces échecs attirent l'attention sur la question de la gestion des risques dans des organisations complexes. L'étude de la décision du lancement de la navette spatiale Challenger (1986) offre un exemple de la façon dont les pressions économiques et politiques peuvent influencer la culture de sécurité d'une organisation (Dassens et al., 2007). Dans ce contexte, on privilégie l'utilisation d'outils sociologiques pour interpréter les risques. Parmi les outils sociologiques utilisés pour recenser les risques, nous pouvons citer : les questionnaires (autoadministrés ou non), les sondages, les observations (participatives, directes, etc.), les entrevues (libres, dirigées ou semi-dirigées), l'analyse en groupe et l'analyse de contenu.

Actuellement, les outils sociologiques utilisés dans la gestion des risques et d'incertitudes sont bien développés (Taylor-Gooby et Zinn, 2006). Ces outils fournissent une vision plus globale des risques et permettent une interprétation plus réaliste des interactions dans un contexte organisationnel complexe. La prise en compte de la vision sociotechnique d'un système et du comportement de l'humain réduit la méfiance envers les approches purement scientifiques. Actuellement, les chercheurs et les experts tiennent compte des changements sociaux et analysent la manière dont ces changements peuvent générer des conséquences négatives sur la santé et l'environnement. À titre d'exemple, Viau (2009) a indiqué que l'environnement social peut avoir une profonde influence sur la relation entre l'exposition aux risques et les maladies (un faible niveau socioéconomique augmente les effets d'exposition aux dangers).

Finalement, le modèle conceptuel du présent projet de recherche fait appel à plusieurs outils dans le cadre d'une approche multidisciplinaire (scientifique, sociologique et de gestion). La combinaison de ces outils est beaucoup plus efficiente surtout pour recenser le maximum de scénarios susceptibles de nuire à l'intégrité de l'humain et à l'environnement dans un contexte industriel. Nous avons privilégié les outils sociologiques de collecte et d'analyse de données suivants : les entrevues semi-dirigées et les questionnaires (formulaire d'entrevue-questionnaire), les observations participatives (grille d'observation) et l'analyse de contenu (rapports d'incidents et d'accidents, procédures, modes opératoires, plan d'actions, etc.) (Figure 2.4). Toute la documentation de référence a fait l'objet d'une validation par les deux comités d'éthique de la recherche de l'ÉTS et l'UQAT avant que nous n'engagions les travaux sur le terrain (Appendices A, B et C).

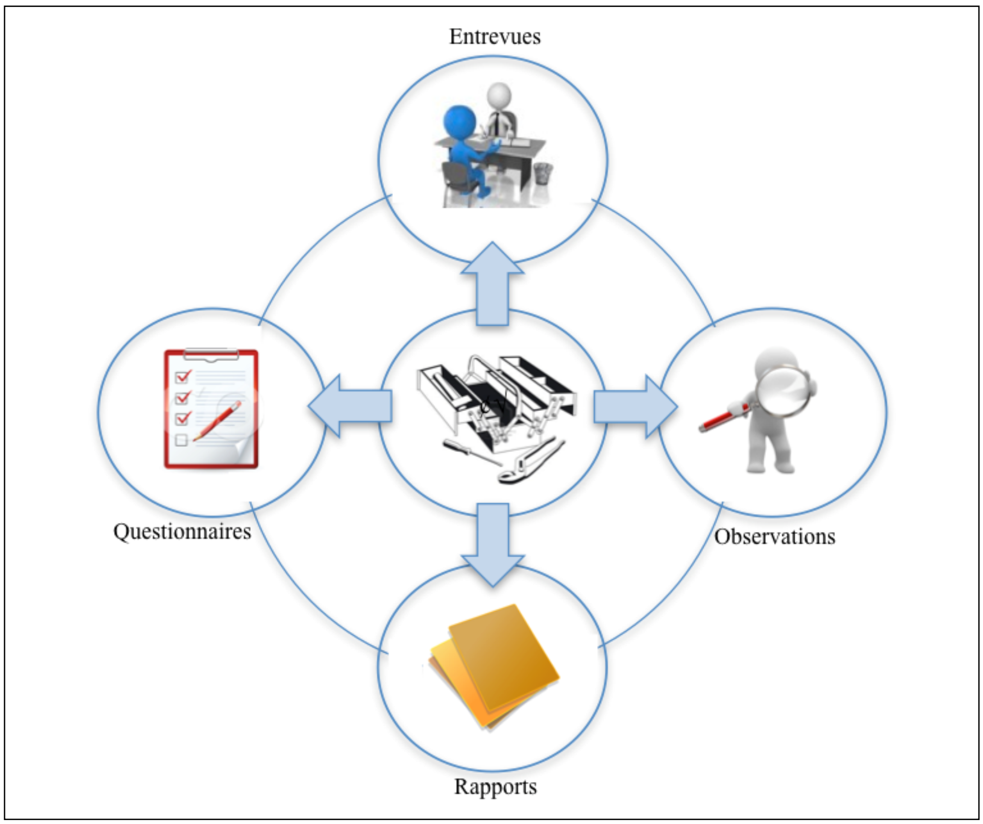

Figure 2.4 Outils de collecte de données
(Étape 5 de la Figure 2.1)

2.5 Structure de la thèse

La thèse est constituée de sept chapitres incluant le présent chapitre de la méthodologie et le premier chapitre de la problématique de recherche. Les cinq prochains chapitres détailleront les articles publiés, acceptés ou soumis à des revues scientifiques avec comité de lecture. Dans ces cinq chapitres, nous exposerons les résultats de nos travaux. La structure de ces chapitres est conforme à la démarche méthodologique expliquée dans la section 2.1. La structure de la thèse est détaillée aux lecteurs dans le but de clarifier le lien et la continuité de ces travaux (Figure 2.5).

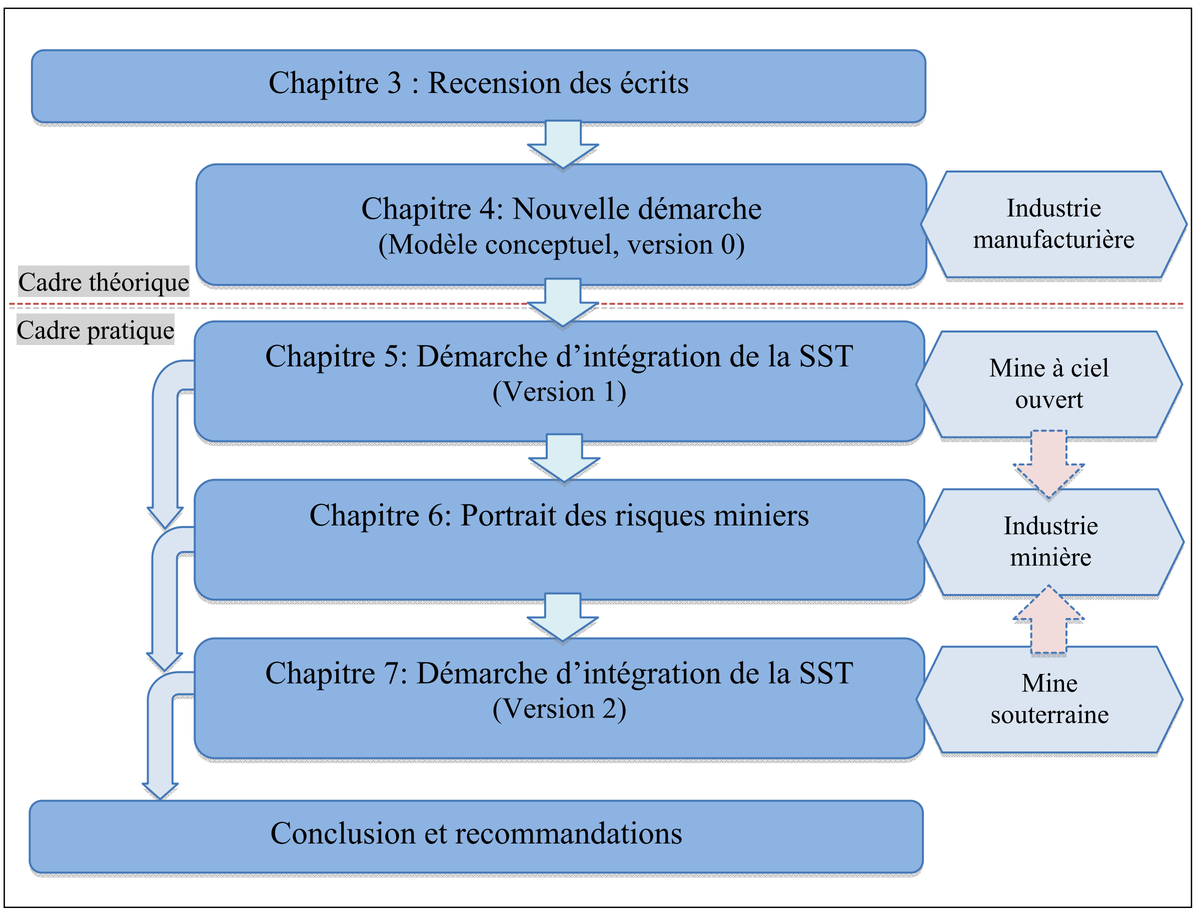

Figure 2.5 Structure des chapitres suivants de la thèse

Dans la première partie de la thèse (cadre théorique, chapitres 3 et 4), nous commençons par recenser les écrits pour vérifier l'état de l'intégration de la SST dans la gestion des risques de projets industriels (chapitre 3, Badri et al., 2012a). Nous commençons par les questions initiales afin de confirmer la pertinence de la problématique abordée. Au chapitre 3, nous présentons un aperçu des pratiques industrielles et des travaux de recherche visant l'intégration des risques de SST dans la gestion de projets industriels. Dans ce chapitre, nous introduisons quelques outils, méthodes et approches développés ou adaptés dans le but d'intégrer la SST dans les pratiques de gestion des risques. Il s'agit d'une description générale de l'état de l'art dans divers secteurs industriels.

Le chapitre 4 (Badri et al., 2011a) présente la construction du modèle conceptuel : il s'agit de la démarche par facteurs de risques proposée pour intégrer la SST dans la gestion des risques de projets. À cette étape, la démarche ne représente qu'une version initiale inscrite dans un cadre théorique ; elle est simulée dans le cas d'une extension d'une usine manufacturière dans un contexte de délocalisation d'activités industrielles. Le modèle repose sur plusieurs travaux (principalement, Freivalds, 1987 ; Henderson et Dutta, 1992 ; Aubert et Bernard, 2004 ; Curaba et al., 2009) et un corpus de connaissances en gestion des risques (Dorofee et al., 1996 ; PMI®, 2008a et PMI®, 2009). La démarche proposée est basée sur le nombre de facteurs de risques (ou sources de dangers) identifiés et leur importance relative. Un nouveau concept appelé la « concentration des facteurs de risques (ou sources de dangers) » et une comparaison multicritère (méthode AHP) sont utilisés pour évaluer et prioriser les risques potentiels.

La deuxième partie de la thèse (cadre pratique) s'ouvre sur notre première présence sur le terrain : il s'agit du premier mandat d'intégration de la SST dans la gestion des risques d'un projet minier à ciel ouvert au Québec (chapitre 5, Badri et al., 2011b). L'objectif principal de ce travail était de tester la nouvelle démarche, proposée et simulée dans un cadre théorique, selon une méthodologie de recherche-action. Durant ce travail, nous utilisons, pour la première fois, les techniques de collecte de données sur le terrain. Nous réalisons des analyses approfondies des rapports d'incidents et d'accidents, des entrevues semi-dirigées, des questionnaires et plusieurs observations participatives sur le terrain.

Le chapitre 6 (Badri et al., 2012b) décrit la continuité de nos premiers travaux sur le terrain impliquant une mine d'or à ciel ouvert au Québec (chapitre 5, Badri et al, 2011b). Ce chapitre a pour but de fournir aux chercheurs et aux praticiens un portrait préliminaire des risques potentiels de projets miniers. Ce travail montre la possibilité d'identifier plusieurs catégories de risques et d'incertitudes, qui sont connues, mais ne sont pas prises en compte de façon systémique et systématique dans la gestion des risques de projets miniers.

La deuxième partie de la thèse est complétée par une deuxième recherche-action menée dans une mine d'or souterraine au Québec (chapitre 7, Badri et al., 2012c). L'objectif de cette partie est d'adapter la démarche proposée dans un autre contexte de projet minier souterrain. Cette partie de recherche vise à généraliser progressivement l'utilisation de cette démarche dans le secteur des mines d'or au Québec. Ce travail utilise une version améliorée de la démarche d'intégration de la SST dans la gestion des risques de projets miniers à ciel ouvert (chapitre 5, Badri et al., 2011b) et utilise le portrait préliminaire des risques de projets miniers identifiés (chapitre 6, Badri et al., 2012b).

Il est important de noter que certains termes de vocabulaire utilisés ont évolué en fonction des publications (chapitres 4, 5, 6 et 7). Dans ce cas, nous tenons à préciser que les éléments « sources de dangers (hazards) » et « facteurs de risques (risk factors) » sont identiques. La même remarque est aussi valable pour les termes « catégorie des facteurs de risque (category of risk factors) » et « famille des sources de dangers (family of hazards) ».

Pour terminer, nous dressons en guise de conclusion le bilan et les contributions de nos travaux, avant d'exposer les limites et les perspectives sur lesquelles s'ouvre la thèse.

CHAPITRE 3

ARTICLE 1: OCCUPATIONAL HEALTH AND SAFETY RISKS: TOWARDS THE INTEGRATION INTO PROJECT MANAGEMENT

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Safety Science,

Volume 50, Issue 2, Page 190-198, 2012.

(doi: 10.1016/j.ssci.2011.08.008)

Abstract

Project management in industrial settings in many cases is deficient with respect to integrating OHS risks. This deficiency manifests itself as problems affecting the safety of industrial practices and is explained generally by poor knowledge of OHS within organizations and project teams.

We present, through this paper, a critical review and provide an overview of research and industrial practices aimed at systematic integration of OHS risks into the execution of projects, based on published scientific literature. We thus introduce some of the tools, methods and approaches being developed or adapted to integrate OHS and a general description of the current status of this integration in various fields.

Our focus includes, in fact, laws, management systems, OHS risk management throughout project life cycle and efforts to integrate OHS risk management to industrial safety practices including approaches using historical data and industrial interventions.

We conclude that publications identified are mainly derived from the construction industry and we stress that the objectives, methodologies and results are largely heterogeneous. The integration of OHS risk is not systematic in all industrial fields despite the changing and improving laws and management systems.

In order to complete the overview of OHS integration, we will suggest future reviews and research that specifically investigates other innovative OHS applications and many analyses of recent industrial accidents. Complete synopsis will give opportunities for researchers to use or improve methods and approaches to promote OHS risk management in the manufacturing sector that suffer from lack of knowledge in this area.

3.1 Introduction

The practice of engineering is called upon increasingly for systematic management that integrates OHS risks with operational risks. This stems directly from article 2.01 of the code of ethics adopted by the Quebec order of professional engineers (OIQ, 2011): “In all aspects of his work, the engineer must respect his obligations towards man and take into account the consequences of the performance of his work on the environment and on the life, health and property of every person”.

In Canada, a new era of governance characterized by attitudes and behaviors expected from “a good parent toward a child” (Pérusse and Bernier, 2009) has emerged owing to Criminal Code amendments adopted in March 2004 (Federal Act C-21) and possible consequences resulting from criminal proceedings where measures to protect the health and safety of workers do not exist.

Taking into account the need to eliminate occupational risks contributes to the success of projects (e.g. Gambatese, 2000a; Gambatese, 2000b; Smallwood, 2004; Baril-Gingras et al., 2006; Fung et al., 2010). The elimination of OHS risks is always more beneficial when introduced at the definition stage of a process and during the fine tuning of projects

(Charvolin and Duchet, 2006), but also when users remain mindful of it all the way to the completion of a project.

Since the 1980s and in particular the inception of the notion of "integrated prevention" (Claudon et al., 2008), engineers and various stakeholders in OHS have sought to integrate health and safety into the list of tools used in the design of projects. Although numerous software programs and workplace measures have been developed, project designers encounter difficulty using the enormous quantity of data generated as a result and deciding when and where to apply the new information without causing delays and cost increases.

3.1.1 Problem and objective of the present review

Actually, industry uses rigorous project management, modern and safe facilities and robust rules of occupational health and safety but accidents continue to cause human and social problems (e.g. Shikdar and Sawaqed, 2003; Smallwood, 2004; Li et al., 2009). Several industrial sectors encounter, continuously, serious accidents during all projects phases (e.g. Li et al., 2009) despite their efforts to integrate OHS in project risk management. This situation leads us to examine the current status of the systematic integration of OHS management risks into project management and industrial safety practices.

This paper is organized as follows. Section 3.2 presents the methodology, including a few definitions related to risk management. Section 3.3 details the results of the literature identified. The studies are categorized as explained in the methodology. We then summarize the state of OHS integration in industry and we suggest some possible directions for future research in Section 3.4. Finally, the conclusion of the manuscript is provided in Section 3.5.

3.2 Methodology

3.2.1 Strategy and research process

To achieve the objective of our research, we have organized our review of the literature as follows: (1) purpose of research; (2) search of the literature; (3) selection of relevant studies; (4) extraction and classification of data obtained from studies; (5) discussion of studies.

Firstly, we survey the recent literature and summarize briefly the extent to which OHS risks are taken into account in the project management and industrial safety practices, with special focus on the construction industry. This work is thus intended to help us in identifying research avenues to address the lack of knowledge noted particularly in the systematic management of OHS risks in the manufacturing sector.

Secondly, we have selected literature and structured our examination of the question surrounding the integration of OHS risks into project management and industrial practices. We queried Compendex, Inspec, IEEE Xplore, Eureka.cc and NIOSHTIC-2 using keywords such as risk, elements of risk, risk factors, risk management, project management, project lifecycle, risk assessment, risk analysis, method, occupational health and safety (OHS), risk management standards, OHS assessment, OHS performance, OHS measurement, OHS intervention, quantitative assessment, qualitative assessment, safety procedures, safety programs, systematic approach, design, ergonomics, safety culture, organization, construction, industry, laws, hazard, causal, model, tools, framework. We also identified books published recently, along with a large number of research reports, by consulting the Internet sites of INRS and IRSST. The search strategy combined two sets of keywords using "AND" or "OR" strategies.

Thirdly, relevant studies were assessed for methodological quality and clarity of their objectives. We analyzed titles, keywords and abstracts of peer-reviewed publications, standards of management and pertinent book chapters. It should be noted that we have analyzed more than 70 peer-reviewed publications for over 5 months. Peer-reviewed publications are from around the world (in English and French) and published between 1997 and today.

Fourthly, how to integrate the management of OHS risks in industry differs greatly from one sector to another. In part, these differences are mainly due to risk acceptability, development of laws and standards, maturity of project management standards and use of management systems.

We attempted to conduct an interdisciplinary review of literature. We stress that the objectives, methodologies and results of relevant studies identified are largely heterogeneous. In the purpose of trying to classify these publications, we used the mutual influences between the categories we've identified. These mutual influences are inspired from influence diagrams used in engineering. An influence diagram traces links between elements of a system adapted to the context of study (Alexandru, 2009).

If we take the construction sector as an example, the development of laws has helped in changing and improved project management standards (Gambatese, 2000b). This development of project management standards has also enabled the creation and the implementation of several tools and methods that improved project management. The efforts of researchers followed law developments and have stimulated developments of best practices (e.g. Zachariassen and Knudsen, 2002; Saurin et al., 2004; Hare et al., 2006).

For this reason we tried to organize the results based on these identified links of influence. These outcome categories (gray rectangles) and links of influences (arrows) are detailed in the Figure 3.1.

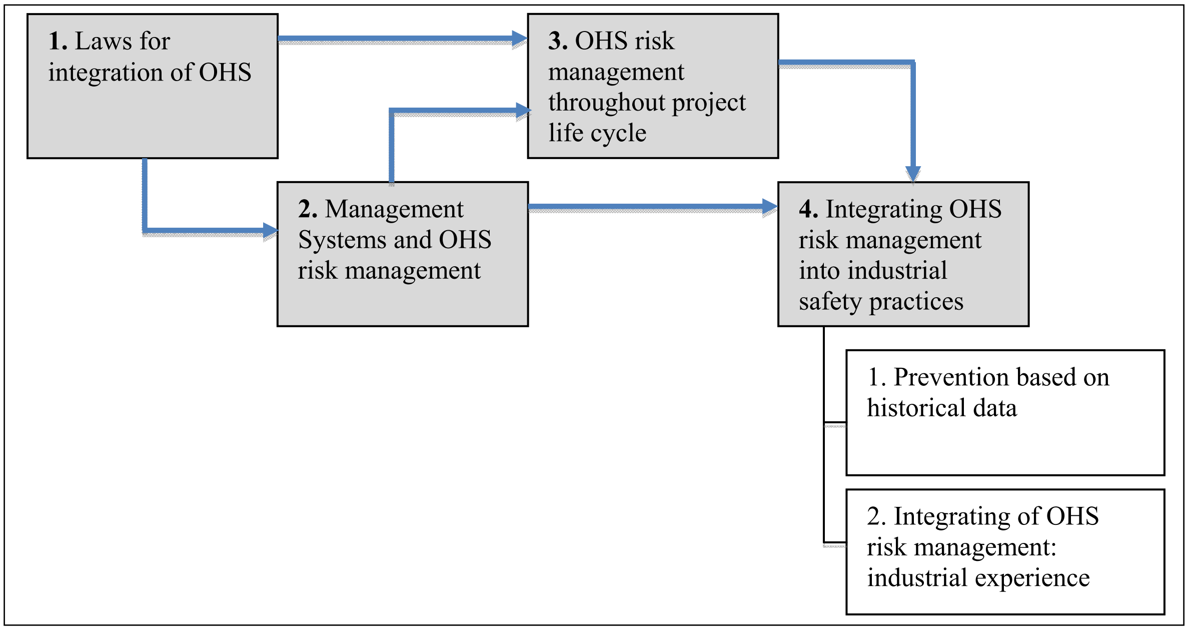

Figure 3.1 Data classification from literature with influences links (Section 3.3)

Finally, we discuss results of literature while following categories and links of influences detailed above. In Section 3.4, we summarize the state of the OHS integration in industry, limitations of the review and recommendations.

3.2.2 Risk and risk management: definitions

The PMBOK® Guide (PMI®, 2008a) states that project management is the application of knowledge, skills, tools and techniques to project activities in response to needs of the project. The management of a project spans five groups of processes: commitment, planning, execution, control and closure. In chapter 3 of the Construction Extension to the PMBOK® Guide (PMI®, 2008b), PMI® gave an overview of the project safety management processes. This process includes "all activities of the project sponsor/owner and the performing organization which determine safety policies, objectives, and, responsibilities so the project is planned and executed in a manner that prevents accidents, which cause, or have the potential to cause, personal injury, fatalities, or property damage". In this extension, PMI® defined the term safety management by both safety management and health management. It is important to note that project safety management interacts with all aspects of project management. These interactions are based essentially on communication between all stakeholders (PMI®, 2008b).

Risk is defined as the influence of uncertainty on the attainment of goals (ISO[3] 31000: 2009). It is defined also as inherent in the activities of man and all enterprises. Risk is a combination of the probability and the consequences of the occurrence of a specified dangerous event (OHSAS[4] 18001: 2007). "OHS Risk" is the significance of a hazard, in terms of the probability, and severity of an injury or illness occurring as a result of the hazard. In this paper, we mean by "Risk" the other forms of risk that must be managed by an organization: contract management, construction cost, planning and statistics, human resources and logistics, etc. (Mi and Nie, 2008).

"Project Risk Management includes the processes of conducting risk management planning, identification, analysis, response planning, and monitoring and control on a project" (PMI®, 2008a). In the risk management process, risks identification step is the foundation (Liu and Guo, 2009) and it presents challenges (Hagigi and Sivakumar, 2009). This definition stresses the goal of reducing a risk by lowering its likelihood (prevention) or its severity (consequence) (OHSAS 18001: 2007). The ISO/CEI 73 Guide (2002) offers definitions of the key elements often used to identify and analyze risks:

- The event is the occurrence of a particular set of circumstances.
- The consequence is the result of an event.
- The probability is the degree of likelihood that an event will occur.
- The source is the element or activity having some potential consequences.

The SEI identifies two risk management strategies used in handling risk (Dorofee et al., 1996). The first strategy is to engage actions that reduce the probability of occurrence. The second strategy employs actions to reduce the negative impact on the project if the risk

[3] Referring to a set of standards relative to quality management published by the International Organization for Standardization (ISO).
[4] Referring to the British Standard for OHS management systems.

condition is activated. These two strategies are also used to reduce OHS risks (OHSAS 18001: 2007). The SEI has neglected other strategies often used in project risk management and are well detailed by Aubert and Bernard (2004):

- Mitigation, which focuses on steps taken to reduce the probability that an undesirable event will occur.
- Deflection, which consists of modifying the direction of the impact of the occurrence of an undesirable event.
- Establishment of a contingency plan consisting of measures to reduce the impact of an undesirable result.
- Avoidance or refusal to assume risk.
- Retention or acceptance of risk.

Executing actions to mitigate risks requires the dedication of resources, such as time and money (Kutsch and Hall, 2010). For this reason, the commitment of management to this aspect of project execution must be strong (e.g. Gambatese, 2000b).

3.3 Results

The strategy and research process were applied to select relevant publications. Table 3.1 shows details about the selected publications. In the same table, we have a summary of each publication which shows the industrial sector, the country, the classification performed (Figure 3.1) and some tools, methods and approaches developed (30% of studies) or adapted (70% of studies) in each study. This summary helps the reader to identify quickly the information about the OHS integration in various industrial projects.

Tableau 3.1 Summary of the relevant publications selected

Authors (year of publication)	**Industrial sector**	**Country**	**Outcome categories* (Section 3.3)**						**Some of the tools, methods and approaches being developed or adapted**
			1	2	3	4.1	4.2	5	
Aubert and Bernard (2004) (book)	--	--						x	Risk factors approach
Baril-Gingras et al. (2006)	OHS sector-based associations	Canada						x	Advisory interventions
Charvolin and Duchet (2006)	Construction	France						x	Multidisciplinary and participatory design; ergonomics and hygiene
Ciribini and Rigamonti (1999)	Construction	Italy						x	Time-space charts
Dassens et al. (2007)	All industries	France				x			MADS and MOSAR methods
Dionne-Peroulx et al. (2003)	Manufacturing	Canada		x					Case study; interviews
Fung et al. (2010)	Construction	Hong Kong	x			x			Historical accident data; accident analysis; Risk Assessment Model (RAM); case study
Gambatese (2000a)	Construction	US			x				Constructability Concepts File
Gambatese (2000b)	Construction	US			x				Project planning and design; owner safety program; best practices database
Gegic (2008)	Metallurgical	Serbia		x					OHSAS standard
Gey and Courdeau (2005) (book)	--	--		x					OHSAS standard
Gibb et al. (2006)	Construction	UK	x		x	x			Construction accident causality; ergonomic approach
Hare et al. (2006)	Construction	UK			x				Interviews with steering groups and expert panels; focus group methods; risk management workshops; control lists; responsibility and assessment charters; audits
Kartam (1997)	Construction	Kuwait	x		x				Critical Path Method (CPM) scheduling software; IKIS Safety
Khodabocus and Constant (2010)	Printing	Reduit, Mauritius		x					OHSAS standard, concept of continual improvement; OHS programs; risk assessments; case study
Kutsch and Hall (2010)	Engineering	UK				x			Qualitative study; interviews
Lamonde et al. (2002)	Construction	Canada					x		Ergonomic intervention; case study

*****) 1. Laws for integration of OHS; 2. Management Systems and OHS risk management; 3. OHS risk management throughout project life cycle; 4.1. Prevention based on historical data; 4.2 Integrating of OHS risk management: industrial experience; 5. Others.

Table 3.1 *(Continued)*

Authors (year of publication)	**Industrial sector**	**Country**	**Outcome categories* (Section 3.3)**						**Some of the tools, methods and approaches being developed or adapted**
			1	2	3	4.1	4.2	5	
Li et al. (2009)	Construction	China						x	Open life-cycle processes
Lingard et al. (2009)	Construction	Australia			x				Project management; model client framework
Molenaar et al. (2009)	Construction	US				x			Structural equation model (SEM); individual questionnaire
Ponting (2009)	OHSAS standard	UK		x					OHSAS standard
Rivas and Ruskin (2004)	Manufacturing	Australia	x						Codes of safety practices; Australian Standards
Saurin et al. (2008)	Construction	Brazil						x	Cognitive systems engineering (CSE); safety management practices
Saurin et al. (2004)	Construction	Brazil			x				Safety planning and control model (SPC); Preliminary Hazard Analysis (PHA); Percentage of Safe Work Packages (PSW)
Shen and Walker (2001)	Construction	Australia					x		Quality management (QM); Environmental Management (EM); construction planning; case study
Smallwood (2004)	Construction	South Africa						x	Investigation
Suraji et al. (2001)	Construction	UK				x			Accident causation model; accident analysis
Tim and Salman (2009)	Petrochemical	UK		x					Drilling Management System (DMS); OHS standards.
Toulouse et al. (2005)	Manufacturing	Canada					x		Ergonomic interventions; Lean manufacturing methods; PVA-Kaizen; interviews
Wynn (2008)	Manufacturing	US							Benchmarking study; interviews
Zachariassen and Knudsen (2002)	Construction	Norway	x		x				Elements of Norwegian legislative basis; project auditing, best practices; experience transfer; OHS data sheets; management tools

*) 1. Laws for integration of OHS; 2. Management Systems and OHS risk management; 3. OHS risk management throughout project life cycle; 4.1. Prevention based on historical data; 4.2 Integrating of OHS risk management: industrial experience; 5. Others.

The results confirm the existence of many publications in order to integrate OHS risks in construction management projects (60% of selected publications). Given the critical nature of this industrial sector and the significant number of accidents occurring at the workplace, several scientifics and experts in this field have proposed some management tools to identify the various OHS risks. It is important to note that the most identified research in construction is generalizable to manufacturing.

3.3.1 Laws for integration of OHS

Worldwide, several laws have been created or amended to facilitate the management of OHS in the workplace. EC Directive 92-57-EEC formally requires all parties involved in European Union projects to address safety. Great Britain has enacted the Regulations (Construction Design and Management Regulation: 1994) to require designers to play a role in the identification and mitigation of safety hazards. In Quebec, the purpose of the OHS Act (OHSA, 1979, c. 63, a. 2) is “the elimination at source of dangers related to the health, safety and physical integrity of workers”. In Canada, a new era of governance characterized by attitudes and behaviors has emerged owing to Criminal Code amendments adopted in March 2004 (Federal Act C-21) and possible consequences resulting from criminal proceedings where measures to protect the health and safety of workers do not exist.

It is through the development of these laws and awareness of the criticality of various industries with regard to human life that we note the existence of numerous publications focused on integrating OHS risks into the project management and industrial safety practices. In construction projects, several researchers and experts (Kartam, 1997; Gibb et al., 2006; Fung et al., 2010) have proposed numerous tools to manage the various risks encountered.

Based on project management legislative considerations, Zachariassen and Knudsen (2002) have discussed key elements in Norwegian legislation concerning the integration of OHS into drilling platform construction projects in high seas. Their experiences suggest favouring a systematic approach to integrating OHS. The study is based on the wording of the legislation enforced by the Norwegian Petroleum Directorate (applied in 1995 and amended in 2001), on the current status of risk integration in petroleum companies and on the issues motivating such integration. Recent legislations essentially obliges companies to integrate OHS measures into the design of installations as well as when altering methods (Rivas and Ruskin, 2004). Integration of OHS risk management, promotes systematic transfer of knowledge, a strategy including a description of responsibilities and active involvement of staff with field experience (Zachariassen and Knudsen, 2002).

3.3.2 Management systems and OHS risk management

The OHSAS 18001 standard is the most widely recognized OHS Management System Standard (Ponting, 2009; Tim and Salman, 2009; Khodabocus and Constant, 2010). This structured management system permits organizations to identify, assess and prioritize risks, and implement appropriate control measures to reduce the potential of occupational injuries, illnesses and accidents. The OHSAS 18001 standard is compatible with ISO 9001 and ISO 14001 and is identical in structure with them and thus they should be complementary (Gegic, 2008).

Other OHS Management System Standards ANSI/AIHA Z10-2005 and CAN/CSA Z1000-06 are consensus standards developed in the US and Canada respectively. These standards include the same principles as OHSAS 18001.

Dionne-Peroulx et al. (2003) undertook the evaluation of the effects of introducing ISO 9000 standards and the management of OHS in private companies. Over 300 manufacturers throughout Quebec, both ISO 9000 certified or not were surveyed. The three main dimensions of the study focused on the ISO process (goal, justification and implementation strategy), internal practices used to manage OHS and the level of performance in OHS. The authors determined that as far as OHS was concerned, ISO 9000 certified companies do not enjoy a higher level of performance than non-certified companies. This is consistent with the conclusion of Gey and Courdeau (2005) that issues pertaining to the management of OHS have been overlooked in these standards.

ISO recently sought to close the long recognized gap with arrival of the new ISO 31000 (2009) standard, which acknowledges the management of risks within organizations. ISO 31000 (2009) offers principles and general guidelines for the management of risk (without specifying categories of risks) and remains applicable in industry. This new standard will serve to unite risk management processes with existing standards (including ISO 9001 and ISO 14001). It offers a common approach to the establishment of standards addressing risks without replacing them and will not lead to certification.

3.3.3 OHS risk management throughout project life cycle

To identify and manage OHS risk associated with a project, an organization requires involvement and participation of the project manager, the project team members, the risk management team, customers, experts, end users, stakeholders and the specialists in risk analysis (e.g. Gambatese, 2000a; Gambatese, 2000b; Zachariassen and Knudsen, 2002; Hare et al., 2006).

Qualitative assessment remains essential in prioritizing OHS risk (e.g. collecting data, modeling techniques and expert opinion). The purpose of this evaluation is to prioritize risks in terms of the likelihood of their occurrence and their impact on the project goals. Qualitative assessment is often supplemented by a quantitative review to the extent possible. Following risk assessment, the process is completed by adopting a risk control action plan integrated into the project management process as an indicator measuring the effectiveness of the approach (PMI®, 2008a).

We must mention the investigation of Hare et al. (2006), which sought to integrate OHS during the planning phase of a project. The researchers (Hare et al., 2006) used an approach based on discussions with four steering groups formed by experts in industry and three expert panels in analysis of supplier performance in order to determine factors critical for success and to develop a management model that integrates OHS. Before that the research team intervened, only an entrepreneur managed OHS-related tasks. Once risk management was integrated into the evaluation of projects, some elements of OHS were introduced, on a limited basis, in order to address other types of risks. Such risks now receive greater consideration in construction projects without diminishing the involvement of entrepreneurs, thanks to the evolution that has occurred in managing these risks. The researchers (Hare et al., 2006) identified events and tasks for which integrated consideration of OHS becomes nothing short of imperative, as in the case of communication. They also proposed methods and tools: responsibility charters, assessment charters, risk management workshops, posters and graphics dealing with safety, control lists, milestone dates and verifications through audits.

We shall discuss the safety planning and control model in projects developed by Saurin et al. (2004). Integrated during the planning and control phase of projects, this model comprises three hierarchical levels updated during production planning. The management of safety is integrated into all planning carried out by the company. Operators receive training based on a safety plan before carrying out their planned tasks.

Our review has identified the possibility and opportunity to integrate OHS into project activities upstream the planning phase. Gambatese (2000b) confirmed that owners who take a pro-active role in safety thus influence the safety experience on a construction project. Their research demonstrates that owners can strengthen project safety by taking actions such as addressing safety in the contract, promoting safety awareness and pre-qualifying constructors based on safety.

Similar work by Lingard et al. (2009) has helped Australian Government Agencies integrate OHS into project management practices. A “Model Client Framework” based on input from construction industry clients was thus developed to embed OHS into project management discipline. This life-cycle approach ensures transfer of OHS information throughout the construction supply chain (customer, designer, constructor and end-users). The model is made up of the following elements: The Federal Safety Commissioner's OHS Principles, the project process map, supporting tools and resources. Among the OHS principles of the Federal Safety Commissioner, we note developing a safety culture, leadership and commitment, developing cooperative relationships, promoting OHS in planning and design, consulting and communicating OHS information to project stakeholders, managing OHS risks and hazards, maintaining effective OHS measures across the project lifecycle and monitoring and evaluating OHS performance. The research shows how this framework improves the integration of OHS and OHS performance into construction projects.

Another important work initiated by Gambatese (2000a) describes recent research in the area of safety constructability and develops a "safety constructability review process" that provides means by which designers can improve safety during the design phase. This process provides access to a range of means and best practices to facilitate, manage and improve safety during the design phase. Among the best design practice, we can cite: (1) minimize the amount of night work and do not allow schedules that contain sustained overtime; (2) provide a clear, unobstructed and spacious work area around all permanent mechanical equipment; (3) position equipment controls and control panels away from passageways and work areas.

We might also mention, as an example, the tool developed by Kartam (1997), who has integrated OHS knowledge into the Critical Path Method (CPM)[5]. This approach is based on four principles of management: (1) planning, (2) organizing, (3) controlling and (4) leading. The tool has three components: control through engineering (specifically regarding the use of protective equipment and safety instructions), training and finally respect for regulatory and

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[5] This tool makes it possible to identify activities having a critical impact on the scheduling of a project. The relationship between activities and deadlines is analyzed to determine which activities are vital to completion of a project within a set timeframe. The consequences of delays are thus brought to light and management of resources can be oriented to reduce bottlenecks.

standards requirements. This tool makes it possible to manage OHS problems throughout all phases of a construction project. Among the benefits reported, project managers are able to plan, manage and control safety within cost, production, quality and scheduling constraints.

Finally, project management depends on communication, worker attitudes, motivation, skill, health and physical condition (Gibb et al., 2006). The workplace is influenced by congestion on the site, planning of the work and maintenance (Gambatese, 2000a). Other risk factors are linked to the management of projects, the culture prevailing with respect to safety and risk management and the economic climate in which a firm operates. Gibb et al. (2006) therefore proposed the integration of several measures into the management of construction projects, for example, the level of care required at the design stage and the degree of commitment on the part of the companies involved.

3.3.4 Integrating OHS risk management into industrial safety practices

The analysis and assessment of risks is viewed as a crucial step. Risk assessment plays a major role in identifying and rectifying inequitable situations (Viau, 2009). Tools used to evaluate risks of accidents vary according to their analytical development.

Researchers (e.g. Ciribini and Rigamonti, 1999; Kartam, 1997; Fung et al., 2010) gathered information from several sources to create databases for the tool, including OHS risks by trade, investigations in the field, incident and accident histories and OHSAS standards.

Experts (e.g. Suraji et al., 2001; Gibb et al., 2006; Wynn, 2008; Kutsch and Hall, 2010) often propose numerous tools adapted to managing OHS risks, such as PHA control lists, brainstorming, constraint analysis, benchmarking studies, statistical data accumulated on accidents and incidents and historical data.

3.3.4.1 Prevention based on historical data

The usefulness of the above-mentioned studies in a given situation depends on planning and managing resources devoted to improving safety and on analysis of a sufficient number of risks associated with accidents that occurred in the past. Accidents are generally caused by interactions between human resources and several risk factors such as work in close proximity to hazardous agents. Human resources can cause hazards by ignorance, negligence or risk-associated behavior (Kutsch and Hall, 2010).

Several recent publications focus on developing methods and tools for risk analysis based on historical data (e.g. Suraji et al., 2001; Gibb et al., 2006; Dassens et al., 2007). Work led by Dassens et al. (2007) stands out in the development of a new method allowing a company to assess dangers emanating from all external and internal sources. The systemic approach adopted using this method makes it possible to study interactions between the company and its environment as well as links in the chain of events leading to danger by using historical data.

The analysis proposed above is carried out following the broad steps of analysis of the system, identification of undesirable events and estimation of the impact of these events (Dassens et al., 2007). Analysis of the system is carried out to acquire in-depth knowledge of the activities, goals, structure, environment and evolution of the system. Identification consists of the recognition, evaluation and characterization of the risks involved in undesirable events. Estimation and evaluation establishes a ranking of the events in terms of their impact. MADS[6] and MOSAR[7] methods are used by Dassens et al. (2007) to address

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[6] Also called the danger universe, was initially used as a teaching tool for construction and understanding of the problem of risk analysis. It is constructed on the basic principles of systematic modelling developed by Jean-Louis le Moigne in ‘‘general systems theory’’.
[7] Systemic structured methodology of risk analysis is a tool used to structure a danger and thereby to identify it in a rational manner. This tool is made up of two modules designed to address two considerations: Module A provides macroscopic

links identified in the chain of events culminating in danger. This research has made valuable contributions to the structuring of elements of risk and the risk management process without providing detail concerning the mechanism required for this management at the operational level.

We have also identified two important models developed by Gibb et al. (2006) and Suraji et al. (2001) for accidents in the construction industry. The first of these was based on an ergonomic approach. Using a procedure based on the study of a 100 accident cases, Gibb et al. (2006) identified the safety breaches that led to the accidents and suggested actions to reduce them. Risk factors for construction industry accidents can be prioritized using this proposed model. Interactions between the work team, workplace and equipment can thus be examined to determine how an accident occurred. The first model confirms that circumstances surrounding an accident are influenced by several factors, such as nature of the operation, the behavior of the worker and communication within the work team.

The second model (Suraji et al., 2001) addressed possible improvements to an existing site. The goal is to propose practical means for investigating accidents, performing safety audits and implementing risk management systems. Suraji et al. (2001) have offered to test this model in case studies involving 500 reports drafted by HSE inspectors. The authors of this model classify causes of accidents according to two types of risk factors: factors termed "distant" and others said to be "proximal":

- Distant factors include constraints on design, project management, management of a business and its sub-contractors. These factors also include the influence of decisions, organizational constraints and problems related to the environment within a firm.
- Proximal factors are problems relating to planning, control of projects, construction operations, working conditions and response when faced with danger.

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analysis of proximal risks. Module B provides a microscopic analysis and focuses on detailed and complementary analysis of technical and operational dysfunctions detected in module A (Périlhon, 2003).

The study revealed that proximal factors cause 80% of all accidents in the construction industry. In great part, these factors are influenced by the organizations safety culture. Management and safety culture affect directly safety performance (Molenaar et al., 2009).

Among the findings of publications in this area, we wish to highlight certain tools, including the principle proposed by Fung et al. (2010), based on a model called RAM[8] created to assess safety risks in construction (Figure 3.2) and having as its main goal the classification of risk level for each type of trade or job. Fung et al. (2010) stress the need to assess risks in a faster and systematic manner in response to occupational accidents. This assessment becomes a critical step in achieving safer management of worksites. They followed four steps in developing this principle: (1) examine current safety issues in construction; (2) investigate and identify the various types of risks associated with different trades or occupations; (3) develop a tool based on the RAM model; and, (4) conduct a case study to verify the reliability of the model proposed. This study was based on historical data gathered in the context of a local project over a period of 40 months.

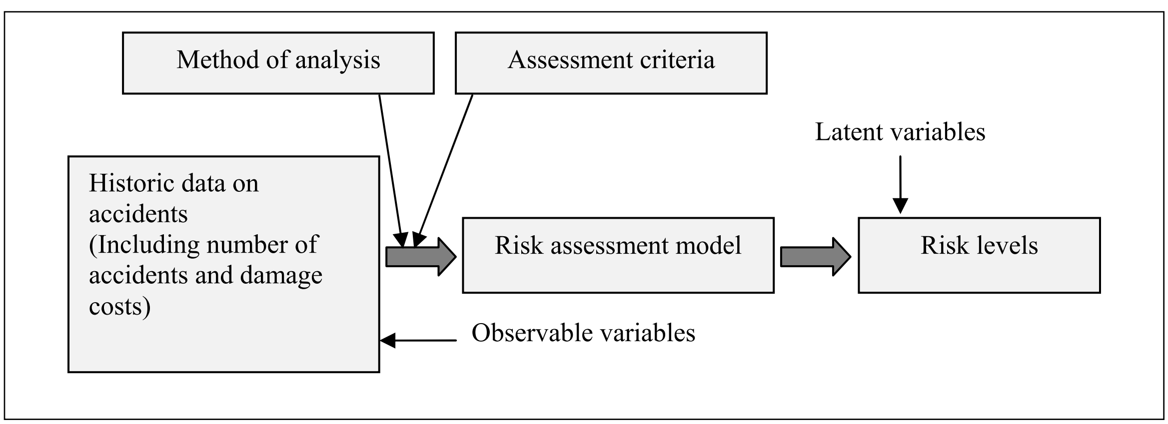

Figure 3.2 RAM principle
Fung et al. (2010)

[8] A model used to predict dangers in construction.

Fung et al. (2010) relied on a statistical study for the purposes of the model and identified 14 types of jobs and 18 types of accidents in the construction industry. Then, they proposed the use of a formula combining frequency of occurrence and severity of accident to interpret the data and estimate the level of risk ($R = F \times S$), excluding other criteria such as the detection and control of risk recently added by some experts and researchers (e.g. Dassens et al., 2007).

Models presented above have contributed to the prevention of OHS risks by exploiting history (background) and know-how in the field. Researchers have validated these models and declared that project performance has improved. The sequence of events leading up to a hazardous situation cannot be identified in some of the models developed because several of these studies separate undesirable events from risk factors.

3.3.4.2 Integration of OHS risk management: industrial experience

We have identified a limited number of publications on this topic. These publications (e.g. Lamonde et al., 2002; Toulouse et al., 2005) indicate a correlation between integration of OHS and experience of companies to involve their workers.

We uncovered one industrial intervention attempting to integrate prevention of musculo-skeletal disorders (MSD) and OHS problems into the PVA-Kaizen[9] approach. This work was performed by Toulouse et al. (2005) and relied on knowledge acquired during ergonomic interventions. Lean manufacturing methods are used through the intermediary approach based on Kaizen-blitz[10]. Results obtained from the study show that senior managers in small and medium-size businesses and some consultants are in agreement with the use of the PVA-Kaizen approach to integrate OHS. Integrate OHS with continuous improvement projects

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[9] A program aimed at improving productivity proposed to Quebec firms by the Ministry of Economic Development and Regional Research.

[10] Also known as ''radical change'', a Kaizen-inspired approach designed to play on a sense of urgency and focus energies on specific improvements.

continues to bring dividends to companies, but success in this regard varies depending on the priorities and motivation of the senior managers (Toulouse et al., 2005).

Shen and Walker (2001) have proposed another intervention to integrate OHS into quality and environment management. Their work opens with a discussion of difficulties confronted in attempting to integrate OHS risks into the system of quality control or management used in projects. Then they comment, with a case study, the advantages such integration conveys in designing and planning projects. This case study of the development of urban infrastructure in Australia (Shen and Walker, 2001) confirms improvements in performance indicators and construction project deadlines that take into account the need of considering OHS risks in concert with the management of the environment. This improvement makes it easier in identifying the risks at the design stage. It also shows how the adoption of a design and construct procurement approach, together with appropriate management techniques, on a successful major freeway project in Melbourne, Australia, was driven by a sound construction planning process, and integrated the construction planning system with OHS, EM and QM systems. The classical system of management fails to address the principles of constructability in design, thereby hampering the completion of projects (Shen and Walker, 2001). Integrating OHS risks with management of the environment permits to develop good practices for project planning. Among the advantages of this integration, we cite improvements in communication and pro-activity.

Finally, we cite the ergonomic intervention to integrate OHS into an industrial project (Factory design in Quebec) as described by Lamonde et al. (2002). This involved analyzing the interactions of two prevention specialists and an ergonomist with the project team. This analysis led to the development of five strategies for achieving more successful integration of OHS: "go step by step, accommodate engineering, legitimize their actions, test whether the design is logical, and record the steps taken." The authors claim that thanks to these strategies, the three stakeholders were able to eliminate a large number of risks at the source and to establish a prevention program prior to start-up of the factory. They also observed other benefits resulting from actions taken by the prevention specialists and the ergonomist, such as equipment operating at higher levels.

We emphasize the guiding principles proposed by Lamonde et al. (2002) and which are applicable to other projects when choosing the approaches to follow, linking actions taken to design and alter projects and optimizing interventions made by experts in ergonomics and OHS with others made initially by persons who are not experts within the firm.

3.4 Discussion

3.4.1 State of the OHS integration

Firstly, the integration of OHS risk management in the industry is recognized progressively through the movement toward Total Quality Management (TQM) and Environment Management (EM) (e.g. Shen and Walker, 2001; Matiast and Coelho, 2002). Currently, the researches oriented towards the study of the economic impact of health and safety problems are beginning to unveil the shortfalls in introducing OHS (e.g. Fung et al., 2010). In practice, industry began to introduce OHS considerations to avoid economic losses that are easy to estimate (e.g. Hämäläinena et al., 2009). We can evaluate these losses by the costs of compensation and insurance, the company's reputation and ability to retain its skilled workforce. Currently, several scientifics in this field are working to confirm the gains of OHS's integration with productivity tools (e.g. Shikdar and Sawaqed, 2003). Other researchers involved experts in project teams to improve working conditions and protect workers against diseases (e.g. muscular-skeletal disorders) and dangers (e.g. injuries) (e.g. Lamonde et al., 2002; Toulouse et al., 2005). In many industries, we can see the gap between the willingness of researchers to integrate OHS and priorities of managers (Toulouse et al., 2005).

History has shown that without serious laws and regulations, the companies have a difficulty of changing their practices and perceptions in the absence of tangible economic data. Laws and regulations need time and some effort to build them based on consultations within the OHS network and the working community. On the other hand, we can note that despite the willingness of companies, the support of validated and published solutions, the application of laws and regulations, the dangers are still occurring and sometimes they cause fatal accidents (e.g. Shikdar and Sawaqed, 2003; Smallwood, 2004; Li et al., 2009).

Integrating risk management is not mentioned in several known management standards applied by most industrial sectors. The ISO certification system does not allow company to promote a culture of health and safety (e.g. Dionne-Peroulx et al., 2003; Gey and Courdeau, 2005), without integrating the risk management throughout the processes and organizational framework. Otherwise the specific standards such as environmental management (ISO 14000) do not cover all the OHS risks. The weakness of the OHS integration in management standards mentioned previously is satisfied by the OHSAS 18001 standard. The OHSAS 18001 allows us to have a better control of OHS problems and ensure of maintaining an "acceptable" level of risk. It is important to note that the acceptable level is specified in OHSAS standard by the "level that can be tolerated by the organization having regard to its legal obligations and its own OHS policy" (Section 3.1, OHSAS 18001: 2007). This definition could cause problems in OHS risks assessment and management, especially in the absence of laws and regulations. Actually, this problem is present mainly in the manufacturing sector exposed to the mass transfer of activities in developing countries. These countries generally suffer from several problems including lack of laws and regulations that protect workers (e.g. Enno et al., 1995; Baram, 2009).

In the field of project management, if we refer to the PMI® standard (about 323 000 practicing members worldwide), it is clear that risk management does not indicate the systematic integration of OHS risks. The only exception in this area occurs in the Construction Extension (PMI®, 2008b) that is implemented through the development of laws and regulations, especially in North America and Europe. Applying the Construction Extension certainly favors a consideration of OHS by defining safety policies, objectives, and responsibilities so the project is planned and executed in a manner that prevents injuries. Most of the previous publications have shown the need of integrating OHS risks throughout the project management (e.g. Gambatese, 2000a). The proposed approaches demonstrate clearly that an involved team project in safety planning and communication and teamwork skills development are necessary (e.g. Gibb et al., 2006; Hare et al., 2006; Saurin et al., 2008). It is important to note that researchers of the same fields do not always agree on the vocabulary used to name the different project management phases and how to do the integration of OHS. These problems complicate the generalization of practices and use of data in research.

Researchers and experts have developed several methods and adapted in most of the cases some tools and approaches known in industry to integrate OHS (Table 3.1). Despite the use of these known tools and approaches, we mention that the objectives, methodologies and results are largely heterogeneous. Furthermore, there are no consensus among the various sectors regarding the methods and criteria of measurement of OHS integration. In our review, we also reported that only Fung et al. (2010) and Zachariassen and Knudsen (2002) have clearly identified and tried to solve the problem of lack of a systematic approach to integrate OHS risk management.

Briefly, workplace injuries continue to occur for several reasons, relating in particular to the degree of the systematic integration of OHS into project management, the effectiveness of measures taken to promote OHS, exogenous factors (competition, inter-business communication, etc.), endogenous factors (internal communication, culture, organizational approach, etc.) and difficulty associated with managing different types of risks at the same time (Badri et al., 2011a).

3.4.2 Limitations of this review and recommendations

The identification of publications was limited to the databases queried. Almost all of the publications found are peer-reviewed. Other types of literature (e.g. government reports,

unpublished reports) were not considered. This literature would provide access to a wider variety of potential sources of knowledge. There are many tools and processes for integrating OHS into construction project decision-making that are not identified in the databases used.
To address these limitations, we suggest future reviews and research that specifically investigate the following innovative areas not mentioned in the present article and which are applicable to OHS: mental models; thinking process tools; cognitive modeling; problem-solving theory; creativity approach; intuitive learning and artificial intuition.

3.5 Conclusion

This review has examined the recent literature and has summarized briefly the extent to which OHS risks are taken into account in the project management and industrial safety practices, with special focus on the construction industry.

We have thus provided a review of research and practices addressing the integration of OHS risks into the execution of projects and an overview of some of the tools, methods and approaches being developed or adapted to integrate OHS, in addition of a general description of the current status of this integration in various fields.

Our review demonstrates the need to spell out the OHS project risks and plan adequate funding to the project risk management team, if organizations want to avoid dangers and losses that threaten them. Attempts are underway to integrate OHS through timely intervention within a framework of continuous improvement. We now know that researchers are assigning increased priority to integrating ergonomics and OHS risks with production activities.

We conclude that publications identified are mainly derived from the construction industry and we stress that the objectives, methodologies and results are largely heterogeneous. The integration of OHS risk is not systematic in all industrial fields despite the changing and improving laws and management systems.

In order to complete the overview of OHS integration, we will suggest future reviews and research that specifically investigates other innovative OHS applications and many analyses of recent industrial accidents. Complete synopsis will give opportunities for researchers to use or improve methods and approaches to promote OHS risk management in the manufacturing sector that suffer from lack of knowledge in this area.

CHAPITRE 4

ARTICLE 2: PROPOSAL OF A RISK-FACTOR-BASED ANALYTICAL APPROACH FOR INTEGRATING OCCUPATIONAL HEALTH AND SAFETY INTO PROJECT RISK EVALUATION

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Accident Analysis & Prevention: Construction and Engineering,

In Press.

(doi: 10.1016/j.aap.2011.05.009)

Abstract

Excluding occupational health and safety (OHS) from project management is no longer acceptable. Numerous industrial accidents have exposed the ineffectiveness of conventional risk evaluation methods as well as negligence of risk factors having major impact on the health and safety of workers and nearby residents. Lack of reliable and complete evaluations from the beginning of a project generates bad decisions that could end up threatening the very existence of an organization.

This article supports a systematic approach to the evaluation of OHS risks and proposes a new procedure based on the number of risk factors identified and their relative significance. A new concept called risk factor concentration along with weighting of risk factor categories as contributors to undesirable events are used in the analytical hierarchy process multi-criteria comparison model with Expert Choice© software.

A case study is used to illustrate the various steps of the risk evaluation approach and the quick and simple integration of OHS at an early stage of a project. The approach allows continual reassessment of criteria over the course of the project or when new data are acquired. It was thus possible to differentiate the OHS risks from the risk of drop in quality in the case of the factory expansion project.

4.1 Introduction

Industrial accidents continue to cause human suffering, capital losses, environmental destruction and social problems (Kartam, 1997; Shikdar and Sawaqed, 2003; Duijm et al., 2008; Li et al., 2009). In recent years, accidents in construction and industry have occurred in spite of rigorous management of projects and robust occupational health and safety (OHS) management systems (Makin and Winder, 2008) in all phases of project lifecycle (Li et al., 2009).

The explosion of a power plant in the start-up phase while testing a gas line in a populated region (43,000 inhabitants) of Connecticut (USA) on February 7, 2010 is reminiscent of a series of similar industrial accidents over the decades in terms of gravity and consequences. In most cases, inquiry into the causes of the accident revealed failure in the identification and evaluation of the impending risks, placing at peril the health and safety of human beings on site and in the surrounding areas. This was the case notably at Bhopal (1984) and at Chernobyl (1986).

In general, risk is evaluated in terms of its consequences with respect to project performance and rarely in terms of human suffering. Smallwood (2004) confirmed that quality, planning and costs are the parameters given the greatest consideration. This is reflected in the decision to install many high-risk production plants near or in densely populated areas (e.g. the AZF chemical plant in Toulouse, France; the now closed Sigma-Lamaque mine in Val d'Or, Quebec). In Quebec, high-risk installations still get the go-ahead in spite of the efforts by the

Environmental Public Hearings Office to provide transparent information and to consult citizens.

The aim of this paper is to present a new systematic approach to the evaluation of OHS risks and proposes a new procedure based on the number of risk factors identified and their relative significance. This approach is able to overcome the difficulties of current tools in the manufacturing industry. The proposed approach is based on known techniques and tools, such as multi-criteria analysis techniques (e.g. analytic hierarchy process), expert judgment and the analysis of accidents and incidents. The Analytic Hierarchy Process (AHP) is selected to minimize the inconsistencies in expert judgments (Fera and Macchiaroli, 2009) and to support approaches that use mixed qualitative–quantitative assessment data (Chao et al., 2005).

This document is structured as follows. In Section 4.2, we begin by discussing the relevant tools and approaches used to manage project risk in different industrial sectors. We also give an overview of the use of qualitative and quantitative tools in various industries. Section 4.3 presents the methodology, including the conceptual model of the systematic approach to the evaluation of OHS risks. Given its importance in the approach proposed, the AHP method is outlined in Section 4.4. The proposed approach is then described in detail in Section 4.5 and a case study of a factory extension is presented to test the proposed approach. Section 4.6 follows with discussion and suggests possible directions for future research and a conclusion is provided in Section 4.7.

4.2 Literature review

Industrial work is risky in many economic sectors, in particular the construction industry (Fung et al., 2010), chemical plants (Vernero and Montanari, 2010), nuclear power plants (Young, 2005) and the mining industry (Hermanus, 2007). Safety problems can result from any of several combinations of causes, which vary from one industry to another. The high level of risk in the construction industry is explained by the nature and characteristics of construction work, low educational level of workers, lack of safety culture and communication problems (e.g. Gambatese, 2000b; Fung et al., 2010). In the mining sector, increasing numbers of subcontractors working in mines, the emergence of new mining ventures and recognition of small-scale mining pose new challenges to the practice of risk control (Hermanus, 2007).

The most effective way to improve OHS performance is to identify and eliminate hazards at the source (Glickman and White, 2007). Risk identification and assessment thus become primary tasks that are part of hazard prevention (Manuelle, 2005). Risk analysis is the foundation of the risk management process (Liu and Guo, 2009; Fung et al., 2010) and presents several challenges (Hagigi and Sivakumar, 2009).

OHS has not always been a preoccupation of process engineers (Hassim and Hurme, 2010). The motivations for integrating OHS risk management into engineering have been discussed recently. These include legislation (Gambatese, 2000b; Zachariassen and Knudsen, 2002), awareness of the importance of protecting workers (Gambatese, 2000a) and in some cases perceived potential to increase profitability and remain competitive (Sonnemans et al., 2002).

Industry has attempted to adapt engineering tools and methods to the assessment of OHS risks. These include quality management tools (e.g. failure methods and critical analysis (FMECA), "What If" analysis and check lists) and other industrial safety approaches (e.g. fault tree analysis (FTA), event tree (ET) and human reliability analysis (HRA)). Several authors have developed OHS risk reduction tools and models used in conjunction with historical data and shop floor know-how (e.g. Cameron and Hare, 2008; Ciribini and Rigamonti, 1999; Fung et al., 2010; Gibb et al., 2006; Hare et al., 2006; Kartam, 1997; Saurin et al., 2004; Suraji et al., 2001). It is important to note that the abovementioned tools are used alone rather than integrated into other types of risk management by an organization.

Quantitative methods of risk management are widely used in many industrial fields (Fera and Macchiaroli, 2009), for example the aerospace and nuclear industries (e.g. Skelton, 2002). These methods generally use equipment and software to analyze data. Quantitative methods are generally expensive and require specialized analysts (Restrepo, 1995). One of the best-known methods is that of the safety review and hazard and operability study (HAZOP) (Calixto, 2007). This method allows assessment of complex situations based on knowledge of several key parameters of a system.

In many industrial fields, the data and information used to assess risk are imprecise and incomplete (Ferdous et al., 2009). Quantitative approaches do not give reliable results when data are lacking (Pinto et al., 2010). Acquiring useful information using quantitative risk assessment based on probabilistic models is not yet possible (Jabbari Gharabagh et al., 2009). In the petrochemical industry, Jabbari Gharabagh et al. (2009) attributed the current difficulties in risk assessment to the complexity of the current quantitative methods. These problems are more significant in the design stage of industrial projects (e.g. Pinto et al., 2010).

Pinto et al. (2010) proposed a qualitative model for health and safety risk assessment based on available data and using a fuzzy logic approach. They concluded that qualitative approaches for human-centered problems are flexible enough to assess risk. Another method worth mentioning was developed by Hassim and Hurme (2010) for assessing the health risks of a chemical process during the design phase. The method takes into account both the hazard associated with the presence of the chemicals and the potential for the exposure of workers to them. An “Inherent Occupational Health Index” has also been proposed to conduct the risk evaluation early in the design phase. Jabbari Gharabagh et al. (2009) concluded that the use of historical data is not only important in risk management, but is also helpful in risk evaluation as an indicator of acceptable risk criteria.

Neglecting the consideration of human factors in risk analysis is due in part to the difficulty of quantifying many of them (e.g. Human risk-taking behavior in Kotani et al., 2007). In addition, human behavior cannot be predicted from analysis of accident and incident histories alone. Evaluation based solely on historical information always runs into difficulties in meeting the challenge of the proactive treatment of risks.

It is always more effective and profitable to integrate risk evaluation beginning at the project design phase (Charvolin and Duchet, 2006). Complete and accurate evaluation will contribute to reducing risks as well as justify monitoring of workers and residents of the surrounding community in the event of damage to the installation, whether caused by an industrial accident or a natural event. Determining the risks and measures for dealing with them before setting the project in motion is without question the wisest course to follow (Gray and Larson, 2006).

Starting from the need to create an appropriate and effective approach that integrates the management of all project risks in the manufacturing sector, our paper explores the possibility of creating such a model for industrial projects using an approach based on mixed techniques.

The proposed approach allows quick prioritizing of identified risks and allows evaluators to identify additional potential causes of undesirable events without nullifying the previous risk element compilation effort. The simplicity of the procedure should facilitate its use in small and medium-sized businesses without requiring a major investment.

4.3 Methodology

Based on the literature (Freivalds, 1987; Henderson and Dutta, 1992; Aubert and Bernard, 2004; Curaba et al., 2009) and on continuous risk management standards (Dorofee et al., 1996), this paper proposes a conceptual model for integrating occupational health and safety into project risk evaluation based on multi-criteria comparison (AHP). We have considered a model of risk composed of three elements detailed below and the conventional steps of risk management.

In order to propose a conceptual framework for identifying and assessing risks, we began by tracing the elements of risks that are used for the identification steps. Once the elements of risk are identified, the causality links form the basis of the evaluation and the control steps. Our analysis is based on a model of risk composed of three principal elements (Figure 4.1), namely the risk factors, the undesirable event, and the impact of the undesirable event. In order to control risk, all of the elements must be identified and the various causal links likely to appear in a field or area of study must be clarified as well as their mechanisms and the conditions that trigger them.

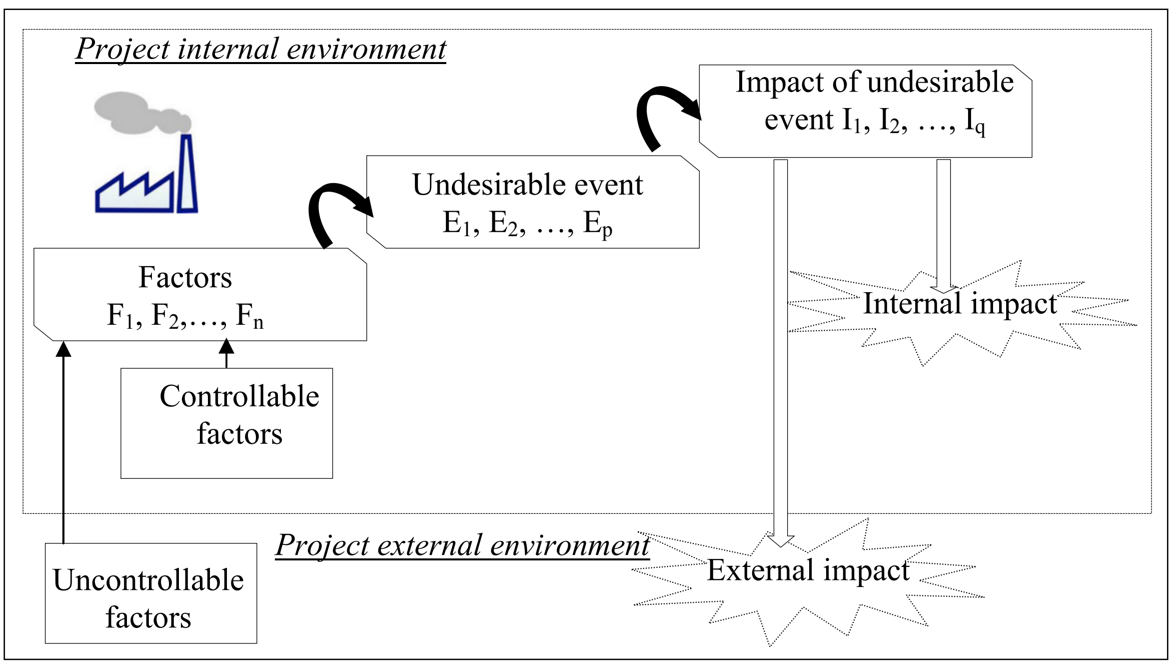

Figure 4.1 Modelling of risk and its influence

It should be noted that the project internal environment is made up of controllable variables such as the effectiveness of health and safety measures. The variables of the external environment (e.g. weather-related) are always the most difficult to control or modify.

The proposed approach is based on a risk factor approach (Figure 4.2). This is an original approach to risk evaluation, since it is based on a novel parameter expressed as a fraction and representing the presence or likely appearance of the risk factors that trigger an undesirable event, or more specifically the direct influence of the number of risk factors present on the probability of occurrence. This new concept is called the “risk factor concentration”. When this concentration increases, there is a greater chance of triggering the associated undesirable event.

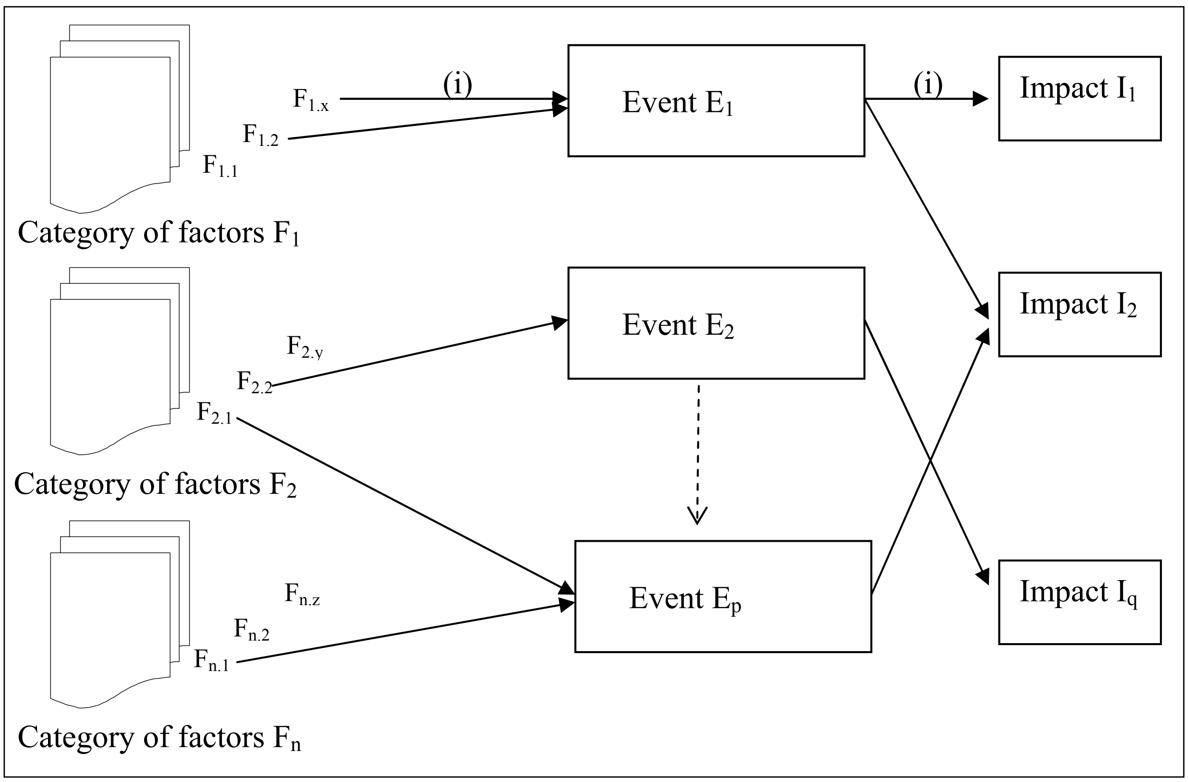

Figure 4.2 The links in a risk factors approach to risk analysis
Inspired from Aubert and Bernard (2004)

Aubert and Bernard (2004) present a similar approach without specifying that the impact of an undesirable event may include several types of loss. The causality links are identified by the evaluators and determine how the potential impact of a risk will be evaluated. Each link (i) between a factor, an event and an impact thus defines a possible route of concretization of a risk as an event having a negative impact.

4.4 The Analytical Hierarchy Process (AHP)

The AHP (Saaty, 2000) method is a structured multi-attribute decision method used in complex decision making and is the most widely used of the multi-criteria comparison methods. Developed in the USA by Saaty in the 1970s (Simei et al., 2009), this method is based on three fundamental principles: decomposition of the structure, comparison of judgments and hierarchical composition (or synthesis) of priorities. AHP is applicable to decision situations involving subjective expert judgments and uses both qualitative and quantitative data (De Steiguer et al., 2003). This method creates a priority index for each expert decision or judgment. AHP summarizes these judgments by ensuring their consistency.

The proposed approach involves the AHP method for the paired comparison of the risk factors, which was carried out using the decision aid software Expert Choice©. The AHP method is used in project management as a decision aid in order to choose a project on the basis of company objectives. Al-Harbi (2001) discussed this method in the context of the pre-qualification of construction contractors.

In the OHS field, attempts to use AHP began in the context of ergonomic analysis done by Henderson and Dutta (1992) and the comparison of ergonomic standards by Freivalds (1987). Henderson and Dutta (1992) compared NIOSH recommendations with those of the ECSC for the two-handed handling of loads in the sagittal plane. In this study, 11 risk factors were compared using the AHP model. These factors, namely frequency, distance, height, dimensions, load shape, position of the load center of gravity, anthropometric dimensions, gender and age of the individual and limited biomechanical and physiological criteria, were proposed in a previous study by Freivalds (1987). Using AHP, Freivalds (1987) showed discrepancies between NIOSH and ECSC standards, which were attributed to differences in the respective equations, hypotheses and concepts.

Padma and Balasubramanie (2008) used AHP to develop a decision aid system that draws on a knowledge base in order to rank risk factors associated with the occurrence of musculoskeletal problems in the shoulder and neck. Another system using AHP to compare risk factors associated with human error and with the causes of accidents in the maritime transport sector was developed in a study by Zhang et al. (2009b). Topacan et al. (2009) used AHP to evaluate a health information system with the aim of investigating the factors that influence user preferences in the selection of health services. Fera and Macchiaroli (2009) have selected AHP for their model of industrial risk assessment to identify major events and validate the actions taken.

In ergonomics research, AHP has been described as a reliable method for comparing risk factors, evaluating risks, defining priorities, allocating resources and measuring performance (Henderson and Dutta, 1992). The use of AHP to analyze human factors should make the hierarchical model more clear, simple and practical (Zhang et al., 2009b) and should also allow more structured discussion and easier examination of relevant information (Larson and Forman, 2007). AHP reduces the inconsistency of expert judgments and appears acceptable in terms of reliability (Fera and Macchiaroli, 2009). This multi-criteria method allows incorporating both objective and subjective considerations into the decision process (Forman and Selly, 2002).

In conclusion, the feature of combining both quantitative and qualitative data and controlling the consistency of expert judgments makes AHP the most applicable to the proposed approach. We will provide objective judgments and reliable prioritization of risks.

4.4.1 The theoretical background of AHP (Nguyen, 2009)

Given n alternatives $\{A_1, A_2, \ldots, A_n\}$ from which a selection is to be made, the expert attributes a numerical scale a_{ij} from the scale of binary combinations (Appendix I) to each pair of alternatives (A_i, A_j). The term a_{ijk} expresses the individual preference of expert k regarding alternative A_i compared to alternative A_j.

Once the overall expert judgments are created and computed using the geometrical mean (4.1), they are inserted into the comparison matrix D (4.2).

$$a_{ij} = \sqrt[n]{a_{ij1} . a_{ij2} \dots a_{ijn}} \tag{4.1}$$

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{4.2}$$

Matrix D is a comparison matrix with inconsistent judgments and has the following properties:

$$a_{ij} > 0;\ a_{ij} = 1/a_{ji} \ \ \forall\, i \quad where\ j = 1, 2, \dots, n \tag{4.3}$$

Matrix D is considered consistent when its elements meet conditions (4.4) and (4.5):

$$a_{ij}.a_{jk} = a_{ik};\ \forall\, i, j, k \quad where\ i, j, k = 1, 2, \dots, n \tag{4.4}$$

$$a_{ij}.a_{ji} = 1 \quad where\ i, j = 1, 2, \dots, n \tag{4.5}$$

The ordering of alternatives is taken as a result of the approximation of comparison matrix D using matrix P:

$$P = \begin{bmatrix} p_{11} & p_{12} & \dots & p_{1n} \\ p_{21} & p_{22} & \dots & p_{2n} \\ \dots & \dots & \dots & \dots \\ p_{n1} & p_{n2} & \dots & p_{nn} \end{bmatrix} \tag{4.6}$$

The elements of which are consistent judgments presented in the form of weight ratios among alternatives:

$$p_{ij} = p_i / p_j \qquad where\ i, j = 1, 2, \dots, n \tag{4.7}$$

p_i signifies the weights of the alternatives of the order vector p:

$$p = (p_1, p_2, \dots, p_n)^T \tag{4.8}$$

We obtain the standardized order vector after the arithmetic normalization:

$$p^* = (p^*_1, p^*_2, \ldots, p^*_n)^T \tag{4.9}$$

$$where\ p_i^* = {p_i}/{\sum_{i=0}^{n} p_i} \tag{4.10}$$

Saaty (2000) uses the maximum eigenvalue method to approximate the judgment matrices:

$$D.p = \lambda_{max} p \tag{4.11}$$

where λ_{max} is the maximum eigenvalue of matrix D.

For reliable comparison, it is important to note that the inconsistency of the comparison matrix D must be less then 10%. This condition means that the number of times that condition 4.4 is not met must be below 10%.

4.5 Results and analysis

4.5.1 The proposed risk-factor-based analytical approach

The proposed approach is divided into three phases and each phase is divided into steps. This approach outlines all phases of risk management including: (1) risk identification; (2) risk assessment and (3) actions.

The approach uses several methods and tools such as systematic observations, interviews, multi-criteria analysis (AHP), analysis of accidents and incidents and the new concept of risk factor concentration. In Table 4.1, we report the tools and methods used for each phase and step.

Tableau 4.1 Details of the proposed approach by risk factors

Phase	Step	Description	Method
1	1	Identification of risk elements (on the shop floor)	Observations
			Interviews
		Identification of risk elements (historical data)	Analysis of accidents and incidents
	2	Identification of causal links between the risk elements	Expert judgment
2	3	Paired comparison of categories of risk factors	AHP
	4	Estimation of the probabilities of occurrence	Concept of risk factor concentration Eq. (4.13)
	5	Evaluation of the impact of undesirable events	Expert judgment Eq. (4.14)
	6	Evaluation and prioritization of identified risks	Eq. (4.12)
3	7	Action prioritization	AHP
	8	Action monitoring and control	Prevention plan

The model is based on teamwork and knowledge of multi-criteria analysis techniques. The purpose of this model is to integrate OHS risk with operational risk without creating a conflict and without complicating the process for the risk management team. It should be noted that multi-criteria analysis is used partly to compare the risk factors, not to compare the risks identified.

Like any approach to risk management, the model gives appropriate consideration to the phase of identifying risk elements (risk factors, undesirable events and impact of undesirable events). The risk assessment phase uses multi-criteria analysis, expert judgment and the new concept of risk factor concentration. The analysis is made according to the causal links between elements of identified risks. The action phase is based on risk prioritization. This step can be assigned to the project manager, who will plan the project risk evaluation review. In the following subsections of the paper, we describe and analyze in more detail the eight steps of the proposed approach used to manage OHS risk.

4.5.1.1 Phase 1: Risk identification

Risk identification necessarily involves identification of the elements of the risks. The risk model includes three elements: (1) risk factors, (2) undesirable events and (3) the impact of undesirable events (Aubert and Bernard, 2004). Once the risk elements are identified, experts with the collaboration of workers involved trace the possible causal links between these elements. This work simplifies the conceptualization of the various risks identified in order to trace their possible impact on project progress. In our model, industrial expertise is crucial to identifying causal links.

The main objective of this step is to establish an OHS database. To collect the data needed to establish this OHS database, the model uses several tools such as analysis of documentation (identifying events and sources of hazards in historical data), field observations (identifying operations, work methods, equipment and risky behaviors) and interviews with workers. Interviews are also used to confirm the presence of sources of industrial hazards gleaned from the database of Curaba et al. (2009). The use of expertise (interviews, expert opinion and teamwork) can avoid the problem of lack of historical data especially in startup organizations. This database also facilitates access and use of data required for project risk management in more and more competitive environments, in which pressures that mount following delays often undermine the quality of the analysis and the evaluation.

Historical data have not been used for direct estimation of the risks, unlike in several other studies (e.g. MacNab, 2004; Liu et al., 2007; Furukawa et al., 2009). The historical portion is rather a grouping of sources of information (Figure 4.3) that includes the elements necessary for identifying the causal links and evaluating the possible impact of each risk.

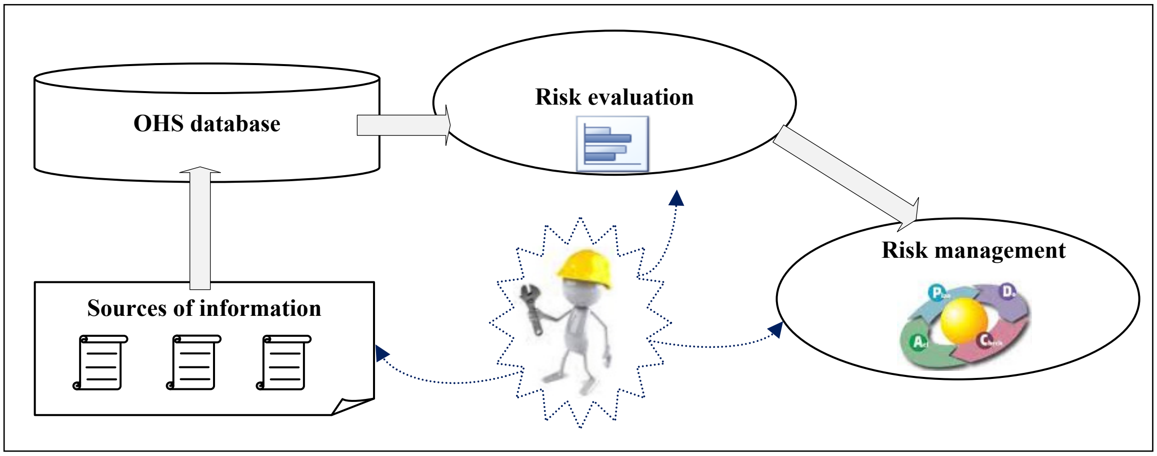

Figure 4.3 The role of information sources and risk evaluation in risk management

4.5.1.2 Phase 2: Risk assessment

Based on Eq. (4.12), which combines the probability of occurrence and the impact of an undesirable event taken from the literature (Aubert and Bernard, 2004; Fung et al., 2010), estimates of these two parameters are needed in order to assess risk.

The direct cause of an undesirable event is the activation of one or more categories of risk factors:

$$Risk_{(i)} = P_i . I_i \quad (4.12)$$

where P_i is the probability of an undesirable event *E(i)* and I_i is the impact of an undesirable event *E(i)*.

The multicriteria comparison used in the first step of the risk assessment phase is to quantify the importance of risk factors identified in the first phase of the process. This comparison is used to estimate the weight of the influence of each category of risk factors. These weights give the categories more credibility as contributors to an undesirable event.

In the majority of cases analyzed in the OHS field, risks and accidents arise from human behavior or an organizational problem (Saurin et al., 2008). Using historical data to estimate probabilities supposes that human behavior and organizational constraints are characterized by linear continuity. This hypothesis is far from reality, since both of these parameters depend on several latent and sometimes non-probabilistic phenomena, which are difficult for analysts to identify and monitor (Saurin et al., 2008; Molenaar et al., 2009).

In the second step of the risk assessment phase, the new concept highlighted in this research, namely risk factor concentration, is applied to estimate probabilities of occurrence. The probability that an undesirable event will occur depends primarily on the number of the risk factors in the risk categories linked with the event in the situation under study (link "(i)" in Figure 4.2).

The concentration is calculated as follows:

$$C_{ij} = \frac{x_i y_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{m} x_i y_{ij}} \quad (4.13)$$

where x_i is the number of risk factors by category *Fi* and y_{ij} is the weight of risk factor category *Fi* causing an undesirable event *Ej* estimated by AHP. $i \in \{1, 2, \ldots, n\}$ and $j \in \{1, 2, \ldots, m\}$.

Once the concentration is calculated, a scale is used to convert this concentration to probability. In the proposed approach, two categories of conversion (numerical or qualitative) can be used. This conversion does not affect the linearity of the results.

The reasoning applied here to risk level estimation emphasizes that the probability of occurrence is influenced by the presence of risk factors (Rosness, 1998; Coppo, 2003; McLeaod et al., 2003). Since the probability of occurrence is generally not available and no statistics exist for its direct estimation (Aubert and Bernard, 2004), evaluators use indirect estimates with relative scales (e.g. Restrepo, 1995; Hallowell and Gambatese, 2009).

The proposed approach allows identification of risk factors and calculation of the concentration of these factors in relation to each identified undesirable event. The conversion of these factors (which form the basis of the estimated probabilities) does not distort the calculations or change the philosophy of risk assessment and therefore has the advantage of allowing the organization to act according to its risk tolerance or perception (e.g. Ewing and Campbell, 1994; Marszal, 2001, Frank, 2010; Hallowell, 2010) and change the scale levels to suit the levels of risk factor concentration that it finds acceptable.

The third step of the assessment phase is used to estimate the impact of each undesirable event on the progress of a project. The list of impacts is determined and causation connections are made from the identification phase (Figure 4.2). The model uses a grid to estimate the magnitude of the loss suffered by the company.
The impact of an undesirable event is calculated as follows:

$$I_i = Max_{impacts\ set\ by\ the\ organization(i)} \tag{4.14}$$

Once the level of each identified risk has been calculated (Eq. (4.12)), the fourth step of the evaluation phase is undertaken to prioritize the risks.

4.5.1.3 Phase 3: Actions

The selection of actions to manage identified risks will depend on risk prioritization and multi-criteria analysis (AHP), taking into account technical and economic constraints. The main purpose of this phase is to eliminate, reduce or make available the necessary means for workers to protect themselves from hazards. Actions involving monitoring and controlling must be in line with the principle of continuous improvement in quality (ISO 9000), safety (OHSAS 18001) or environment management systems (ISO 14000). The prevention plan includes prevention actions that must be assigned to individuals who have knowledge and expertise in the field and who must: (1) take responsibility, (2) choose the best approach to resolve the danger and (3) define its scope of intervention (Dorofee et al., 1996).

4.5.2 Application of the proposed approach

4.5.2.1 Case study background

Industrial relocation is a form of globalization. The emergence of offshoring is caused by two factors: technological progress and international agreements that promote trade. Faced with fierce competition, businesses turn to outsourcing, which has become one of the most common ways to reduce production costs and expand into new markets. Manufacturers choose the least developed countries for several reasons, but especially because of the availability of cheaper labor. Relocation involves many challenges, including dealing with a lack of safety culture, a condition encountered in many developing countries. In addition, the chosen project management approach often gives priority to increased productivity and reduced delays at the expense of the health and safety of workers.

Society in developing countries is often unfamiliar with worker health and safety protection culture (Baram, 2009) and supports 80% of the global burden of accidents and occupational diseases (DCPP, 2007). The transfer of production from developed to developing countries is increasing (Hämäläinen et al., 2009). Poorly trained and sometimes illiterate workers are exposed to new risks and environments (Baram, 2009).

The present study is focused on a major expansion of a factory for assembly of mechanical parts. This expansion is intended to double production capacity and improve workshop organization. The project includes all fields of activities, in particular architecture, structural and mechanical processing and all related systems. The case study is limited to installation of the new production line and the various facilities in the new building without considering construction aspects. Our primary concern is identifying the elements of OHS risk. This theoretical example was chosen to demonstrate the novel aspect of the proposed approach to risk analysis and to test its conceptual model in the hope of providing small-to-medium-sized businesses (involved in relocation projects) with a simple and inexpensive tool for integrating OHS risk management.

4.5.2.2 Phase 1: Risk identification

Risk identification was done using the know-how of the project team and experts and the accident and incident history of the company or of a similar company (same trade, environment, etc.). An initial consultation of the database tables allowed the team to narrow down its research.

In order to identify the risk factors, the team used adapted tables of industrial risk factors. These were developed with the aid of the MOSAR method (organized systematic method of risk analysis) and on the basis of the industrial risk records in the INRS Guide (INRS, 2004) to help evaluators detect risks in small businesses and institutional organizations (Curaba et al., 2009). The team then selected, depending on the type of risk, the factors judged as capable of having an influence on the course of the project. Appendix II summarizes the corresponding details for each risk factor.

Table 4.2 summarizes the undesirable events identified in the case of the factory expansion project.

Tableau 4.2 Case study: undesirable events in OHS

Undesirable event	
Code	
E1	Work-related illness
E2	Drop in productivity
E3	Drop in quality
E4	Inadequate design
E5	Pollution
E6	Explosion and fire

Table 4.3 lists the aspects of the project that could suffer negative impact.

Tableau 4.3 Case study: aspects vulnerable to negative impact

Impact	
Code	
IP	On performance
IC	On cost
ID	On delays
IE	On the environment

The causal links are shown schematically in Figure 4.4, in which each link (arrow) represents possible risk.

Example:

- R1 is the risk of work-related illness caused by mechanical factors (MF) and by ambient physical and other nuisance factors (AF).
- The impact of R1 could affect two aspects of the project: performance and cost.

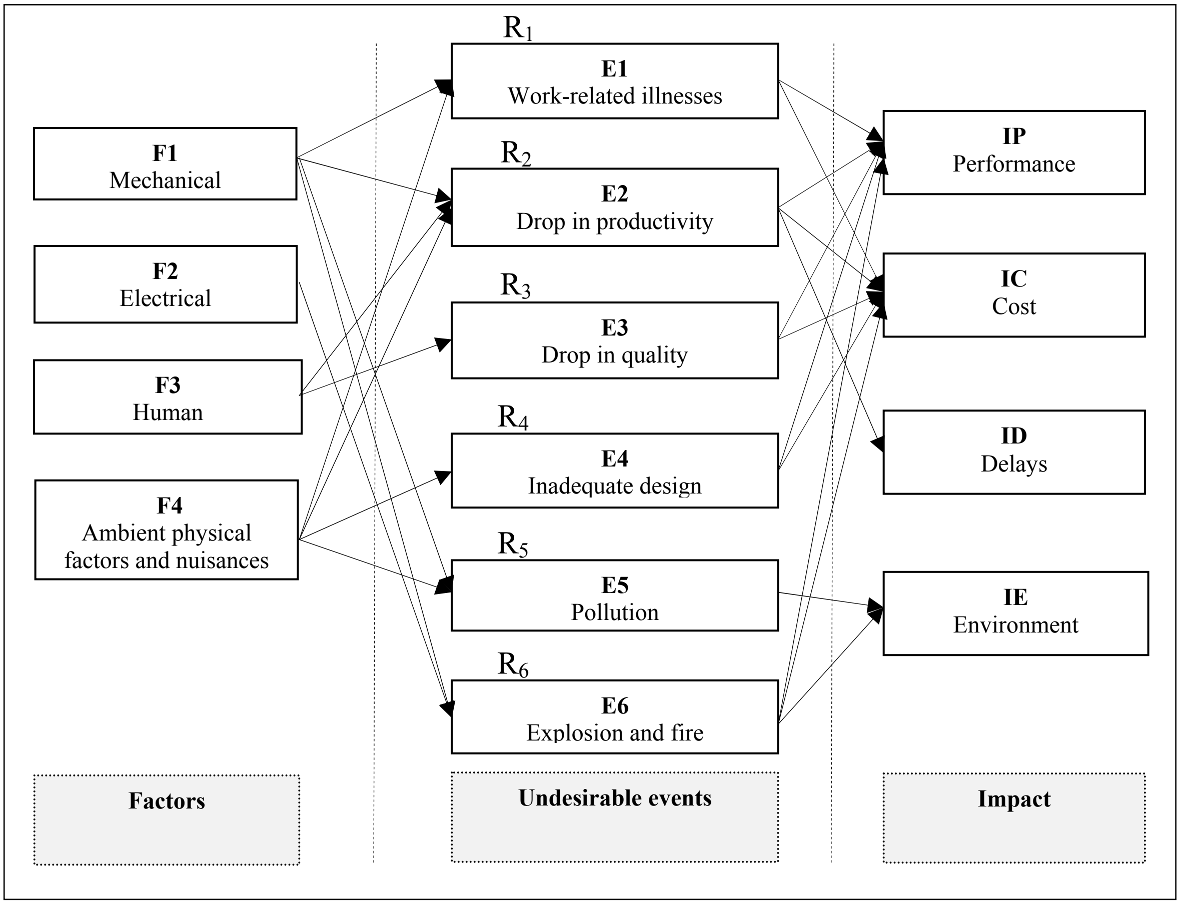

Figure 4.4 Case study: links between undesirable events, their risk factors and their impact

4.5.2.3 Phase 2: Risk assessment

Based on binary comparisons, the relative significance of each risk factor is calculated using the AHP method. Appendix I provides the basis of the calculation, attributing a numerical value to each verbal decision. Once the relative significance is calculated for each factor, the overall significance of each category of risk factors is evaluated in order to assign weighting factors. The overall significance is determined by calculating the relative significance of each category of factors using Expert Choice© software. Expert Choice© allows identification of data entry errors and thus eliminates one of the most frequent causes of inconsistent judgments. The instant control of inconsistency of Expert Choice© allows experts to avoid having to provide arbitrary judgments.

Based on binary comparison matrices for each category of risk factor in relation to various undesirable events (Appendix III), Table 4.4 highlights the weight of influence (relative significance value) estimated by AHP. It should be noted that the consistency of each comparison matrix is verified each time the team renders a decision.

Tableau 4.4 Ranking by the influence level of risk factors (AHP)

Undesirable event		**Influence of the risk factor**			
Code		++	+	-	- -
E1	Work-related illness	F4	F1	F3	F2
E2	Drop in productivity	F3	F4	F1	F2
E3	Drop in quality	F3	F1	F4	F2
E4	Inadequate design	F1	F2	F3	F4
E5	Pollution	F1	F4	F2	F3
E6	Explosion and fire	F2	F1	F3	F4

To determine the overall significance (OS) of each category of risk factors, multiplication of its relative significance value for each undesirable event is done. This calculation is used to assign the weighting value to each risk factor category.
Results (AHP):

$$OS_{F1} > OS_{F4} > OS_{F3} > OS_{F2}$$

Weightings are assigned to each of the risk factor categories as a function of their overall significance (OS) ranking, based on the values in Table 4.5. The weighting thus increases the numerical value of the risk factor categories having greater influence on the occurrence of undesirable events.

Tableau 4.5 Case study: assignment of risk factor category weighting

OS rank	**Weighting assigned**
1	4
2	3
3	2
4	1

In the present case, Table 4.6 summarizes the assignment of weighting to risk factor categories.

Tableau 4.6 Case study: assignment of weighting to risk factor categories

OS rank	Risk factor category	Weighting
1	Mechanical factors (F1)	**4**
2	Ambient factors and other nuisances (F4)	**3**
3	Human factors (F3)	**2**
4	Electrical factors (F2)	**1**

For each type of undesirable event, there is a concentration of risk that is calculated as shown in Table 4.7 using the number of factors and the weighting associated with each risk category that is linked according to Figure 4.4 and Eq. (4.13). The risk concentration for each event is thus proportional to the number of linked risk categories and to the number of factors and the weighting associated with each of these.

Tableau 4.7 Case study: calculation of the risk factor concentrations for each undesirable event

Undesirable event Ej	Linked risk factor category (Fig. 4.4) Fi	Factors in the category (Appendix II) x_i	Weighting (Table 4.6) y_{ij}	$x_i y_{ij}$	Fraction of total Equation (4.13)
E1	F1	7	4	28	--
	F4	7	3	21	--
			Sub-total E1	***49***	***0.23***
E2	F1	7	4	28	--
	F3	3	2	6	--
	F4	7	3	21	--
			Sub-total E2	***55***	***0.26***
E3	F3	3	2	6	--
			Sub-total E3	***6***	***0.03***
E4	F4	7	3	21	--
			Sub-total E4	***21***	***0.10***
E5	F1	7	4	28	--
	F4	7	3	21	--
			Sub-total E5	***49***	***0.23***
E6	F1	7	4	28	--
	F2	2	1	2	--
			Sub-total E6	***30***	***0.14***
			TOTAL	**210**	***100%***

The probability that an undesirable event will occur is determined from the concentration of linked risk factors calculated for that event type. For example, Hallowell and Gambatese (2009) used data from American industry to convert the impact of accidents into probabilities in construction projects. We used Table 4.8 as a numerical scale for the conversion of risk factor concentration to probability of occurrence of the event.

Tableau 4.8 Case study: Conversion of concentration to probability

Relative concentration of risk	Probability of occurrence
0 to 0.15	0.1
0.16 to 0.25	0.3
0.26 to 0.5	0.5
0.56 to 0.75	0.7
0.76 to 0.9	0.9

Based on Table 4.8, Table 4.9 provides the probabilities of occurrence of each of the undesirable event types considered.

Tableau 4.9 Case study: Estimation of the probability of each undesirable event

Undesirable event	Relative concentration of risk	Probability of occurrence
E1	0.23	**0.3**
E2	0.26	**0.5**
E3	0.03	**0.1**
E4	0.10	**0.1**
E5	0.23	**0.3**
E6	0.14	**0.1**

The impact on performance, cost, delays and the environment are evaluated on the basis of a scale corresponding to the magnitude of the losses suffered by the company (Table 4.10):

- Minor impact: [1, 2 or 3]
- Moderate impact: [4, 5 or 6]
- Strong impact: [7, 8 or 9]

Tableau 4.10 Case study: Estimation of impact of undesirable events on the project

Undesirable event	**Impact on Performance IP**	**Impact on cost IC**	**Impact on delays ID**	**Impact on the environment IE**
Work-related illness (E1)	7	7	3	1
Drop in productivity (E2)	9	7	6	1
Drop in quality (E3)	7	6	6	1
Inadequate design (E4)	6	6	4	5
Pollution (E5)	7	5	2	9
Explosion and fire (E6)	7	7	7	8

The level of the risk or risk index (Table 4.11) associated with each undesirable event is calculated using Eqs. (4.12) and (4.14).

Tableau 4.11 Case study: Calculated levels of risk or risk index

Undesirable event	**Max (IP, IC, ID, IE)**	**Probability of occurrence**	**Level of risk (i)** Eq. (4.12)
Work-related illness (E1)	7	0.3	**2.1**
Drop in productivity (E2)	9	0.5	**4.5**
Drop in quality (E3)	7	0.1	**0.7**
Inadequate design (E4)	6	0.1	**0.6**
Pollution (E5)	9	0.3	**2.7**
Explosion and fire (E6)	8	0.1	**0.8**

Finally, Table 4.12 summarizes the hierarchy and prioritizing of the risks based on the values obtained in the previous step. This prioritizing will allow the project team to control the risks in a stepwise manner.

Tableau 4.12 Case study: Ranking of the risks by priority

Undesirable event	**Level of risk (i)**	**Priority**
Drop in productivity (E2)	4.5	**1**
Pollution (E5)	2.7	**2**
Work-related illness (E1)	2.1	**3**
Explosion and fire (E6)	0.8	**4**
Drop in quality (E3)	0.7	**5**
Inadequate design (E4)	0.6	**6**

4.6 Discussion

The simulation illustrates the use of the proposed approach, which ranks risks as a function of their impact in terms of undesirable events. In the example studied, the calculation allowed us to differentiate the OHS risks from the risk of drop in quality. For the paired comparisons of the identified risk factors we chose Expert Choice© software, based on the following advantages (Al-Harbi, 2001; Larson and Forman, 2007):

- Minimizing difficulties associated with calculation and verification of the logical consistency of the judgments.
- Avoiding influence of experts and domination by a single group member.
- Facilitating modification of judgments and data updates.
- Possibility of voting when no consensus can be reached.
- Calculating and displaying the sensitivity analysis used to test the robustness of the judgments.
- Documenting the decision process and allowing the traceability of modifications.

The verbal judgments (Appendix I) supported by Expert Choice© were important in the decision-making process. Forman and Selly (2002) note that humans are comfortable using words to measure the intensity of feelings and comparing two entities. This scale allows reliable comparison without specifying the exact value of the significance of one entity compared to another.

The proposed approach allows the combination of several tools used in practice, namely know-how and feedback from experience to fill databases and to some extent the AHP method for comparing categories of risk factors. In evaluating risks, the proposed approach uses the new concept of concentration of risk factors for estimating probabilities of occurrence of events. The risk management team can calculate the concentration of factors and do the paired comparison of risk factor categories quickly and with ease.

The AHP model offers the advantage of decomposing a complex system into a hierarchical structure showing the links between risk factors, undesirable events and their impact, allowing lucid evaluation of dangers. The possibility of managing conflicting criteria using AHP also allows a more realistic evaluation of OHS risks. The AHP method reduces the inconsistency of expert judgments and appears acceptable in terms of reliability (Fera and Macchiaroli, 2009). The feature of combining both quantitative and qualitative data and controlling consistency of expert judgments makes AHP the most applicable to the proposed approach.

The proposed approach is iterative, which allows modifications and revision of weighting criteria and of judgments based on project advancement and also supports testing of the measures taken to reduce or eliminate identified and prioritized OHS risks.

4.7 Limitations and recommendations

Given the complexity of judging and comparing OHS risk factors, we grouped them into categories in an attempt to simplify the paired comparison. This allowed us to compare risk factors initially using a combination of empirical data and subjective judgments. This evaluation was limited to the causal links that we identified in the first phase of the proposed approach without evaluating reinforcement effects between risk factors. We will present in a future article paired comparison of risk factors in an attempt to identify and evaluate reinforcement effects.

Several authors have criticized the constraining of evaluators to predefined choices of comparison criteria, the inversion of the coefficient of comparison, the use of the interval scale and especially the lack of theoretical bases of the AHP method (Belton and Gear, 1983; Harker and Vargas, 1987; Dyer, 1990; Perez, 1995; Al-Harbi, 2001). We agree with the conclusions reached by Forman and Selly (2002) that AHP "*is not a magic formula or model that finds the 'right' answer. Rather it is a process that helps decision-makers to find the* *'best' answer*". The AHP model also does not exclude inconsistent judgments. When such inconsistency occurs, it may contaminate the entire series of judgments. Its causes are listed below (Forman and Selly, 2002):

- Data entry errors, especially when filling the judgment matrices (the most frequent cause).
- Missing information: if judgment is based on incomplete information and knowledge, it becomes random and potentially inconsistent.
- Poor concentration: evaluator fatigue and motivation are factors to consider.
- Modeling problems: the underlying model and hierarchical structure must be representative of reality.

Expert Choice© allows identification of data entry errors and thus eliminates one of the most frequent causes of inconsistent judgments. This tool also allows us to monitor the degree of inconsistency by providing an instantaneous display of the compatibility index of each comparison matrix. We consider the generalized use of AHP as a decision aid in industrial practice to be proof of its success and reliability. In future work, we shall use other multi-criteria decision aid methods such as MACBETH, ELECTRE and PROMOTHEE in order to expand the range of potential users of the proposed approach.

In this article, the final phase of the proposed approach, called "action", is not included in the case study, since it is based on a list of actions and a preventative plan is generally implemented on the shop floor. In this plan, each action will be grouped into one of four strategies, as presented in part by Aubert and Bernard (2004):

- Mitigation is concerned with the measures implemented in order to reduce the probability of occurrence of an undesirable event.
- Deflexion consists of changing the direction of the impact of an undesirable event.
- Establishment of a contingency plan consists of implementing measures that have the effect of decreasing the impact of an undesirable event.
- Assuming or accepting the risk.

An OHS database corresponding to the field must be created in order to facilitate faster identification of the elements of risk using the approach devised in the present study. The resulting increase in the responsiveness of the approach at this stage will save time and thus allow the group of experts and project manager to concentrate more on identifying the causal links with greater reliability and realism.

We plan to consolidate our approach by examining several industrial fields in order to upgrade the input data with observations, interviews and analysis of performance obtained from a variety of project teams. Once the database containing the elements of risk has reached a sufficient level of completeness, risk (or danger) sequences will be taken into consideration. OHS risk will be considered primarily as an entity interacting with other types of risk that must be managed in an organization.

4.8 Conclusion

Numerous industrial accidents have exposed the ineffectiveness of conventional risk evaluation methods as well as negligence with respect to factors having major impact on the health and safety of workers and nearby residents. Lack of reliable and complete evaluations from the beginning of a project will generate bad decisions that could end up threatening the very existence of an organization.

This article presents a novel risk-factor-based approach comprising eight steps and allowing the integration of OHS risks, based on identifying elements of risk and on a new concept of risk factor concentration weighted by multi-criteria comparison using the AHP method and Expert Choice© software. This OHS risk identification and evaluation is integrated upstream in the risk analysis process in order to increase the effectiveness of preventative measures undertaken at the outset of a project.

The proposed approach allows quick prioritizing of identified risks and allows evaluators to identify additional potential causes of undesirable events without nullifying the previous risk element compilation effort. The simplicity of the approach should facilitate its use in small and medium-sized businesses without requiring a major investment.

The practical use of the approach was tested using a simulated case study and the results of the paired comparison step were calculated using the decision-aid software Expert Choice©. We were thus able to determine, by applying more rigorous evaluation of factors associated with human health and safety and integrating these into the risk analysis, that the business in this case study was more exposed to the OHS risks than to the risk of drop in quality.

CHAPITRE 5

ARTICLE 3: INTEGRATION OF OHS INTO RISK MANAGEMENT IN AN OPEN-PIT MINING PROJECT IN QUEBEC (CANADA)

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Minerals: Safety & Health in Mining,

Volume 1, Issue 1, Page 3-29, 2011.

(doi: 10.3390/min1010003)

Abstract

Despite undeniable progress, the mining industry remains the scene of serious accidents revealing disregard for occupational health and safety (OHS) and leaving open the debate regarding the safety of its employees. The San José mine last collapse near Copiapó, Chile on 5 August 2010 and the 69-day rescue operation that followed in order to save 33 miners trapped underground show the serious consequences of neglecting workers' health and safety.

The aim of this study was to validate a new approach to integrating OHS into risk management in the context of a new open-pit mining project in Quebec, based on analysis of incident and accident reports, semi-structured interviews, questionnaires and collaborative field observations. We propose a new concept, called hazard concentration, based on the number of hazards and their influence. This concept represents the weighted fraction of each category of hazards related to an undesirable event. The weight of each category of hazards is calculated by AHP, a multicriteria method.

The proposed approach included the creation of an OHS database for facilitating expert risk management. Reinforcing effects between hazard categories were identified and all potential risks were prioritized. The results provided the company with a rational basis for choosing a suitable accident prevention strategy for its operational activities.

5.1 Introduction

Canada is a world leader in the mining industry and among the largest producers of minerals and metals (MAC, 2009). The mining industry is a major contributor to the Canadian economy, employing 351,000 people in mineral extraction and related sectors and contributing $40 billion to the GDP in 2008 (MAC, 2009). According to a recent study by the Quebec Mining Association (QMA and QMEA, 2010), mineral extraction contributed $7 billion or 2.4% of the GDP of the province of Quebec in 2008, employing over 52,000 people earning total wages estimated at $1.9 billion.

In Canada, statistics published recently shows that the mining industry is among sectors with the highest injury incidence rate (IIR) (HRSDC, 2011). The four most hazardous industries are classified according to the IIR as follows: Longshoring (20.34), Energy and Mining (17.64), Air Transport (14.39) and Bridges and Tunnels (11.67). According to recent CSST statistics based on five industrial sectors, the mining sector is ranked fourth with 792 job-related accidents and second with 156 cases of job-related illness (CSST, 2009). In comparison, the construction and civil engineering sector is ranked first with 6,881 job-related accidents and 298 cases of job-related illness. It is noteworthy that mining accidents have been reduced by 76% over the past 20 years (QMA, 2010). Despite this remarkable performance in Quebec and the positive trend in Canada, the mining industry has experienced several serious and fatal accidents. Among these are the incidents in the Stobie mine near Sudbury (Ontario), in which a muck slide killed two experienced miners (June, 2011), and the Lac Bachelor mine in Desmaraisville (Quebec), in which three workers died at the bottom of a flooded shaft (October, 2009). It is cold comfort that the number of victims was fewer than in the Ferderber mine accident in Val d'Or in 1980, resulting in eight deaths and at least 16 serious injuries (Sweeney and Scoble, 2007), or in the Westray disaster in Nova Scotia in 1992, which killed 26 coal miners.

The OHS performance of the mining industry varies from one country to another and does not reflect the current trend in Quebec. In the United Kingdom, quarries are considered the most dangerous industrial sector, with injury and accident rates far exceeding those of the construction industry (Foster et al., 2008). It is important to note also that miners are four to five times more likely to die in South African mines than in Australian mines (Hermanus, 2007). In the USA, the mining sector performance is clearly improving, despite production growth under unfavorable operating conditions and changes in methods and mining equipment (Esterhuizen and Gürtunca, 2006). China also suffers from frequent serious mining accidents. A recent statistical study ranked Chinese coalmines among the top three sources of fatalities (37.26% between 2001 and 2008) (Zhangtao, 2010). Data for other developing countries are not available, but the mass media provides some indication of the current status of the global mining industry, painting a rather dismal picture.

The mining industry is currently experiencing a period of intense activity and growth with new projects and increasing numbers of workers (QMA, 2010). Increasing metal prices have increased profit margins and are making production and exploration more worthwhile. The recent launch of the "Plan Nord" program in Quebec, which includes several planned mining projects with anticipated investments totaling $80 billion, is an indication that the trend is expected to continue. In this favorable economic situation, the renewal of the aging workforce, the scarcity of workers and the arrival of a new diverse workforce (immigrants, First Nations people, etc.) represent significant OHS challenges (Ouellet et al., 2010; QMA, 2010).

The skill and the means used in risk management vary from one industry to another. The construction industry is among the most developed in this area in North America. Sectors such as nuclear energy, aviation and chemical industries are leaders in the use of sophisticated and advanced tools of risk identification and assessment (Young, 2005; Vernero and Montanari, 2010). However, integration of OHS into risk management remains incomplete and the methods and tools being used are poorly suited (Fera and Macchiaroli, 2010).

The aim of the proposed approach was to manage and evaluate the integration of OHS risks with other types of risk in the context a new mining project. Several risk identification techniques and multi-criteria analysis were adapted for this purpose and a new concept called hazard concentration was developed. This concept represents the weighted fraction of each category of hazards related to an undesirable event. The weight of each category of hazards is calculated by the AHP method. When the hazard concentration increases, the probability of an undesirable event increases (Badri et al., 2011a). In an earlier study, the example of the expansion of a manufacturing facility revealed that the proposed approach achieves the goal of integrating OHS into risk management. In this article, we present a preliminary validation of the proposed approach in the mining sector, based on action research with the active involvement of the industrial partner. We start by discussing in Section 5.2 the current level of integration of OHS and the tools used to manage risks in the mining industry. Section 5.3 presents the action research methodology adopted for the study. In Section 5.4, we summarize the risk-factor-based approach and important points to retain. Section 5.5 presents the implementation of the results of this approach in the case of the open-pit mine. In Section 5.6, we discuss the results, the impact of our study and the opportunities for future research in order to generalize our concepts to Quebec's gold-mining industry. Finally, Section 5.7 presents our conclusion.

5.2 Literature Review

OHS is gaining importance in the field of industrial projects management. Thanks to legislation (Gambatese, 2000b; Hallowell and Gambatese, 2009), improvement of several management standards (Hare et al., 2006), development of a culture of safety (McKay and

Lacoursière, 2008; Cai, 2009; Molenaar et al., 2009), better organization of tasks and responsibilities (Kontogiannis, 2005), improved communication (Huls, 2005) and the emergence of several new decision support tools and approaches (Gibb et al., 2006; Hare et al., 2006; Cameron et al., 2008; Larry Grayson et al., 2009; Fung et al., 2010), OHS is becoming a major criterion in project management alongside quality, cost and delays. Being able to offer work in safe environments is becoming essential for attracting and retaining skilled labor (Hull, 2006).

The level of integration of OHS varies from one industry to another. The methods and criteria for measuring this integration are not universally accepted among the different sectors. For example, petrochemicals, construction, mining and manufacturing all use different approaches to OHS integration (e.g., statistics, methods of risk assessment, involvement of design engineers and subcontractors, etc.) (Gambatese, 2000a; Gambatese, 2000b; Foster et al., 2008). These differences stem from the urgency implicit in legislation and laws, the danger associated with the industry, the wherewithal to invest in the promotion of OHS and public pressure (Gambatese, 2000b).

Although the mining sector is being built more and more on leading-edge technologies, the human contribution in mining operations is still prevalent. Interaction between vehicles, equipment and humans in generally limited spaces and in the presence of concentrated energies in an environment in perpetual change gives this industry a dynamic character (Kumar and Paul, 2004) such as that seen in construction (Hallowell and Gambatese, 2009). According to Hermanus (2007), recent developments such as the increasing number of subcontractors, the emergence of new mining firms and the increasing presence of women place new constraints on the mining industry. Development of technical and engineering aspects such as rapid sharing of information and the use of specialized equipment with the aim of improving health and safety in mines has led to much progress (Jennings, 2001) and the recognition of several emerging risks (e.g., noise, vibrations, ergonomic issues, etc.).

In view of mining project volume and the dominance of economic and budgetary factors, integration of human factors is not always considered as an important element in project evaluation (Bruseberg, 2008). Several researchers have attempted to integrate human factors and OHS risks into the management of various mining projects and several efforts have been made to improve risk comprehension and evaluation (Jansen and Brent, 2005; Schutte, 2005; Terbrugge et al., 2006; Wang et al., 2008). Jansen and Brent (2005) used an integrated approach to risk management based on a human behavior study and concluded that proper organizational culture is an essential condition to promote responsible and safe behavior. Schutte (2005) used participatory ergonomics intervention to eliminate OHS risks related to noise caused by mining equipment and involved legislators, mining firms, workers and equipment suppliers and concluded that in order to benefit from participatory ergonomics, all work management practices must undergo marked changes. Kumar and Paul (2004) proposed an OHS risk assessment and management manual involving miners and managers based on a statistical study of work accidents occurring in open-pit mines. Terbrugge et al. (2006) used a risk analysis approach designed with fault tree analysis (FTA) to categorize the risks associated with design problems of slopes in open-pit mines. Risk categories are identified according to their consequences for workers, equipment, production, economics, various industrial operations and public relations. Through the involvement of technical staff and the definition of the level of acceptable risk in an organization, the mining industry can improve design and make proactive decisions to protect workers (Terbrugge et al., 2006).

Risk evaluation is based on assessing the probability (or frequency) and impact (or consequence) of one or more undesirable events (Gibb et al., 2006; Larry Grayson et al., 2009; Fung et al., 2010;). Assessment of the probability of equipment failure is sometimes based on expert subjective judgment without checking for consistency (Terbrugge et al., 2006). The limitations of assessing risks associated with human factors have become obvious as a result of numerous industrial accidents over the years. To the best of our knowledge, systematic integration of OHS risk has yet to find its way into technical or environmental feasibility studies of mining projects (Schafrik and Kazakidis, 2011). Feasibility studies of mining projects usually integrate environmental impact without using methods for assessing the total number of identified risks overall. Risk evaluation tends to be influenced by the economic viability of a project more than by its long-term consequences for humans and the environment (Hagigi and Sivakumar, 2009). The mining industry is concerned primarily with chemical, mechanical, geotechnical and other immediate physical risks (Owen and Potvin, 2003). For many years, this industry has focused its risk reduction efforts on the improvement of procedures and the establishment of training programs (Ghosh, 2010). However, integrated risk management has become a topic of great interest (Owen and Potvin, 2003) and the need for adapted and appropriate approaches to integrating OHS in this sector has been confirmed (Saleh and Cummings, 2011).

Our aim is to help the mining industry benefit from certain tools, techniques and approaches that have proven efficient in the industrial sectors most advanced in OHS integration. This study is limited to risk identification and assessment. Risk identification and assessment are the most important steps towards hazard reduction (Liu and Guo, 2009; Fung et al., 2010) and they present several challenges (Hagigi and Sivakumar, 2009). We have adapted several techniques of risk identification and multi-criteria analysis (AHP) and we have developed the new concept of hazard concentration in order to manage OHS risks along with operational risks in the context of a new mining project.

5.3 Methodology

The risk factor approach is designed to integrate OHS into industrial project risk management. An application of this approach has been simulated using the example of the expansion of a manufacturing facility (Badri et al., 2011a). The same approach is now being applied in the mining sector.

In this article, we apply action research methodology to improve and validate the risk factor approach. The choice of action research methodology was motivated by the participation of a mining company wishing to benefit from a support tool for the decision to integrate OHS into risk management for the purposes of a new project. Since human interaction and influences are significant in OHS, it was necessary to introduce a sociological dimension to the engineering approach in order to make the management complete. Action research is the methodology most favored by the World Health Organization and the US Centers for Disease Control because it allows commitment and involvement of the stakeholders in order to resolve problematic situations quickly (Guzman et al., 2008).

Action research has been grouped into several categories (Lavoie et al., 1996) differentiating by degrees of participation: (1) research on action, but without action; (2) the partner exposes the problem and the researcher proposes solutions; and (3) total commitment of the partners in the research (Desroches, 1982). The last category is also referred to as “soft systems methodology” (Checkland, 2000). The action research adopted in the present study falls between these two categories: the industrial partner exposes the problem and the researchers suggest solutions. In our case, the problem arose from the lack of a tool for OHS integration into the risk management portion of the mining project and from the absence of assessment of the impact of OHS risk on the project and the organization. To propose solutions, we used the approach by risk factors based on soft systems methodology. The involvement of the industrial partner throughout the intervention improved the fit between the conceptual model underlying our approach and the reality of the constraints on the open-pit mining business. Details of the methodology are presented in Figure 5.1.

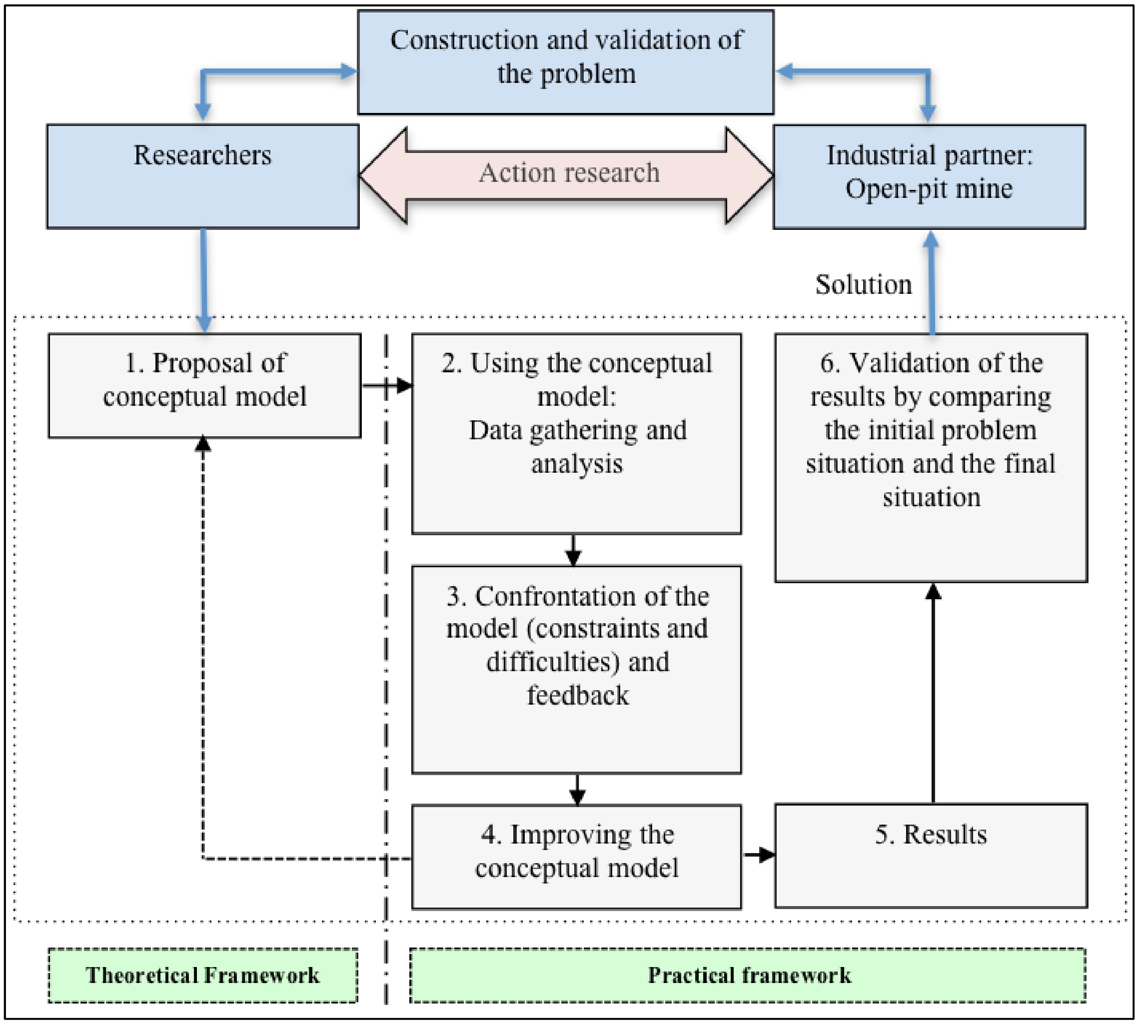

Figure 5.1 Methodology of application and validation of the proposed approach

Data collection in this action research is mainly based on semi-structured voluntary interviews combined with questionnaires. Interviews were done using a questionnaire previously validated by the researchers and the company representatives. The questionnaire is designed using the list of occupational hazards raised by Curaba et al. (2009). These authors have developed lists of occupational hazards using the MOSAR method. These lists are used to achieve and improve the assessment of occupational hazards in European industry. We begin by verifying the presence of these hazards in our study and we add specific hazards identified in the open-pit mining business.

We also use collaborative observations and analysis of incidents and accidents reports. The observations were done using a checklist that describes the details to be observed in each zone of the mine. All reference material received approval from the research ethics committees (University of Quebec in Abitibi-Témiscamingue and École de technologie supérieure) before starting the project.

5.4 Results and Discussion

5.4.1 The new approach based on risk factors

For the purposes of the present research, the previously published risk factors approach was used (Badri et al., 2011a). This approach, based on the principle of continuous improvement, features the following steps in risk management: (1) identification of risk elements; (2) risk assessment and (3) action planning. The important points to retain in each phase of the approach are highlighted below.

The approach uses several methods and tools such as interviews and questionnaires, observations, methods of multi-criteria analysis (AHP), analysis of incidents and accidents and the new concept of hazard concentration. Figure 5.2 illustrates the phases and steps of the approach and the methods and tools used in each step.

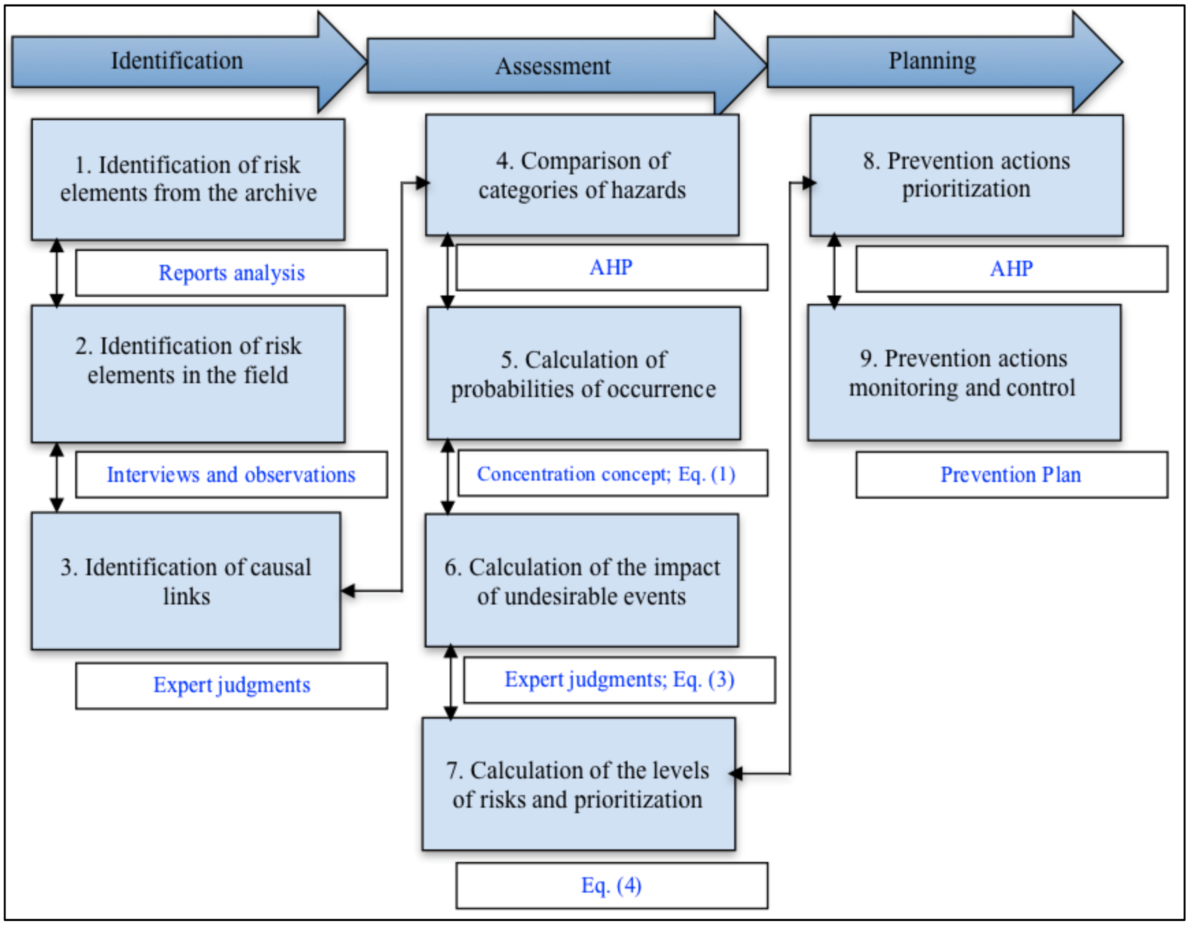

Figure 5.2 Details of the proposed approach based on risk factors

5.4.1.1 Identification Phase

Identification (Figure 5.3) is the most important phase for reliable management of risk (Liu and Guo, 2009). This phase requires much effort and time in order to constitute a database of risk elements in the field (hazards, undesirable events and impact).

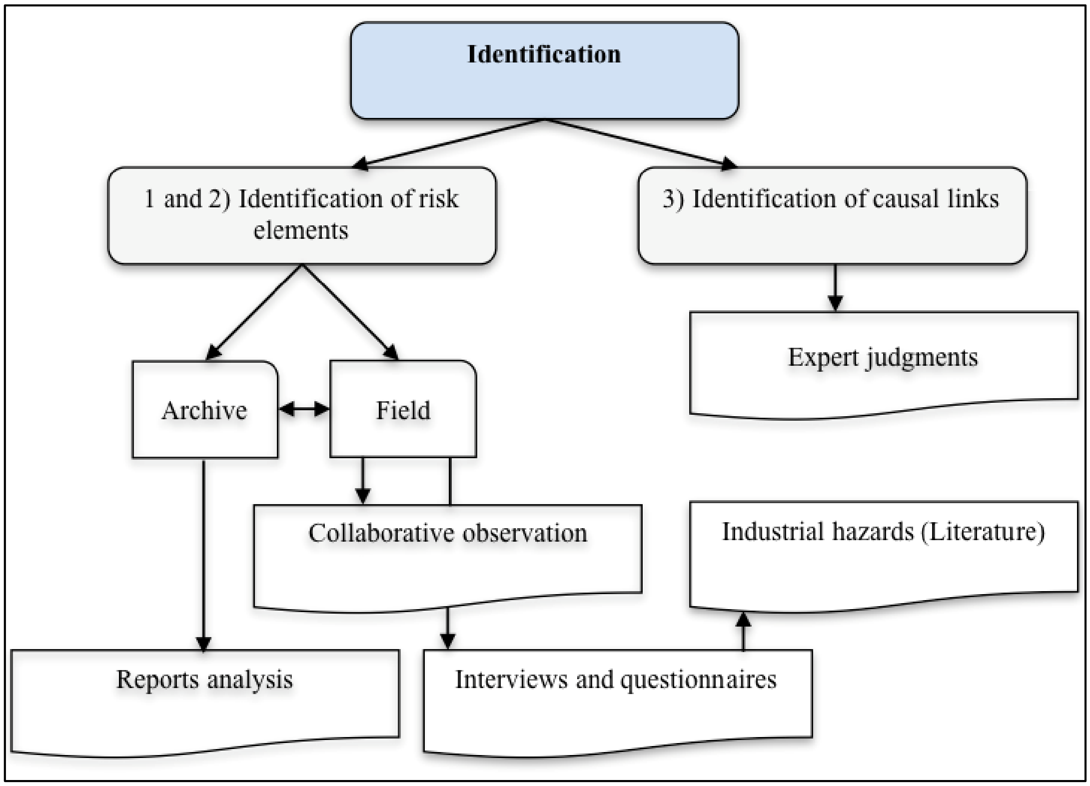

Figure 5.3 Identification phase of the risk-factor-based approach

5.4.1.2 Assessment Phase

Assessment (Figure 5.4) completes identification and is based on expert opinion, multi-criteria analysis (AHP) and the new concept of hazard concentration. This phase requires complete information on the hazards, the people or equipment exposed to risk and the associated effects (Owen and Potvin, 2003).

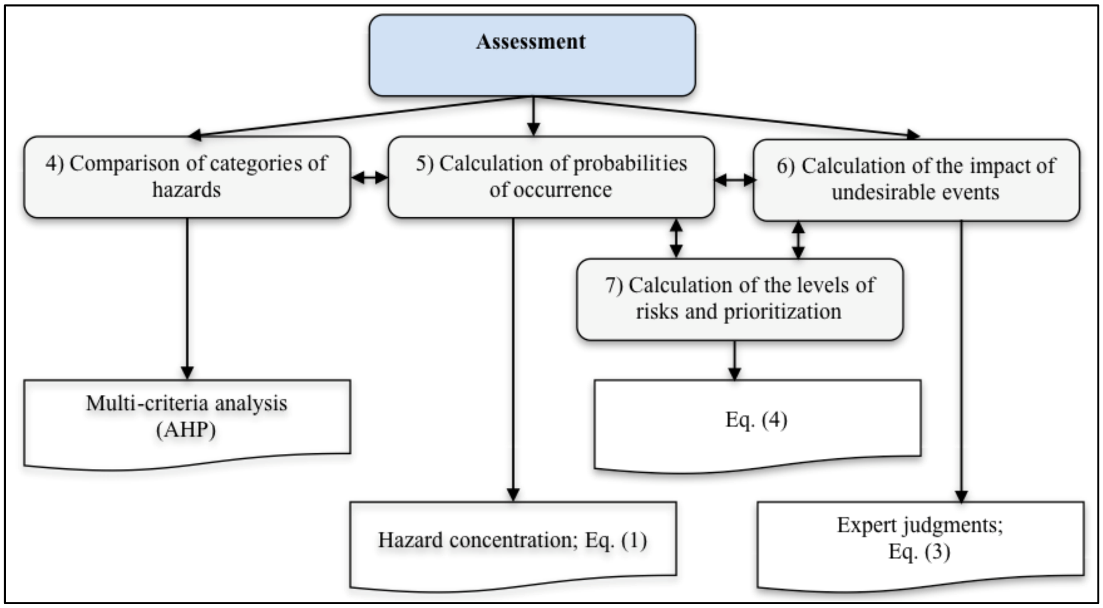

Figure 5.4 Assessment phase of the risk-factors-based approach

It is important to note that the proposed approach uses AHP (Saaty, 2000) supported by Expert Choice© software. The AHP method allows instant testing of the consistency of expert judgments, thus lessening the problem of inconsistent decisions. AHP uses a fixed numerical (or verbal) scale and judgment consistency is defined only within these fixed limits. To the best of our knowledge, AHP has not been used in a study of Quebec mines.

The AHP method was introduced into the OHS field in the 1990s in the USA. This method was used in ergonomic analysis conducted by Henderson and Dutta (1992). It has also been used for ranking of musculoskeletal disorder risk factors (Padma and Balasubramanie, 2009) and to compare the risk factors linked to human errors (Zhang et al., 2009b). Fera and Macchiaroli (2010) recently introduced AHP into a model developed to evaluate risks at work in small and medium-sized industry and service businesses. Ishizaka and Labib (2011) have reviewed AHP methodology, its applications and its limits. Badri et al. (2011a) explain the AHP concept and use of the method in detail.

5.4.1.3 Planning Phase

The planning phase (Figure 5.5) is crucial to the elimination of hazards. The purpose of including multi-criteria analysis in this phase is to minimize the influence of weak managerial decisions on the choice of solutions (Clarke and Ward, 2006), through active involvement of project team members.

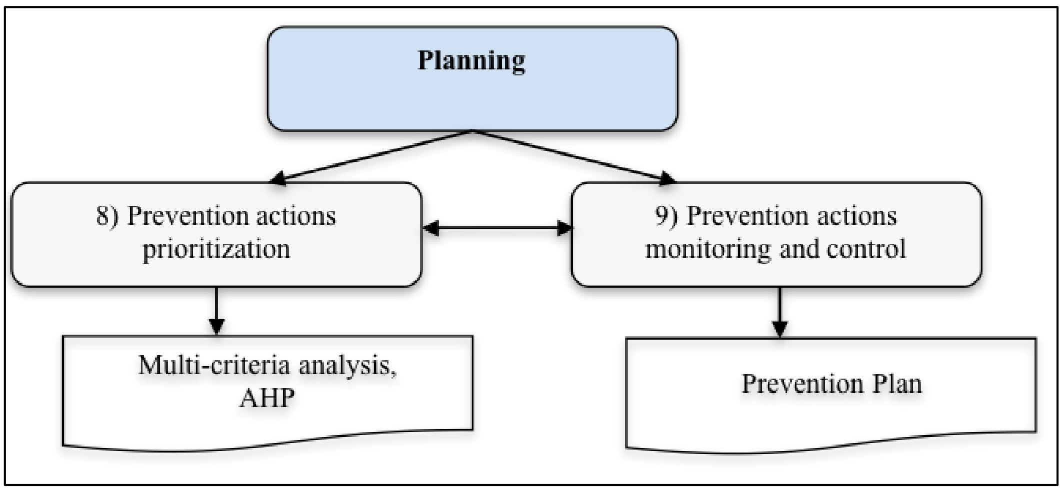

Figure 5.5 Planning phase of the risk-factor-based approach

Finally, we emphasize that the different phases of the proposed approach converge with the majority of OHS laws and regulations (e.g., Loi sur la santé et la sécurité du travail, 2011, Québec and Construction Design and Management Regulations, 2007, UK) and that over the course of the project, the approach is compliant with the following criteria suggested by Baxendale and Jones (2000):

- Systematic consideration of health and safety from the outset of the project.
- Commitment of all workers contributing to the health and safety of people involved in the project.
- Prioritization of actions and elimination of hazards.
- Communication and sharing of information.
- Recording of information for later use.

5.4.2 Context

Our intervention concerned an open-pit gold mine in Quebec and began in September 2010. The mine is divided in two main areas of activity: mining operations and the processing facility, each with totally independent administration. Mining operations refer to the activities surrounding ore extraction, while processing refers to gold extraction. The research began with the direction of mining operations, which involved about 100 people, including the miners, managers and support crews, excluding subcontractors actively involved in various areas of the mine. The main activities undertaken were associated with infrastructure, establishment of crews and preparation of the main pit and residue treatment zones.

Due to constraints on the project start date, non-functional areas, time and so on, we limited our research to the main pit, primary crusher, main conveyor, mechanical maintenance workshop and explosives storage room plus some operational departments (health and safety, mining operations, engineering, maintenance, environment and geology). We defined the areas targeted for the intervention in terms of their criticality and volume of industrial activity in progress and based in part on the work of Kumar and Paul (2004).

The operational departments involved are those directly related to ore extraction and main pit preparation activities. In the risk element identification step, we introduced the analysis of data relating to subcontractors. This component is very important in view of the interaction and overlap of subcontractor activities with those of the mining crews. This interaction is inevitable in starting an industrial project and presents major OHS risks (Spittler et al., 2008). Performance in health and safety of industrial projects is also influenced by the role and quality of subcontractors directly involved in operational activities (Huang and Hinze, 2006; Lingard and Cooke, 2010).

The company gave us authorization to contact those involved and engage in voluntary discussion. We validated extracted data and submitted proposals with managers of certain departments involved. The risk management team was formed mainly of managers of these departments plus researchers. Meetings were conducted and project progress reports were shared with these managers throughout the intervention.

5.4.3 Risk elements and the OHS database

To identify risk elements, the approach provides for three methods of data collection. These are consultation of records of accidents and incidents occurring in the company, semi-structured interviews and collaborative observation in the field. Interviews were done using a questionnaire previously validated by the researchers and the company representatives. The duration of each interview and questionnaire was about one hour. Collaborative observation was done using a checklist that describes the details to be observed in each zone of the mine. All reference material received approval from the research ethics committees (University of Quebec in Abitibi-Témiscamingue and École de technologie supérieure) before starting the project. Interview results, field observations and incident and accident reports were analyzed using a macro of specific calculations in MS-Excel© and MS-Access©.

We began by analysis of accident and incident reports filed since the beginning of company activities, including data relating to subcontractors involved in installations and process start-up. For the analysis of accident records, we identified five major subcontractors (codes S-1, S-2, S-3, S-4 and S-5). These five were present in the mine for more than two years. We classified the data relating to the remaining subcontractors conducting minor operations in the field under code S-6. Data relating to mine workers are classified under the code S-Mine. In the course of the study, a total of 346 reports of incidents and accidents covering 2009 and 2010 were analyzed. The 346 reports analyzed are those approved by the Health and Safety manager. The mining company has only given us access to approved reports. This step was performed with the involvement of the health and safety department. Discussions with workers directly affected provided better understanding of the circumstances. Reports not validated by the manager of the health and safety department were excluded.

The company data included the impact of the incidents in terms of injuries and material damages. Differentiation on this basis was subjective and often focused on material damages. Verbal descriptions of the events and depth of analysis varied widely from one report to another.

Table 5.1 summarizes the risk elements obtained from incident and accidents report for 2009. Analyses showed that most accidents were caused by failure to comply with working methods or instructions as well as lack of experience, training or competence. Undesirable events related to these hazards had impact on equipment (fire, collision and material damages) or on humans (foreign body in the eye, fall, injury).

Tableau 5.1 Analysis of incidents and accidents (S-Mine and Subcontractors, 2009)

S-Mine and Subcontractors: 2009		
	Source of danger	**Undesirable event**
1	Failure to respect working methods: instructions, procedures, hazardous areas, safety equipment, inadequate equipment, locking, vehicle parking	Fire, injuries, foreign body in the eye, loss of balance, fall, collision, material damages
2	Work area constrained, closed, cluttered with obstacles or debris	Pain, jamming, loss of balance, fall, injury
3	Inattention or lack of concentration	Electric shock, injury, jamming of the body
4	Mishandling and/or poor posture	Pain, back pain, injury
5	Frost and ice	Loss of balance, fall, injury and collision
6	Insufficient experience, training or competence	Injury
7	Communication insufficient or lacking	Body jamming or crushing
8	Vehicle operation on slopes	Slip, body or organ jamming or crushing, injury
9	Misjudgement of distance and towing	Collision and material damage

Table 5.2 summarizes risk elements identified in accident and incident reports for 2010. Failure to respect working methods remained the predominant cause of incidents. New hazards related to driving vehicles appeared due to the start of activities for preparing the main pit and residue treatment areas. The number of vehicles and drivers increased during this period. Communication problems arose in association with integrating new workers and from the presence of other subcontractor crews that did not use the same means and

standards of communication. New undesirable events such as pain in upper limbs (back and shoulders) and legs began to occur.

Tableau 5.2 Analysis of incidents and accidents (S-Mine and Subcontractors, 2010)

S-Mine and Subcontractors: 2010		
	Source of danger	**Undesirable event**
1	Failure to respect working methods: instructions, procedures, hazardous areas, safety equipment, inadequate equipment, locking, driving	Injury, loss of balance, fall, collision, material damage
2	Lack of visibility or inattention	Vehicle accidents, damage to power lines
3	Misjudgement of distance and towing	Collision, material damage
4	Work area constrained, closed, cluttered with obstacles or debris	Jamming, loss of balance, fall, injury
5	Inattention or lack of concentration	Electric shock, injury, jamming
6	Lifting or moving heavy loads	Shoulder pain, back pain, sore legs
7	Mishandling and/or poor posture	Pain, back pain
8	Lack or absence of communication	Body or organ jamming
9	Frost and ice	Loss of balance, fall, injuries, collision
10	The vehicle is operating in slope (slope)	Slip, body or organ jamming
11	Communication insufficient or lacking	Driving accident
12	Fatigue	Driving accident
13	Conduct not tailored to the situation or the environment	Collision, material damages
14	Sudden movement	Pain, twisting of the back, back pain
15	High falling object	Injury
16	Non-compliant safety equipment, detachment of fasteners	Injury
17	Fire	Material damage
18	Rockslide or fall	Injury
19	Heatstroke or chill	Pain, fatigue and problems concentrating
20	Climatic conditions (snow)	Lack of visibility, collision, material damage
21	Power sources	Electric shock, burns
22	Use of dangerous equipment, handling without precautions	Injury
23	Moving or unstable part	High fall
24	Evacuation during blasting	Injury
25	Poorly distributed load	Loss of balance, fall, injury
26	Bursting, explosion	Injury
27	Gas leak	Fire and injury
28	Manoeuvre in high winds	High fall, twisting of the back

In 2010, most incidents caused by subcontractors were related to inattention, lack of visibility, congested areas and poor communication. Among the most frequent undesirable events were vehicle collisions and contact with high-energy devices. Lack of concentration during tasks was due to fatigue related to work overload. Failure to respect working methods (protective equipment not used, access to hazardous areas not limited, etc.) was also a common source of danger to all subcontractors. The undesirable events included injuries, fire, fall, electric shock and pain in upper limbs.

Subcontracting was associated with 73% of incidents and accidents, thus confirming the importance of considering and collecting risk elements related to these activities. OHS risks related to the presence of subcontractors is frequently neglected in the management of industrial projects. Grusenmeyer (2007) confirmed the positive correlation between the numbers of industrial accidents and subcontracting activities. Several researchers have highlighted this problem in the construction industry and emphasize the importance of improving communication, task organization and the safety culture (Gambatese, 2000a; Molenaar et al., 2009)

Semi-structured voluntary interviews with workers (43 in all, from all company departments involved in the research) were conducted during working hours to identify new hazards and to confirm certain observations made during the analysis of accident and incident reports, in particular regarding the presence of hazards as defined by Curaba et al. (2009). They were combined with questionnaires and allowed identification of potential dangers in each area of the mine. Details of the experience of these workers in the mining industry are presented in Figure 5.6. Among the workers with more than five years of experience, 65% had more than 10 years of mining experience in various functions.

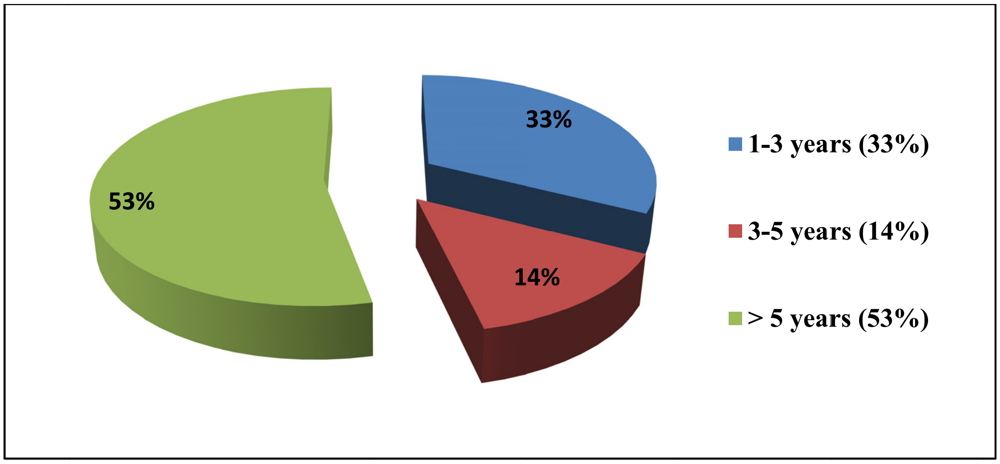

Figure 5.6 Distribution of workers based on their experience

The interviews and the 35 hours of collaborative observations in the field confirmed the potential occurrence of hazards as listed by Curaba et al. (2009). This step allowed us to generalize a portion of these in the case of an open-pit mine. Table 5.3 shows the association between identified hazards and specific areas of the mine based on interviews, questionnaires and observations.

Tableau 5.3 Presence of hazards in specific areas of the mine

Hazard Curaba et al. (2009)*	**Area of the mine**				
	Main Pit	Primary Crusher	Main Conveyor	Mechanical maintenance workshop	Storage of explosives
Mechanical*	✓	✓	✓	✓	
Electrical*	✓	✓	✓	✓	
Ambient physical*	✓	✓	✓	✓	
Human	✓	✓	✓	✓	✓

The criticality of the areas of the mine as ranked by the consulted workers is shown in Figure 5.7. The questionnaire allowed us to synthesize estimates of workers. Workers choose an answer on a scale of three levels of criticality (low, medium and high). Their opinions are based on their knowledge of the company and their expertise and experience in the mining industry. The mechanical maintenance workshop was ranked first, while storage of explosives was ranked last. The perception of explosives storage as less critical was explained in terms of (1) its distant location from areas of operations; (2) access limited to specialized and highly qualified staff; and (3) the rarity of human interaction and man-machine interaction in that zone.

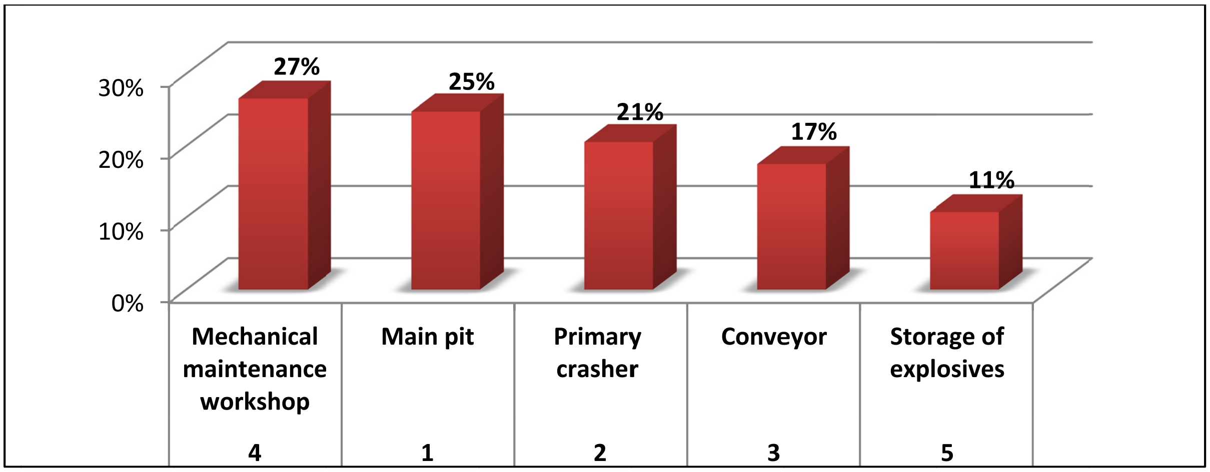

Figure 5.7 Criticality of the areas of the mine as perceived by the consulted workers

Before weighting the influence of each category of hazard to cause an undesirable event, it is important to note the criticality of these as perceived by the consulted workers (Figure 5.8). Their ranking was (1) mechanical; (2) human; (3) ambient physical factors; and (4) electrical (conspicuously lower than the other three). The major concerns were congestion of working areas, the presence of moving parts (tools, conveyors, etc.) and constraining elements (structures, pipes, etc.). Hazards related to ambient physical factors were emphasized, suggesting ergonomic problems in vehicle design (excavators, trucks, drills, bulldozers, etc.) and concern regarding the dusty environment (main pit, traffic patterns, crusher, etc.). Human hazards associated with the problem of communicating with new, inexperienced workers and interacting with subcontractors not knowing the safety rules of the company or not sharing safety concerns were also emphasized.

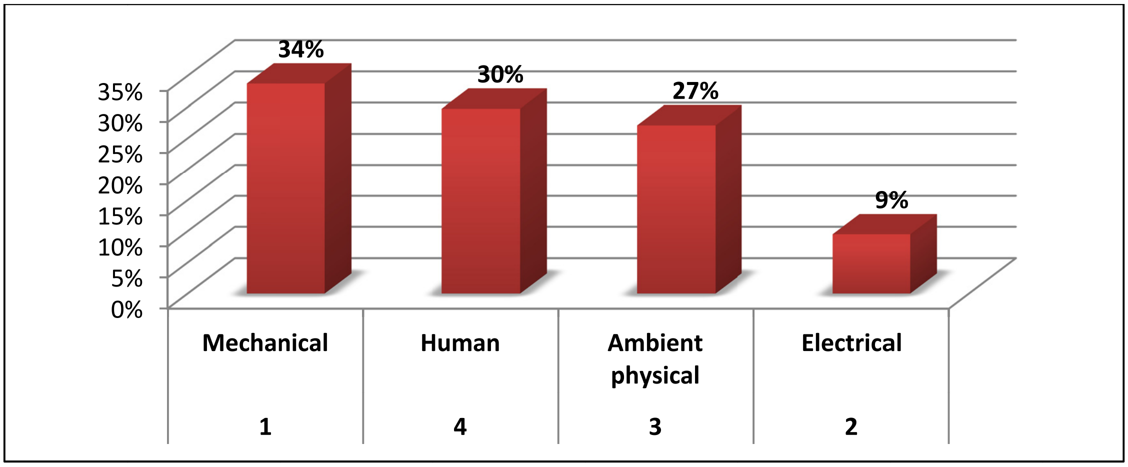

Figure 5.8 Criticality of different sources of hazards (consulted workers)

The OHS database (Appendix IV) was thus developed to feed the model underlying our approach to integrating OHS into the risk management aspect of the mining project in progress. Identified hazards were evaluated in accordance with: (1) the consulted workers' expertise; (2) collaborative observations in the field; and (3) analyses of incident and accident reports. The OHS database allowed grouping of all possible hazards for quick integration into project risk management.

Incident and accident reports of the company were adapted as shown in Table 5.4. The new database allowed new hazards to be entered continuously. The proposed tables are adaptable and improve the current incident and accident monitoring system and aid the extraction of necessary data for risk assessment.

Tableau 5.4 Proposed structure for the monitoring and logging of hazards in the mine

Category	**Hazard**	**Code**	**Details of most recent event**	**Victim**	**Area**	**Impact**	**Accumulated activations**	**Date of last activation**
MC	…	MC-1	…	…	…	…	…	…
HM	…	HM-2	…	…	…	…	…	…

To complete the risk element identification phase, research team members noted their preoccupation with the following undesirable events: job-related illness (E1), drop in productivity (E2), drop in quality (E3) and industrial accidents (E4). These undesirable events have negative impact on mine performance (IP), project costs (IC), project delays (ID) and the environment (IE).

These elements (undesirable events and impacts) were much simpler to identify by the team throughout the hazard identification phase. Tolerance of risks by the company may play an important role when choosing the types of negative impact. The nature of the industry also influences their choice. In the case of mining operations, final product quality (gold in the present case) is not a determining factor compared to the quality of the gold ore mining before processing.

Once the risks elements were identified, the team traced the possible causal links between hazards and undesirable events using the OHS database (Appendix IV). This allowed monitoring and prediction of possible progression of risks. In view of the importance of this step, the team consulted workers having more than 10 years of experience. Figure 5.9 shows the final version of the causality linkage between different elements of the identified risks. During the interviews, certain reinforcing effects of ambient physical hazards were identified (red full arrows in Figure 5.9). For example, rain and flood hazards reinforced the effect of human hazards by subjecting the workers in the main pit to greater stress (fear of electrocution) as well as reinforcing electrical hazards. Other factors worth mentioning are snowstorms complicating vehicle use and shorter daylight hours increasing collision and injury risks.

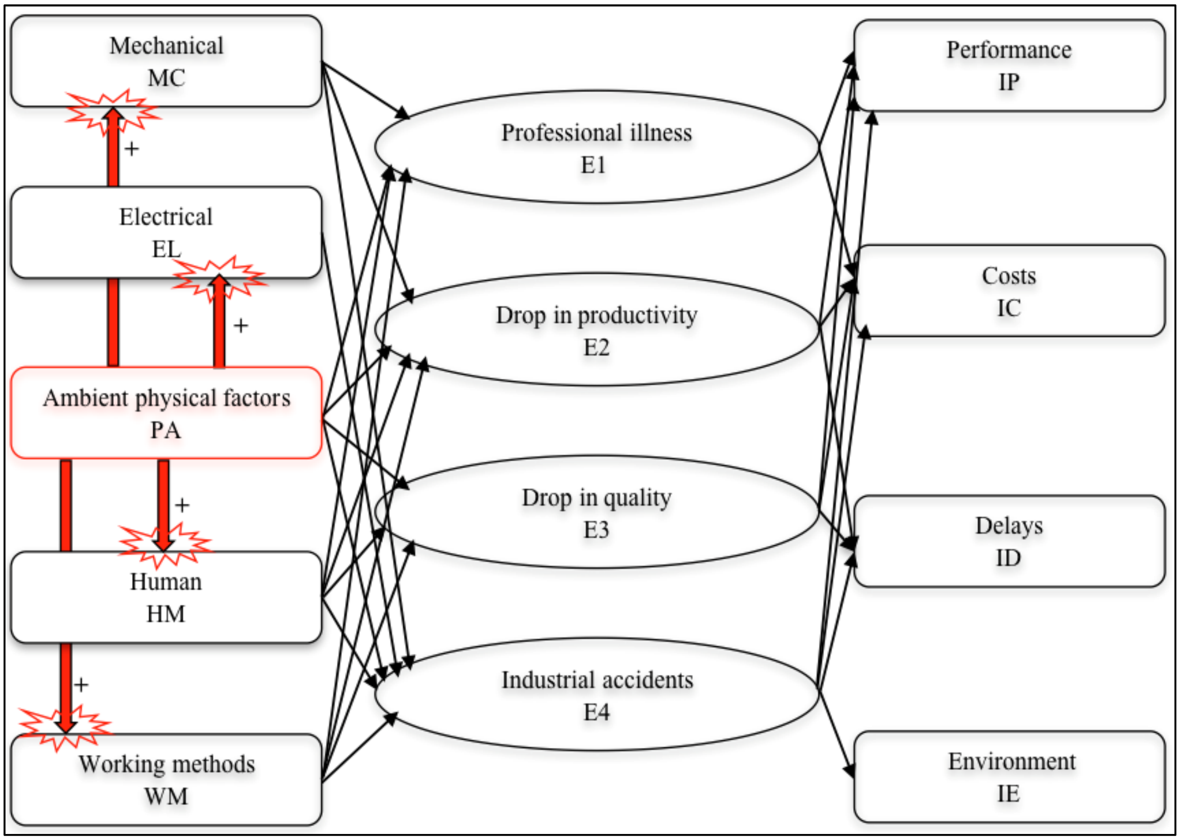

Figure 5.9 Causal links between the elements of risk and reinforcing effects of ambient physical factors
[+: reinforcing effect]

5.4.4 Risk assessment and prioritization

Comparison of hazard categories was done using the AHP method (Appendix V), which involves the paired comparison of the five categories of hazards (MC, EL, PA, HM and WM). Comparisons were based on the influence of the hazard categories on each identified undesirable events (E1, E2, E3 and E4). The consistency of the expert judgments was verified instantly using Expert Choice© software. As obtained by Saaty (2000), the consistency index (CI) of each comparison matrix did not exceed 10%.

Table 5.5 shows the relative and overall weights of each category of hazards, its rank and its assigned weight for the purposes of calculating the weighted concentrations.

Tableau 5.5 Weight calculation of the hazard categories

Undesirable event	Relative weights (AHP) of the hazard categories				
	MC	EL	PA	HM	WM
E1	0.50	0.03	0.22	0.13	0.12
E2	0.18	0.03	0.16	0.36	0.27
E3	0.05	0.03	0.21	0.40	0.31
E4	0.52	0.19	0.06	0.13	0.09
Rank (AHP)	2	5	4	1	3
Weight b_{ix}	**4**	**1**	**2**	**5**	**3**

The probability theory of risk occurrence involves the calculation of the relative concentration of each category of hazard.

As indicated above, hazard concentration (**CR_{ij}**) represents the weighted fraction of each category of hazards (**i**) containing **a_i** hazards and related to an undesirable event (**j**). The weight (**b_{ij}**) of each category of hazards is carried out according to the AHP pairwise comparison. When this concentration increases, the probability of an undesirable event increases. It is therefore more likely to trigger the associated undesirable event.

Concentration was calculated as follows:

$$CR_{ij} = \frac{A_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{m} A_{ij}} \tag{5.1}$$

With:

$$A_{ij} = a_i b_{ij} \tag{5.2}$$

where: a_i: Number of hazards of category (i) (Level 1 in Appendix IV); *bij*: Weight of category (i) of hazards causing an undesirable event (j). $i \in \{1, 2, ..., n\}$ and $j \in \{1, 2, ..., m\}$.

Table 5.6 summarizes the calculation of the probabilities of occurrence based on hazard concentration and the corresponding probability conversion scale applicable in the case of this mine. The concentration conversion stems from the reasoning underlying that the probability of occurrence of an undesirable event increases with the number of hazards present (Rosness, 1998; Coppo, 2003; McLeaod et al., 2003). It is important to note that the value of this probability of occurrence is difficult to estimate. According to Aubert and Bernard (2004), no statistical analysis can directly assess this probability. These constraints have forced many researchers to develop intermediate conversions to estimate the probability of occurrence (e.g., frequency-probability, incidence and injury rates-probability) (Restrepo, 1995; Hallowell and Gambatese, 2009; Talmor et al., 2010).

Tableau 5.6 Calculation of the probabilities of occurrence of hazards

S-Mine probability scale		**Probability of occurrence**		
Concentration	**Probability of occurrence**	**Undesirable event**	**$CR_{(j)}$ concentration**	**Probability assigned**
0.10 à 0.25	20	**E1**	0.276	40
0.26 à 0.55	40	**E2**	0.276	40
0.56 à 0.75	60	**E3**	0.168	20
0.76 à 0.95	80	**E4**	0.281	40

The hazards concentration makes the weighting of each hazard category more realistic in terms of direct influence on the associated undesirable events. Based on this idea, evaluators no longer consider the identified hazards as entities having the same influence-weighting factor. The conversion of the measured concentrations does not introduce a bias into the calculation or change the reasoning underlying the risk estimation. This conversion has the advantage of allowing the organization to act according to its tolerance of risks (Ewing and Campbell, 1994; Marszal, 2001; Frank, 2010; Hallowell, 2010), that is, to change the levels in the conversion scale to match the concentrations of hazards that it is able to tolerate.

The risks were selected for consideration on the basis of the risk management strategy of the company. Based on the loss that would be (or had been) incurred, the impact of an undesirable event associated with a given risk was judged as minor (1, 2 or 3), average (4, 5 or 6) or high (7, 8 or 9) and calculated as follows:

$$Impact_{\ Risk\ (i)} = Maximum\ impact_{\ (Performance,\ Costs,\ Delays,\ Environment)} \tag{5.3}$$

In other words, the impact associated with risk (i) was that of the event considered to have the greatest impact. In project management and according to Aubert and Bernard (2004), risk is defined as the combination of the probability of occurrence and the impact of an event.

The following equation was used to calculate and prioritize risks at the end of the evaluation phase:

$$Risk_{(i)} = Probability_{\text{Undesirable event }(i)} \times Impact_{\text{Undesirable event }(i)} \quad (5.4)$$

Table 5.7 shows the risks prioritized on the basis of probability of occurrence and the impact of undesirable events.

Tableau 5.7 Prioritization of identified potential risks

Priority	**Code**	**Type of event**	**Probability of occurrence**	**Negative impact**	**Risk level** Eq. (4)
1	E4	Industrial accident	0.4	9	**3.6**
2	E1	Job-related illness	0.4	8	**3.2**
3	E2	Drop in productivity	0.4	7	**2.8**
4	E3	Drop in quality	0.2	8	**1.6**

5.4.5 Problems and constraints

In this study, OHS integration was limited to tasks handled by the Health and Safety department that manages and promotes worker health and safety. We assert that Health and Safety department has limited capacity for attaining health and safety objectives without the active involvement of the other operational departments, especially in the case of a project start-up, in which several latent phenomena may occur. These latent phenomena are associated with: (1) new recruited workers; (2) the presence of much machinery and new equipment; (3) communication between crews and their managers; and (4) the presence of several subcontractors in operational areas for a great diversity of tasks.

The feasibility study focused on technical, economic and environmental aspects and did not integrate OHS with conventional risks. It is important to note that the environmental aspect deals with OHS only partially. Risk management teams are usually more focused on risks that are known and require attention by law and regulations (Kutsch and Hall, 2010).

Preventing OHS risks by improving mining project design remains a goal to be achieved by researchers and practitioners alike.

Current operation of the mine is geared towards discovering OHS problems during operations (corrective vision). For example, we observed the risk of collision between the excavator and loading trucks. If the company had already developed an OHS database and implemented routine evaluation of OHS risks, this problem would have been discovered before running mobile equipment and starting work in the main pit. This example of risk management can be justified economically (material damages and shutdown) and in terms of OHS (injuries or fatal accident). In both cases, the mine could benefit from a non-negligible gain if it focused on a prevention strategy based on a rigorous evaluation of risks before the beginning of mining activities.

Companies usually benefit on the long term from accident and incident histories to formulate policy recommendations in favor of prevention. Start-up activities usually take into consideration project progress and the point at which economic profitability is expected. With the pressure of starting a new business, it is difficult to benefit immediately from the experience of the new recruits to build a usable knowledge base for the purpose of improving worker health and safety. We emphasize this observation in the present case, in which the mine had a large potential knowledge base of experienced workers oriented for technical purposes.

To make incident and accident reports reliable and more useful, they must identify clearly the risk elements (hazards, undesirable events and impact). A complete and detailed description of the risk elements provides more clarity and allows quicker use of the data when necessary. We have drawn attention to this fact and have started discussions with accident victims to improve the analysis or to complete event descriptions.

5.4.6 A new approach for a new vision

The above action research stemmed from evaluation of the overall situation in this mining company and was intended as a practical decision support tool in the specific context of integrating OHS with a new mining project.

Several hazards were identified during our presence using the proposed approach. We were able to confirm the presence of certain hazards identified in other studies of mines (Joy, 2004; Kumar, 2004; McBride, 2004; Schutte, 2005; Seal and Bise, 2002; Ghose, 2007; Ghosh, 2010) and we noted in particular dangers associated with equipment and machines, worker-machine interferences, power sources, mechanical sources, driving of vehicles and ambient physical factors (dust, noise, vibrations, rain and floods, explosions, etc.). Kumar and Paul (2004) also noted hazards such as high-risk driving behavior, failure to respect instructions and procedures, as well as work in limited spaces. We confirmed the criticality of several areas of the mine that were cited in other studies, including mechanical workshops, explosives storage areas, pits, conveyors and electrical stations as discussed by Kumar and Paul (2004) and Singh (2009).

The analysis of incidents and accidents, the interviews and collaborative observation all helped create an OHS database usable by the company in particular and by open-pit mines in general. Through the development of this database, we were able to utilize the mining experience of workers in support of a safety and prevention policy. The company thus benefited from the expertise of new workers during the first months of their employment.

The approach allowed prioritizing of potential risks by involvement of the crews, analysis of available data and our presence in the field. The new concept of hazard concentration added a more realistic dimension to the influence of hazards and led to the identification of certain reinforcing effects of ambient physical hazards. The use of multi-criteria analysis (AHP) allowed the combination of quantitative and qualitative data and testing of the consistency of expert judgments in order to provide consistent decisions and reliable prioritization of risks. Data collection tools were chosen to maximize the extraction of information in a relatively short period of time.

This action research has the potential to promote the convergence of OHS with all operational activities of mines. Collaboration between the researchers, the company and workers accelerates the solving of certain problems (Checkland, 1991; McKay and Marshall, 2001). By applying the approach and examining the results, the mine will be able to utilize OHS data sooner. The increasing priority given to industrial accidents and job-related illness shows that consideration of OHS is gaining ground and catching up to productivity and quality. Identifying and prioritizing risks is crucial to gaining control over known hazards and avoiding their negative impact on projects in particular and on the company in general.

5.4.7 Limitations and avenues of future research

The methodology of action research has its benefits and drawbacks. According to Hales and Chakravorty (2006), advantages can be summarized as complete answers to the questions "why" and "how", which cannot be obtained through statistical analyses alone. Field study allows us to describe the actual problem and identify solutions based on the selection of data reflecting a more complete vision of the system and more realistic consideration of the interactions within it. Among the disadvantages of action research, the difficulty of generalizing the results and the influence of the corporate culture on the effectiveness of the proposed solutions should be mentioned (Lavoie et al., 1996).

To the best of our knowledge, no study of the integration of OHS into risk management in open-pit mining projects has been published, and meaningful comparison of our findings with those of other researchers is difficult. We use summary categories to estimate the criticality and confirm the presence of hazards. It is important to note the necessity of drilling down into the data and targeting interventions, when needed to allow the user to focus on details at the practical level of operations. Our intervention was limited to risk identification and assessment, since the company had the capability of devising a safety and prevention plan based on its risk prioritization. The medium-term impact of the intervention on the company will be the subject of monitoring and rigorous verification by the researchers. We have also planned to conduct interventions in other mines in order to generalize the approach and make it available to gold mines throughout Quebec.

5.5 Conclusions

In this action research involving a company exploiting an open-pit gold mine in Quebec, we used a new risk-factor-based approach to integrating OHS into risk management in the context of a new mining project. The approach has been tested previously in the simulation of a factory expansion project. The work was based on thorough analysis of accident and incident reports, interviews, questionnaires and collaborative observation in the field. A new concept of hazard concentration, based on the number and influence of hazards by category is proposed with multi-criteria comparison by the AHP method.

During this work, we created an OHS database including all the identified and confirmed hazards in the context of an open-pit mine. The database thus developed allows researchers to identify hazards sooner and apply more rigorous risk management. The proposed approach allowed the company to prioritize the potential risks and to identify reinforcing effects among hazards in order to choose the best safety and prevention strategy.

This action research involved several types of actor from the outset of the project and promoted sharing of industrial expertise. It allowed correction of biases and gathering of consistent opinions and thus allowed the company to benefit from the accumulated experience of workers in the mining industry. The study enabled the company to construct a knowledge base useful in the effort to prevent OHS problems that cause delays in the achievement of project objectives.

CHAPITRE 6

ARTICLE 4: A MINING PROJECT IS A FIELD OF RISKS: A SYSTEMATIC AND PRELIMINARY PORTRAIT OF MINING RISKS

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International Journal of Safety & Security Engineering,

Accepted for publication.

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 underestimate 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 article is to provide researchers and practitioners a preliminary portrait of the risks related to new mining projects. To attain this objective, we have primarily used results from research undertaken in the field. We completed this portrait using the results of hazard identification studies that we conducted in an open-pit mining project in Quebec.

During this study, we used a number of data-gathering techniques, including documentation analysis, collaborative field observations, and interviews with managers and workers.

Our 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.

6.1 Introduction

The mining industry is among the largest sectors of a number of countries' economies (Komljenovic and Kecojevic, 2007). 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, sulphur, and gypsum). Mining projects are highly complex and often require very large investments (Chinbat and Takakuwa, 2009). 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 ten years in view of intense growth in demand from industries in China and India (ABC News, 2010). Currently, a number of banking and stock market studies support Ric Battelino's forecast and act as encouragement to investment 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. According to the Institut de la statistique du Québec, Quebec mining investments attained the record sum of $2.5 billion in 2010 (Les affaires, 2011).

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 (Quebec Government, 2011). According to the Quebec Government, this program will lead to an $80 billion in investment over 25 years and will create 20,000 jobs a year (Quebec Government, 2011).

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 (Laurence, 2006). 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 (Radio-Canada, 2011). The mining industry is often accused of creating various environmental problems (Fourie and Brent, 2006) and a large numbers of work-related accidents (Larry Grayson et al., 2009; Saleh and Cummings, 2011). Across the world, mines are also the cause of quite a few occupational diseases (CSST, 2009). A significant number of miners suffer from severely poor work conditions and some mines are embroiled in corruption (O’Callaghan, 2010). 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 (Chinbat and Takakuwa, 2009; Luo and Liu, 2010). 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 (Komljenovic, 2008).

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 article 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 article 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, we 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 we construct a risks portrait for a mining project. In this section, we also track influence relations between the different risk categories and their occurrence during each mining project phase. The fifth section discusses results, limitations of our research, and recommendations for future development. Finally, section six comprises the article's conclusion.

6.2 The current situation

6.2.1 A mining project is a field of risks

The life cycle of a mining project is principally divided into four phases, briefly explained here (YMTA, 2010) (Figure 6.1). The first phase of exploration (seven to ten 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 participation of several organizations simultaneously. 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 sub-contracted consultants and other social actors with a view to launching 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 sub-contractors and those 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 re-allocation of installations and equipment. The project closeout phase also includes a stage involving definitive project closure and rehabilitation of lands used and pits exploited.

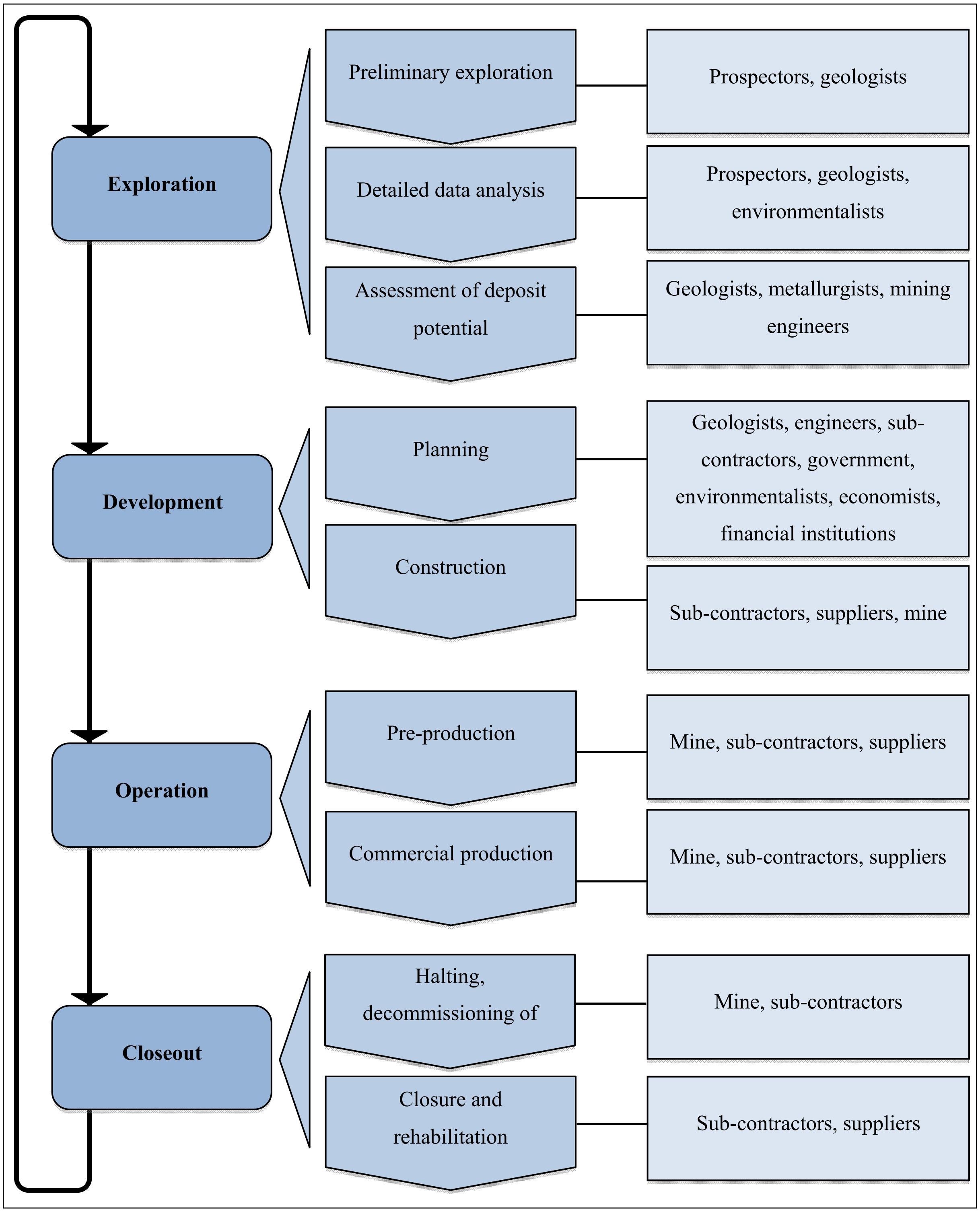

Figure 6.1 Life cycle of a mining project

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 (Chinbat and Takakuwa, 2009). 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 (Heuberger, 2005). 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 (Kumar and Paul, 2004; Schutte, 2005; Singh, 2009; Ghosh, 2010). Uncertainties of price, competition, regulation change, financial, and economic problems are also primary causes of premature closure of many mines (e.g. Lamaque Mine in Val d'Or, Quebec) (Laurence, 2006; Sabour and Wood, 2009). 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 (Galvin, 2006).

6.2.2 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 (Coleman and Kerkering, 2007; Poplin et al., 2008; Zhangtao, 2010) and environmental, economic and social problems caused by mining (Fourie and Brent, 2006; Laurence, 2006). Researchers and practitioners view the mining sector as among the world's most uncertain and dangerous industries (Chinbat and Takakuwa, 2009; Luo and Liu, 2010; Saleh and Cummings, 2011). If we consider the number of workers in the mining sector (351,000 people in Canada) and 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 mining enterprises should put in place. According to Chinbat and Takakuwa (2009), 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 (Atkinson et al., 1996). It is important to note that risk management is predominantly relevant to the mining construction stage (Chinbat and Takakuwa, 2009). 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 multi-disciplinary and complex (Chinbat and Takakuwa, 2009). Mine risk management requires significant efforts to identify various hazards or uncertainties (Schafrik and Kazakidis, 2011). 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 (Schafrik and Kazakidis, 2011). 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 able to continually resolve problems encountered

(Radosavljevic et al., 2009; Orsulak et al., 2010). Systematic risk management permits implementation of a proactive prevention strategy (Orsulak et al., 2010).

According to Evans and Brereton (2007), 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 (Evans and Brereton, 2007). Chinbat and Takakuwa (2009) 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 (2009) 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 (2010) 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 (2010) also add other risks such as use of new technology and changes in regulations and laws.

Sabour and Wood (2009) and Heuberger (2005) 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. (2007) 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 (Ghodrati et al., 2007; Wang et al., 2008; Radosavljevic et al., 2009; Zhao et al., 2010). Some researchers have focused their work on OHS hazards such as fires, worker fatigue, thermal stresses, air quality, and noncompliance with safety instructions

(Dessureault and Doucet, 2003; Roberge et al., 2006; Cliff and Horberry, 2008; Guo and Wu, 2009; Larry Grayson et al., 2009; Saleh and Cummings, 2011). Several other studies have dealt with environmental problems (contamination, pollution, dust, noise, etc.) during mining projects' operational or closure phases (Fourie and Brent, 2006; Laurence, 2006; Akcil, 2006; Komnitsas and Modis, 2009).

Finally, in order to manage different forms of risk identified, researchers and practitioners have employed methods adapted from a number of industries (Heuberger, 2005; Evans and Brereton, 2007). In general, these methods use tools that are: (1) qualitative, such as HAZOP, FMECA, and FTA (Komljenovic and Kecojevic, 2007; Li et al., 2007), (2) quantitative, such as simulation (Arena® and Monte Carlo) and mathematical modeling (Blais et al., 2007; Chinbat and Takakuwa, 2009; Sabour and Wood, 2009), or (3) semi-quantitative, such as multicriteria analysis (Wang et al., 2008) (Figure 6.2).

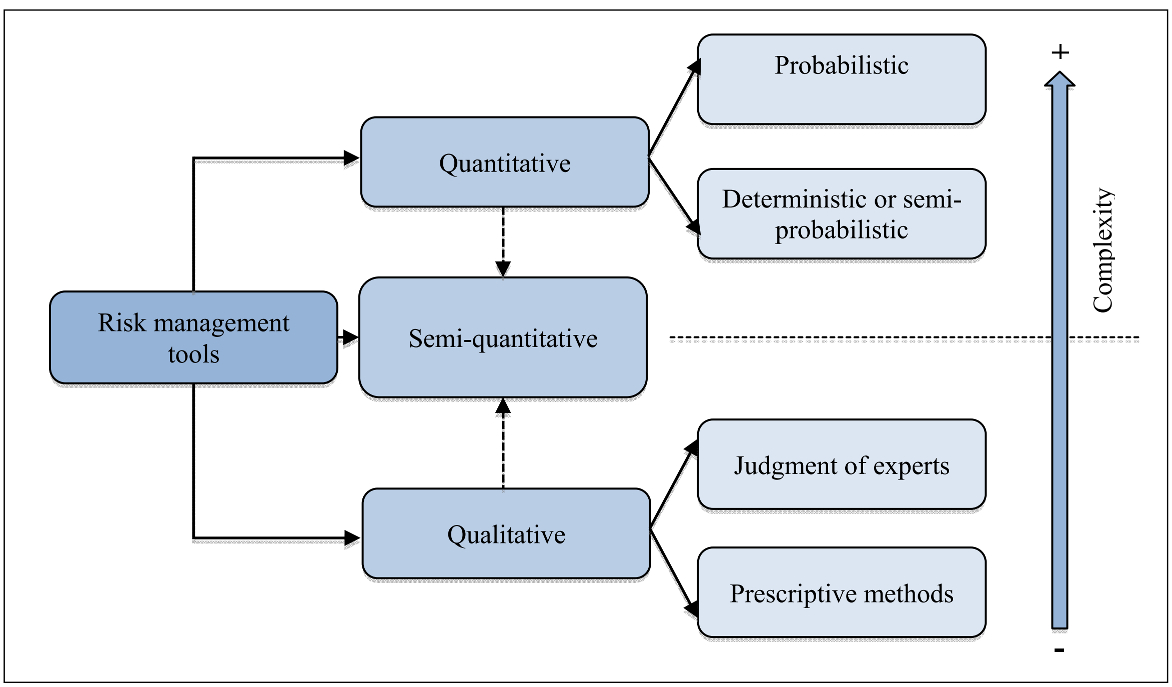

Figure 6.2 Classification of Risk Management Tools
Adapted from Rasche and Wooley (2000)

6.3 Methodology

The objective of this article is to provide researchers and practitioners with a systemic and preliminary portrait of mining project risks. To attain this objective, we primarily employed results from research work conducted in the field. We completed this portrait using results of risk identification that we conducted in an open-pit mine in Quebec (Badri et al., 2011b).

To review project hazards and risks comprehensively, this article 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). We used 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. The research strategy combines two keywords using “OR” or “AND.”

We added to these results of hazard identification for a new open-pit mining project in Quebec the framework of an action-research project that we conducted at the end of 2010 (Badri et al., 2011b). During this action-research project, we used several data-gathering techniques to identify potential project hazards and risks. In the framework of this action-research project, we used semi-structured interviews, questionnaires, analysis of incident and accident reports, and collaborative field observations. We were present at the end of the development phase and the start of the operational phase. In short, we analyzed more than 300 recorded incident and accident reports of the mining company and sub-contractors involved. We completed this analysis with 43 voluntary interviews and questionnaires with workers and managers (a participation rate of around 45 percent). We also used the results of 35 hours of collaborative field observations at the operations sites, primarily at the principal pit, residue processing areas, and mechanical maintenance workshops.

6.4 Results

6.4.1 Mining project risks

We followed the methodology described above to construct a mining project risks portrait. To the best of our knowledge, there is no consensus as to choice of risk categories for mining risk management. In the present study, we employed and adapted primarily the risk categories of Ernst and Young (2007) and Cameron and Raman (2005). When arranging these categories hierarchically, we took inspiration from the project risk breakdown structure of the PMBOK® Guide (PMI®, 2008a).

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

6.4.1.1 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) (Cuske et al., 2008). According to Zhang et al. (2009a), 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) (Evans and Brereton, 2007). 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. (2009a) 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. (2009a) 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 sub-contracting and of partnership among several companies can also add to operational risks. The use of sub-contracting constitutes a significant risk for safety of installations and the health of workers (Grusenmeyer, 2007).

Among operational risks, we underscore problems related to design parameters and to mine operating conditions which cause, in general, (partial or total) interruption of activities. For example, Lind (2005) 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 coalmines. Najafi et al. (2011) 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 (Ghodrati et al., 2007; Louit et al., 2011). Such shortages are sometimes unavoidable and affect performance and progression of project activities (Louit et al., 2011). 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 (Ghodrati et al., 2007).

Steering and management of processes (e.g. procedures for ore extraction and processing), teams (organization, skills, etc.), and operations (Chinbat and Takakuwa, 2009) 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. (2009), 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 (Ernst and Young, 2010). 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 (Larry, 2006; Mol, 2003; Ernst and Young, 2010).

6.4.1.2 Financial and economic risks

According to Nelsen et al. (2010), 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 occupational health and safety. Mine mechanization has led to a number of hazards, including intoxication and respiratory impairment, fires, mechanical failure, slips or falls while accessing to workstations, vibration, ergonomic problems, etc. (Labrecque, 2001).

In this category, it is important to highlight risks related to cost control and allocation of capital (Ernst and Young, 2010). 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. In order to control cost overruns, mining enterprises must continually revise their budgets, form partnerships with other companies, and favor sub-contracting (Ernst and Young, 2010). In order 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.) (Heuberger, 2005; Sabour and Wood, 2009; Bascetin et al., 2011). A number of researchers have proposed models for assessing risks and uncertainties related to financial, economic, and technical parameters (Heuberger, 2005; Sabour and Wood, 2009). 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 materials extracted prices (Heuberger, 2005; Blais et al., 2007; Sabour and Wood, 2009). 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 (Schafrik and Kazakidis, 2011). Information on markets is uncertain and rests on aggregated data (Steyn and Minnitt, 2010). 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 (2010), access to capital is also a significant risk to be taken into consideration by mines. This access to financing permits companies to explore new deposits, set up new projects, and improve and renew equipment and means on a consistent basis.

6.4.1.3 Political and legal risks

Despite the significance of legal and political risks, we 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 (Byrdziak et al., 2002; Maurice, 2004; Malaihollo, 2005). 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 of 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 (Byrdziak et al., 2002). 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.

6.4.1.4 Environmental risks

Several studies have dealt with environmental risks, whether during exploitation or after planned or premature closure of mines (Akcil, 2006; Fourie and Brent, 2006; Laurence, 2006; Komnitsas and Modis, 2009). 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 (Bian et al., 2010; Li et al., 2011).

The majority of work excavating, processing, and utilizing mineral ores creates environmental problems (Reginald et al., 2011). 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 not available 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 (Fourie and Brent, 2006; Laurence, 2006). 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 percent of estimated costs of restoration work) so as to ensure restoration of abandoned sites independently of the financial situation of the mining company. This mechanism permits budget protection, beginning at company startup, to ensure safe closure of a project's operations and avoid chaotic cessation thereof.

6.4.1.5 OHS risks

Recent statistics show a fall in accidents and occupational diseases in the mining sector of several developed countries like those of the US and Canada (Coleman and Kerkering, 2007; QMA, 2010; Saleh and Cummings, 2011). 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 (Coleman and Kerkering, 2007).

Researchers and practitioners have concentrated their efforts on the control of OHS risks in mines in the operational phase. Saleh and Cummings (2011) 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. (2009) using data recorded by the Mine Safety and Health Administration (MSHA, USA) to propose a systematic strategy for attenuating these hazards. Guo and Wu (2009) 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 (Hoffmann and Jöckel, 2006), natural phenomena (Luo and Liu, 2010), mining operations (Komljenovic and Kecojevic, 2007), work conditions (Cliff and Horberry, 2008), and rockfall or gallery collapse events (Stacey and Gumede, 2007). 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 (Larry, 2006; Ghosh, 2010).

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) (Dessureault and Doucet, 2003; Kumar, 2004; McBride, 2004; Roberge et al., 2006; Ghose, 2007; Ghosh, 2010).

It is important to note that accidents and occupational diseases in the mining sector are caused, in large part, by human error (Simpson et al., 2009; Lan and Qiao, 2010). 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.) (Simpson et al., 2009; Patterson and Shappell, 2010). Simpson et al. (2009) 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.

6.4.2 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 (Lind, 2005). According to Lind (2005), 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 6.1 summarizes mining project risks identified in a number of research works and as a function of our interviews with workers, our observations in the field and our consultation of documentation of the mining company concerned. In Table 6.1, we have detailed hazards in terms of the above fixed categories. In this paper, principally we use and adapt the risk categories set out by Ernst and Young (2007) and Cameron and Raman (2005). We also use the PMBOK® Guide (PMI®, 2008a) as a model for hierarchical breakdown of project risk categories. Sub-categories 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.).

Tableau 6.1 Summary of mining project risks

1. Operational	2. Financial & Economic	3. Legal & Political	4. Environmental	5. Health & 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 & Management Methods and procedures; planning, management of resources; management of contracts; partnership; communication. 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.	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 & social Behavior; competence; fatigue; interactions; conflicts; errors (decisions, skills, perceptual); communication. 5.5. Work Methods Inappropriate methods; excessive effort; planning; execution; communication. 5.6. Natural Earthquakes; floods; gas; radiation; geology.

Throughout our study, we 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 (Figure 6.3). 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 (Tien, 2005). Use of sub-contracting as means of costs reduction can also generate OHS problems (Grusenmeyer, 2007). It is important to note that 73 percent of incidents and accidents that we analyzed arose principally from sub-contracting activities.

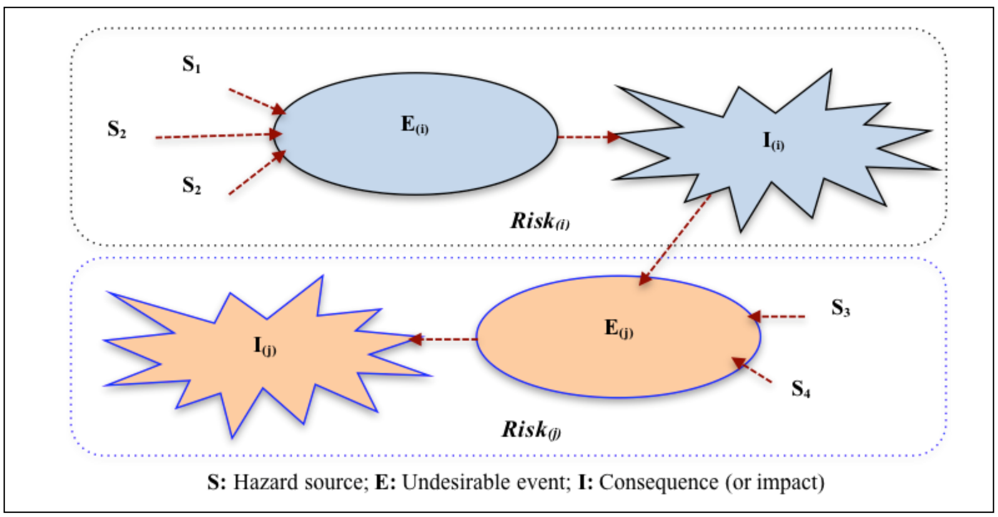

Figure 6.3 Possible influence between two risk categories

Possible influence links between different mining risk sub-categories are detailed in Table 6.2. This table shows that a risk can develop and be transformed into a hazard or a negative consequence belonging to another risk category (Figure 6.3). 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 (Saurin et al., 2008).

Tableau 6.2 Potential influences between mining project hazards

Category	Sub-category	Technical	Organizational	Logistical	Internal social	Workforce	Production	Costs	Market	Capital	Legal	Political	Internal	External	Mechanical	Electrical	Physical	Human	Methods	Natural
Operational	**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	--
Financial and economic	**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 and political	**Legal**	S	S	S	S	--	S	S	--	--		S	S	S	S	S	S	--	--	--
	Political	--	--	S	--	--	--	S	S	S	S		--	--	--	--	--	--	--	--
Environmental	**Internal**	S	S	S	S	S	S	S	--	--	--	--		S	S	--	S	--	--	--
	External	--	--	--	S	S	S	S	--	--	--	--	S		S	--	S	S	S	--
Health and Safety (OHS)	**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$_{(j)}$.

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 sub-category. Interventionists can thus add a new variable "period of possible occurrence" to risk assessment procedures to better prioritize prevention measures.

Our presence in the mine was undertaken during the final phase of development and the beginning phase of operation. During this period, we confirmed the occurrence of a number of mining risks and we completed the portrait with published case studies (Mol, 2003; Heuberger, 2005; Fourie and Brent, 2006; Laurence, 2006; Sabour and Wood, 2009). Table 6.3 shows the possibility of occurrence of each sub-category 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.

Tableau 6.3 Possible occurrence of risks as a function of mining project phases

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

↑: Possibility of occurrence.

6.5 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 (Chinbat and Takakuwa, 2009; Orsulak et al., 2010). 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 multi-disciplinary risk management teams, 4) intensive reliance on sub-contracting 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 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 multi-disciplinary teams and resource availability. In general, risks pinpointed during mine operations are of various 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 reader 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 article is the first part of a research project involving mining enterprises aimed at setup of a systematic approach to mining project risk management. To the best of our knowledge, we 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 in order 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. We used a number of data-gathering techniques to vary means of obtaining information and to enrich the mining risks portrait. This is a preliminary risks portrait, compiled and intended to be a checklist covering all risks a new mining project might involve. We have created hierarchical categories and systematically traced potential influences so as to be able to adapt ourselves to the majority of industrial risk assessment tools used in this sector.

6.5.1 Limitations and future research paths

This study presents a preliminary mining project risks portrait based on collection of known risks. We grouped risks together in categories and sub-categories 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. We 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, we 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, sub-contractors, 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 multi-disciplinary 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 our research. We will give detail of each risk category as a function of the particular nature of each company. We estimate that we 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.

6.6 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, we employed principally results from a number of published research works. We completed this portrait with results of risk identification that we conducted in an open-pit mine in Quebec (Badri et al., 2011b). The portrait established provides evidence for several project risk categories, namely: operational, financial, economical, legal, political, environmental, and OHS risks.

The present paper shows the possibility of identifying several categories of known risks and uncertainties not taken into account as a whole and systematically in the management of a mining project's risk. The risks identified are categorized hierarchically, 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.

CHAPITRE 7

A NEW PRACTICAL APPROACH TO RISK MANAGEMENT FOR UNDERGROUND MINING PROJECT IN QUEBEC

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Safety Science,

Under review (SAFETY-S-12-00254).

Abstract

The mining industry worldwide is currently experiencing an economic boom that is contributing to economic recovery and social progress in many countries. For this to continue, the mining industry must meet several challenges associated with the start-up of new projects. In a highly complex and uncertain environment, rigorous management of risks remains indispensable in order to repel threats to the success of mining.

In this article, a new practical approach to risk management in mining projects is presented. This approach is based on a novel concept called "hazard concentration" and on the multi-criteria analysis method known as the Analytic Hierarchy Process (AHP). The aim of the study is to extend the use of this approach to goldmines throughout Quebec. The work is part of a larger research project of which the aim is to propose a method suitable for managing practically all risks inherent in mining projects.

This study shows the importance of taking occupational health and safety (OHS) into account in all operational activities of the mine. All project risks identified by the team can be

evaluated. An adaptable database cataloguing about 250 potential hazards in an underground goldmine was constructed. In spite of limitations, we believe that the results obtained in this study are potentially applicable throughout the Quebec mining sector.

7.1 Introduction

The mining sector has been experiencing a period of strong growth over the past few years. Mining companies and subcontractors (construction, consulting engineers, equipment suppliers, etc.) are all benefiting from renewed exploration, development and start-ups (Schmouker, 2011). Governments of countries in which these projects are underway view the current boom as a lever for helping the economy out of the recession that has been hindering economies around the world for at least as many years (Humphrey, 2011). These countries, including Canada, pin much hope on the contribution of mining to economic recovery and have put many projects on the fast track by contributing to innovation and the promotion of mining entrepreneurship (e.g. MRNF, 2012).

Canada is a leader among mining nations, world leader in the production of potash and uranium, second producer of nickel and cobalt and third in extraction of several other metals (The Canadian mining journal, 2008). Like several other Canadian provinces, Quebec is benefiting from the current development of the mining industry, with numerous high-potential mineral and metal deposits, including gold, nickel, cobalt, zinc, platinum, iron, copper, lithium, vanadium and rare-earth elements (Quebec Government, 2011). This industry contributes an estimated 2.7% of the provincial GDP (QMA and QMEA, 2010), a figure growing in view of the number of mining projects underway in the context of the Plan Nord® program. There are currently 11 new projects well into the developmental phase (Rousseau, 2011).

A territory twice the size of France has been thus marked for new mining projects (Figure 7.1). The Plan Nord® represents investment potential valued at $80 billion, of which $33 billion will be earmarked for the mining sector, related industries and workers, including roads, housing, transportation, schools, health, telecommunications, airports and so on (Rousseau, 2011).

Figure 7.1 The designated Plan Nord® territory
From Quebec Government (2011)

The development of the mining industry in sparsely populated areas lacking infrastructures poses several challenges, risks and uncertainties associated with overcoming long distances, appealing to an aging labour force, recruitment, training and keeping workers, and availability of subcontractors and suppliers (Kral, 2006; Doggett, 2007; CSMOM, 2012). Starting up several projects at the same time in a given region requires careful planning and huge efforts from both the business community and public authorities. Poor synchronisation between the development of mining projects and of the required infrastructures and labour can lead to early failure. Interruption of projects would have province-wide political and economic fallout and is not an acceptable risk. The mining industry itself will not agree to begin activities in a climate of uncertainty, given the financial burden and complexity of the projects being considered (Chinbat and Takakuwa, 2009). In addition, public pressure to ensure safe and responsible mining of deposits as well as economic benefit to the taxpayer is huge and adds considerably to the challenges of any business or government contemplating such an undertaking.

In an effervescent economy, mining companies must identify and implement risk and uncertainty monitoring and control strategies. The mining industry must also adapt and implement major measures in order to deal with a variety of problems and challenges (e.g. Rousseau, 2011). Concerns with productivity and the advantages of using innovative equipment and new methods of extraction must not be examined only from an economic perspective, nor should personnel requirements be evaluated only in terms of operational indicators. Interdisciplinary and participative evaluation of operational needs and activities throughout all project phases reduce the likelihood of overlooking relevant risks (Pal and Dewan, 2009). A mining project is by nature very complex and marked by numerous interactions between endogenous as well as exogenous factors, thus requiring major efforts in order to eliminate risks that threaten to delay or block the achievement of goals (Badri et al., 2011b).

Systematic management of risks and uncertainties remains the most effective means of ensuring maximum safety of a mining project and covering all phases of the project life cycle

(e. g. Orsulak et al., 2010). For increased effectiveness, risk management should go beyond technical and environmental feasibility studies and take into consideration several types of threats often neglected, underestimated or hidden because of the complexities of the industrial context. Setting and achieving such objectives will not only improve the social capital and image of the industry, it will also increase feelings of security among workers, businesses and surrounding communities as well as throughout the mining sector in general.

With this article, we aim to promote the use of a new practical approach to risk management in underground goldmines in Quebec. New concepts developed, validated and utilized in open-pit mining have been adapted to underground mining. We identify limitations, propose improvements to implementation and consider opportunities expanding the range of applicability. This work is part of a larger research project with the aim of devising an approach suitable for managing practically all types of risks associated with mining projects.

In section 2, we examine the particularities and challenges in the mining industry and discuss risk management as well as several methods thereof in mining companies. In section 3, we present our research methodology and describe the proposed practical approach to risk management. Our results are presented in section 4, while section 5 contains discussion of the value and limitations of the approach. Section 6 contains a summary of our findings as well as our conclusion.

7.2 The current situation

Management of mining projects is often influenced by several factors, which may be internal or external to the organization. These factors complicate the achievement of the objectives and add constraints to the daily management of operations. Among the most notable are (1) project complexity, in particular scale, duration, budget, number of suppliers and subcontractors (Chinbat and Takakuwa, 2009); (2) variability, in particular of equipment, worker experience, skill and geographic origin, management tools and methods (Kral, 2006;

Rousseau, 2011); (3) interdependencies, in particular between workers, promoters, teams, relationships, organizations (Paszkowska, 2002; Radosavljevic et al., 2009) and (4) industrial context, that is, cooperation, competition, work environment, maturity and culture, sense of social responsibility, laws and regulations and so on (Zhou and Zuo, 2002; Kemp, 2010).

In addition to the factors listed above, there are diverse risks and uncertainties peculiar to mining. These also depend on the nature and complexity of the project and evolve throughout the project lifecycle. Several researchers have attempted to define them concisely, hoping to improve the safety of mining project operations (e.g. Mol, 2003; Orsulak et al., 2010). The effort to date is considerable, but has stopped short of integrating the definition of risks and uncertainties into management as a whole. This deficiency is sometimes attributed to the uniqueness of the mining context, lack of data, the complexity of the task, pressure to avoid delays and insufficient risk management skill and knowledge (e.g. Komljenovic and Kecojevic, 2007; Badri et al., 2011b).

Risk analysis is nevertheless one of the biggest concerns in the mining industry (e.g. Lilic et al., 2010). In order to improve risk management, an obvious first step is reliable identification of hazards, based on analysis of the available data (Tchankova, 2002; Komljenovic and Kecojevic, 2007). Komljenovic and Kecojevic (2007) have summarized management of mining risks in terms of systematic application of procedures and standards, evaluation of hazards and consequences, qualitative and quantitative evaluation of risks, and decision-making based on results obtained. In order to meet with success, the overall aim of risk management must be clear and supported by well-defined objectives.

Data and other relevant information must be gathered in order to identify problems associated with technical, environmental or organizational aspects as well as with human nature (Gheorghe, 1996). In a complex industrial setting, identification of potential risks encounters difficulties associated with choosing sources of information and clarifying the various categories of risks. Among the best-known categories, researchers have discussed occupational health and safety (OHS), financial, economic, operational, social, technical, organizational, legal, political and environmental risks (e.g. Bhattacharya et al., 2008; Pal and Dewan, 2009; Lilic et al., 2010; Shen, 2010; Daoud et al., 2011, Badri et al., 2012). In addition to risks, practitioners and researchers must enumerate and integrate the various possible uncertainties (e.g. resource estimation errors).

In general, risk management tools are not designed specifically for the mining industry. They are usually borrowed from the nuclear, petrochemical or construction industries or from military structures. In addition to mining skills, the industry also depends on several other industrial specialties. A mining project actively involves subcontractors from several fields including consulting engineering, construction, mechanics, electricity and fluid mechanics as well as equipment suppliers (machines, measuring instruments, etc.). The use of risk analysis tools borrowed from other industries is justified in our opinion by the advances being made in risk management in these sectors. Development and progress of a safety culture, changes to laws and regulations, and the desire to increase resource security have all contributed to open-mindedness towards the use of these tools in the mining industry.

Komljenovic and Kecojevic (2007) have reviewed risk management practices, standards, tools and approaches used both in the mining industry and in other industrial sectors. They have catalogued risk evaluation standards and guides (e.g. ANSI/AAMI/ISO 14971: 2000; ISO-17776: 2000 and DOE-DP-STD-3023-98: 1998) and risk analysis techniques (e.g. NASA: 2002 and DOE Guidelines: 1992). Other researchers have compiled the risk analysis methods and tools most used in mines (Daling and Geffen 1983; Komljenovic and Kecojevic, 2007; Dhillon, 2009). These are summarized in Table 7.1.

Tableau 7.1 Risk analysis tools

Acronym	Name
BM	Binary Matrices
CA	Consequence Analysis
CBA	Cost Benefit Analysis
ETA	Event Tree Analysis
FMEA	Fault Modes and Effects analysis
FMECA	Fault Modes, Effects and Criticality Analysis
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Study
HEA	Human error Analysis
HRA	Human Reliability Analysis
MORT	Management Oversight and Risk Tree Analysis
PHA	Preliminary Hazards Analysis

According to Daling and Geffen (1983), the six risk analysis tools most widely used in the mining sector were PHA, FMEA, BM, CA, MORT and HRA. Many years later, this list had not changed (Dhillon (2009), at least for risk analysis of mining equipments. In general, dedicated versions of these tools are used for equipment and process safety, with little adaptation to analysis of other risks of various types in specific organizational and human contexts. The CA tool is used during the design of industrial infrastructures primarily to determine the possible consequences of a particular hazard such as dust, explosion, fire or toxicity (e.g. Alonso et al., 2008; Shariff and Zaini, 2010). This tool requires quantitative data and simulation software to evaluate consequences. For example, Alonso et al. (2008) used it to estimate damage associated with an industrial explosion using over-pressure, dust and explosion distance as parameters. The CBA tool is used to analyze risks, but as a complement to other methods (Jones-Lee and Aven, 2009). Jones-Lee and Aven (2009) describe this tool as dedicated to evaluation from an economic and investment perspective in situations of uncertainty. The tools FMEA and FMECA are widely used during product and process design to anticipate possible failures (e.g. Herman and Janasak, 2011; Levinson et al., 2011). Neither of these tools can be used to analyze more than one mode of failure at a time (Dhillon, 2009). Other tools such as MORT require very much time and are quite complex (Daling and Geffen, 1983). Some tools such as HEA and HRA deal with only a single risk typology (e.g. Nelson et al., 1994; Iden and Shappell, 2006), while others provide analysis only of the impact of risks (CA and CBA).

The current industrial context and the rise in metal prices are putting additional pressure on mining companies to maximize production capacity and profits. The industry therefore needs tools that are reliable and easy to use. It would be very useful to group or adapt some of these tools in order to benefit from the advantages of each. However, this effort should not result in increased complexity and must take into consideration the particularities of the use of each tool.

Finally, the uncertainty and risky nature of mining projects and the limitations of conventional risk management tools are motivating practitioners and researchers further to design new systematic approaches better adapted to the industry (e.g. Komljenovic, 2008; Orsulak et al., 2010; Badri et al., 2011b). Proper integration of these approaches into the project risk management process will lead to (1) better protection of human capital and the environment; (2) sparing of resources (human and material); (3) reduced legal, professional and civil liabilities; (4) better public image of mining companies and (5) increased operational stability and flexibility of companies in the face of change and unexpected developments (IBC, 2010).

7.3 Methodology

7.3.1 Research continuity

This article represents the continuation of a three-year research project of which the aim is to integrate OHS into risk management in mining projects in Quebec. We began by reviewing the literature to evaluate the relative importance of OHS in risk management in industrial projects in several fields (Badri et al., 2012a). This overview of industrial practices and research revealed the need to create or adapt methods in order to deal with constraints associated with the challenge of integrating and evaluating OHS risks and also confirmed the need to increase the consideration given to OHS. We then developed an approach to integrating OHS into industrial project risk management (Badri et al., 2011a). The work is based on best industrial practices and a body of interdisciplinary knowledge in risk management. The proposed approach is based on the number of hazards identified and the relative significance of each category. A new concept called “hazard concentration” was combined with the multi-criteria comparison method known as the Analytical Hierarchy Process (AHP) to evaluate and rank potential risks.

This approach was adapted and tested on a new open-pit mining project (Badri et al., 2011b). Researchers used an action research methodology in order to favour exchanges with industry experts and benefit from the active involvement of the industrial partner. Once adapted to the open-pit mine context, the proposed approach was used to compile an OHS database for facilitating the integration of OHS into risk management. The subject of the present study is the possibility of adapting the proposed approach and the hazard source database to the underground mining context. We have thus evaluated the potential advantages and limitations of the practical application of the proposed new concepts in goldmines in Quebec.

7.3.2 Action research: Soft Systems Methodology (SSM)

We opted for a research methodology favouring exchanges with the practitioners of the industrial partner. Practical application of the designed risk evaluation concepts to a human activity system remains crucial to our aim. We therefore require a flexible and interdisciplinary approach that combines the tools of engineering, management and social sciences.

The research project was designed to meet the challenge ascertained within the theoretical framework but also expressed by the industrial partner. In addition, it quickly became apparent that our physical presence would have a direct effect on practices observed in this company. We therefore proposed research action methodology during our initial discussions with the industrial partner. The adopted approach also converges with the definition adopted by Liu (1992), which describes action research as fundamental research in the humanities, borne of melding of “willingness to change” with a “research intention”.

In summary, we view action research as the best adapted methodology for the purposes of our project for several reasons: (1) the research must have a foot in the real world (committed mining project) to give it practical meaning; (2) the challenge of mining project risk management is recognized by the industry and by our industrial partner; (3) willingness to collaborate and participate in the research was expressed unequivocally by the industrial partner; (4) willingness to change practices through action according to objectives specified right from the beginning of the research project was expressed; (5) the interdisciplinary character of the research (using several tools from different disciplines) and (6) the research is designed to yield results potentially applicable throughout the Quebec goldmine sector.

We preferred SSM (Checkland, 1991; Checkland 2000), which draws on the human activity system concept to define a challenging situation (lack of systematic integration of OHS) and propose changes (to mining project risk management). The SSM (Figure 7.2) consists essentially of seven steps: (1) identification of the challenge (how to integrate OHS into mining project risk management); (2) description of the challenge; (3) definition of the relevant elements of the system under study (mining company); (4) development of a conceptual model for meeting the challenge (the proposed risk analysis/management method); (5) comparison of the conceptual model to the reality of the system under study; (6) examination of the feasibility of the suggested changes to the system and (7) implementation of measures meet the challenge. Finally, the flexibility of SSM allows us to adapt in response to constraints as they arise in the dynamic environment characterizing the company and the mining industry in general.

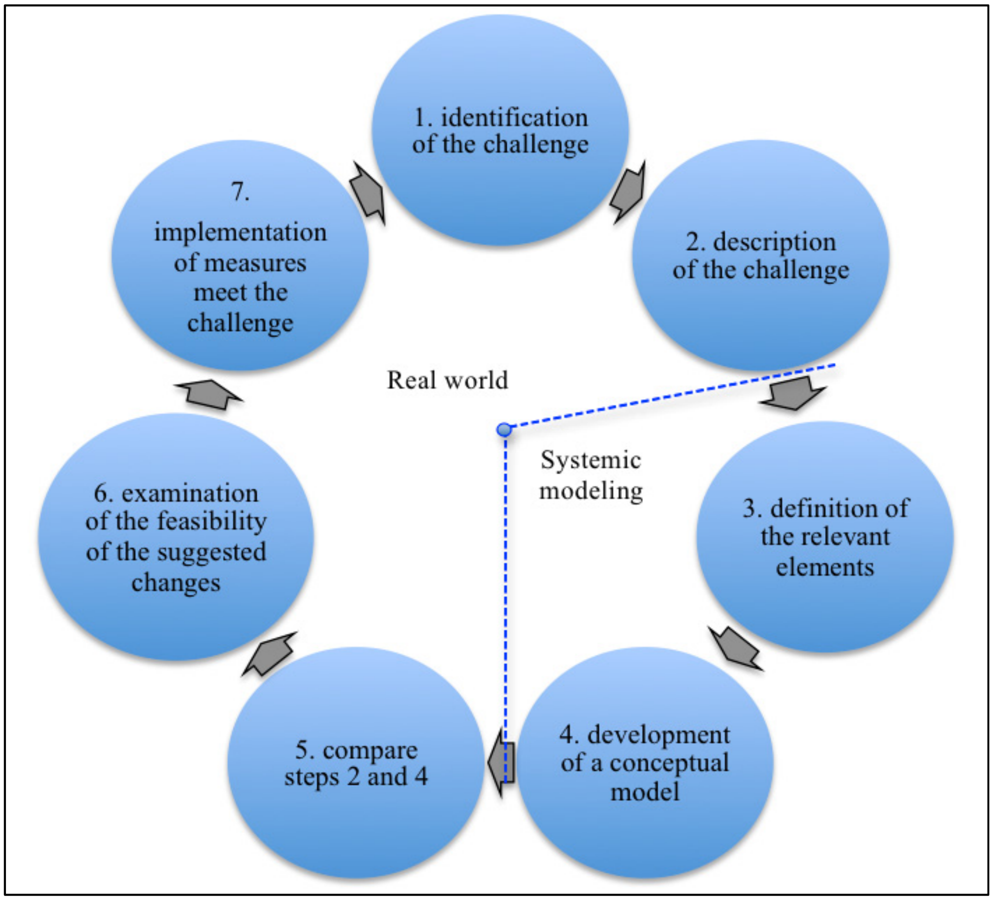

Figure 7.2 The steps involved in applying SSM
Adapted from Checkland (2000)

7.3.3 The new approach to risk management in mining

Combining the tools of engineering as well as management and social sciences makes the new approach to mining project management much more effective, especially for taking into consideration greater numbers of scenarios that could be harmful to humans or the environment. A multidisciplinary method is essential in a rapidly evolving industry.

Team involvement, analysis of available data and field observations allow identification of potential hazards. The "hazard concentration" concept is used to estimate the potential for these hazards to lead to undesirable events. The AHP method is used to form and evaluate various categories of hazards and to monitor expert judgments in order to provide reliable estimates of risk.

Risk analysis is based on decomposition of risk into three essential elements: (1) hazards (causes); (2) undesirable events (caused by one or more hazard) and (3) the impact or consequences of the undesirable event (Figure 7.3).

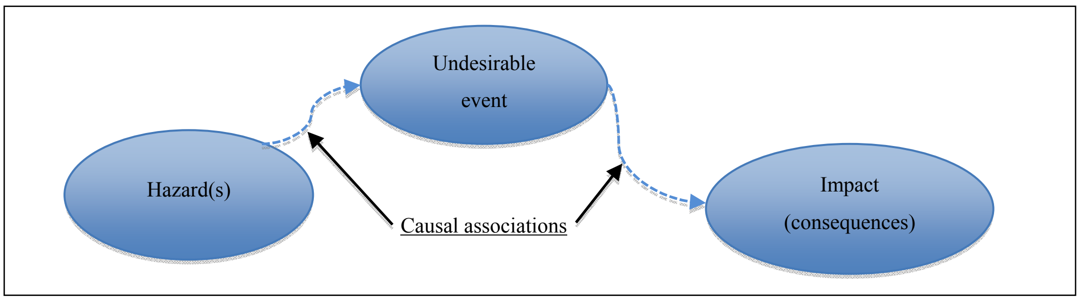

Figure 7.3 Modelling of risk

The OHS database to be developed the hazards identified using the chosen data-gathering tools (document analysis, observation, interviews and questionnaires). The risk management team establishes the lists of undesirable events and their impact based on the principal concerns of the company and also traces the causal associations between the elements of risk. These associations are based essentially on the judgment and experience of the workers involved. During this step, the team may consult other managers, experienced workers or experts to discuss and confirm possible causal associations.

Figure 7.4 shows the steps of the proposed approach to risk management in mining projects, as described previously (Badri et al., 2011b). Risk evaluation based on calculated hazards concentrations and on estimation of the impact of undesirable events is described in detail in the Results section. Improvements or adjustments made to the approach in the context of the present research are also described in this section and in the discussion.

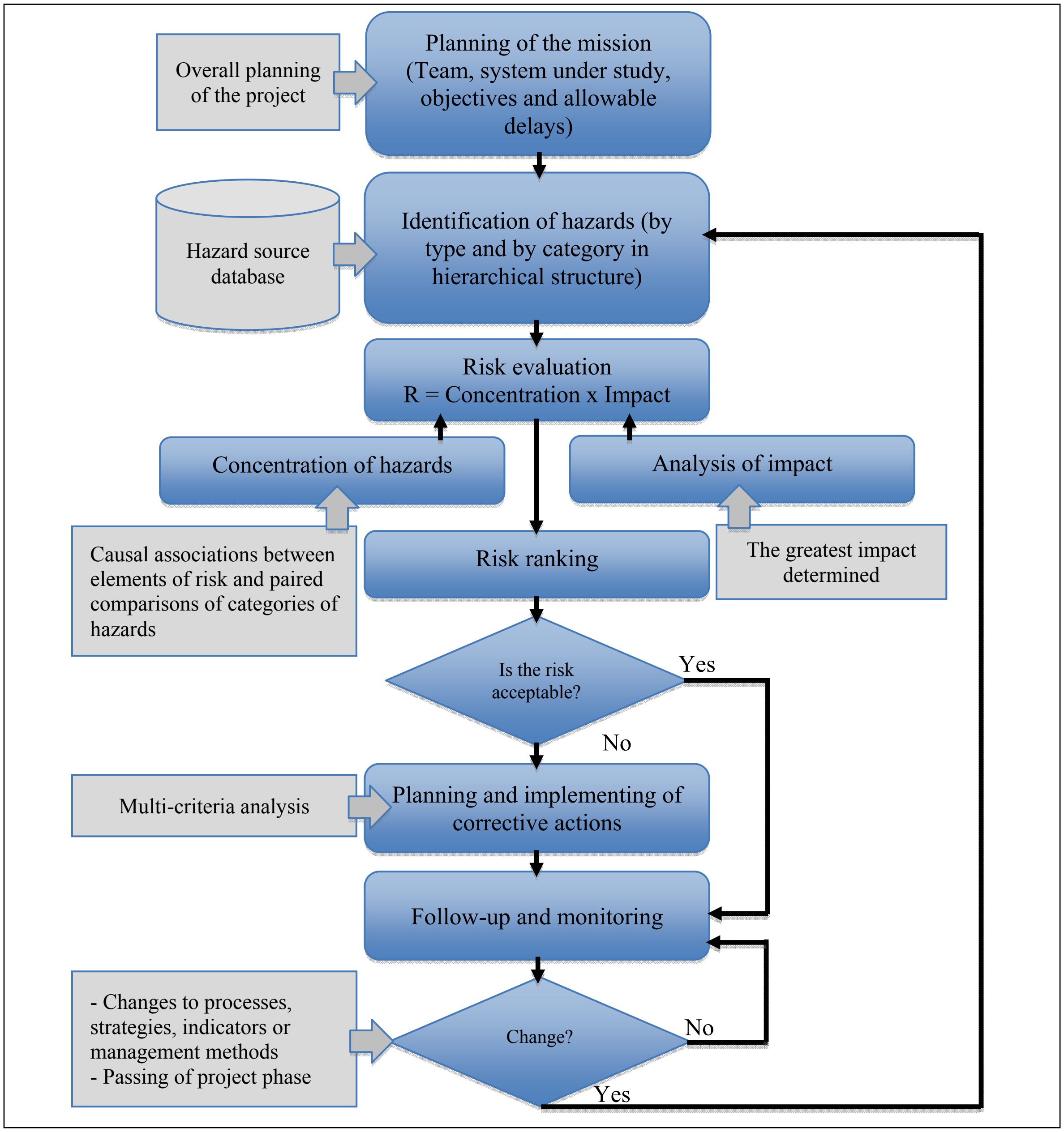

Figure 7.4 The steps involved in the proposed approach to risk management

7.4 Results

7.4.1 Scope of the intervention

The industrial partner has been extracting gold from an underground mine for several years. The principal aim of our mission is to identify effective means of integrating OHS into project risk management. The approach that we propose has been tested previously in an open-pit mine (Badri et al., 2011b). This change in context will test model adaptability in anticipation of extending its use to all goldmines in the province of Quebec.

The company currently operates new deposits in the same underground zone, using existing infrastructure (mineshafts, roadways, equipment, supervision, etc.). We thus have an opportunity to observe several phases of various underground mining projects, namely exploration, development and commercial production. These projects are all under the supervision and direction of the same company crew.

Our intervention is limited to processes and activities associated with ore extraction. In view of the scale of the work and the complexity of the processes under study, we did not examine ore processing. We made this same choice previously during research in the open-pit mine.

To study OHS risks, we covered the entire ore extraction process, beginning in January of 2012. The company directors saw to the involvement of all departments, workers and managers connected with the associated field operations, including the company OHS representative. Throughout the intervention, we maintained direct contact with the managers and workers in order to gather all relevant information for the OHS database and risk evaluation. It should be noted that 80% of the team members had over 20 years of experience in the mining industry and that 96% were involved right from the developmental phase of the principal project of the company. Figure 7.5 describes the ore extraction process. These activities are carried out 380 to 840 meters below the surface.

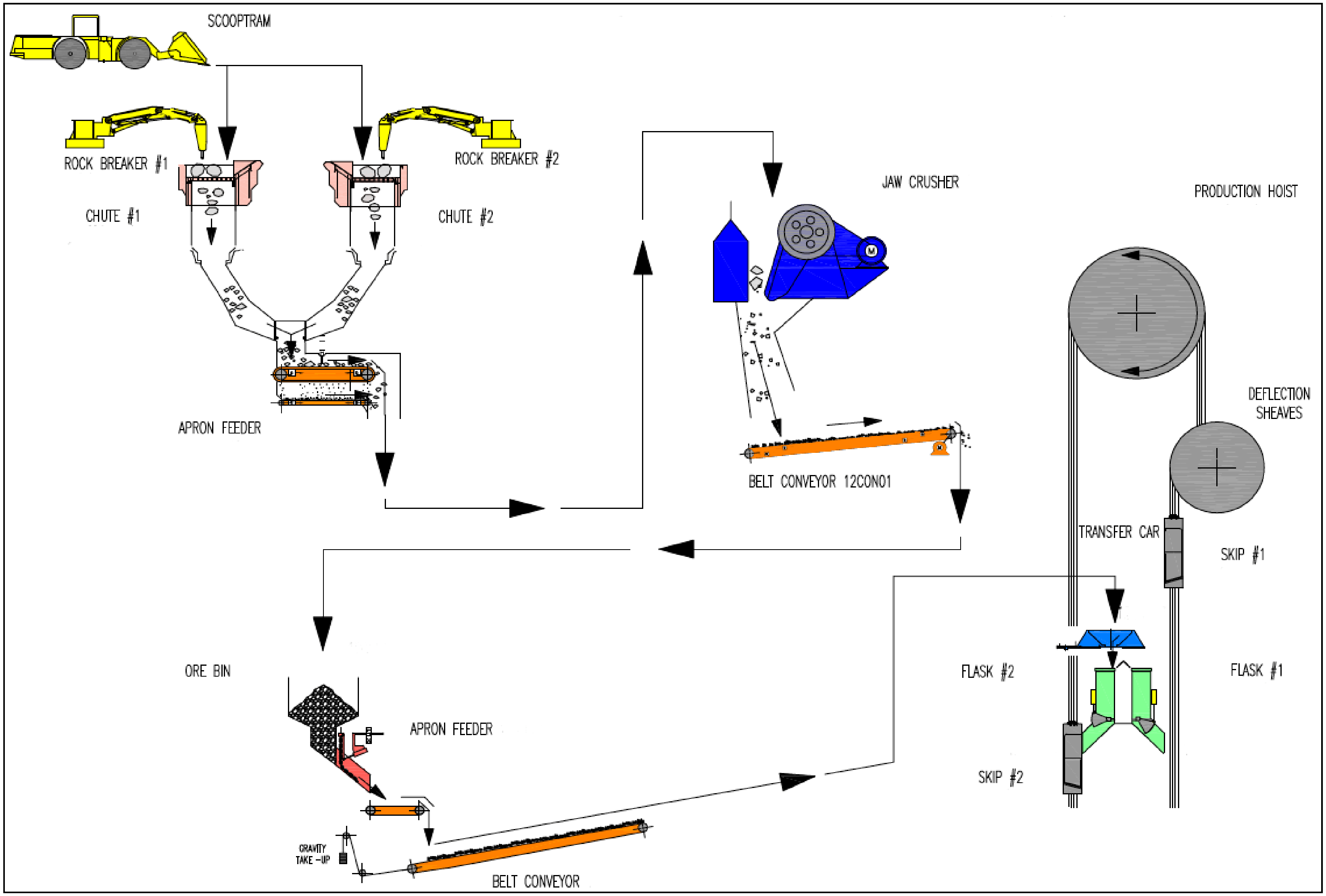

Figure 7.5 Steps involved in the underground extraction of ore (Underground goldmine)

7.4.2 Uncovering the threats (hazards)

We relied on three data-gathering techniques and review of the literature. This included 35 hours of observation, interviews and questionnaires (32 persons) and two months of document analysis (Figure 7.6). The documents contained essentially incident and accident reports, standard work procedures, emergency measures, technical plans, and prevention or correction plans regarding various high-risk situations.

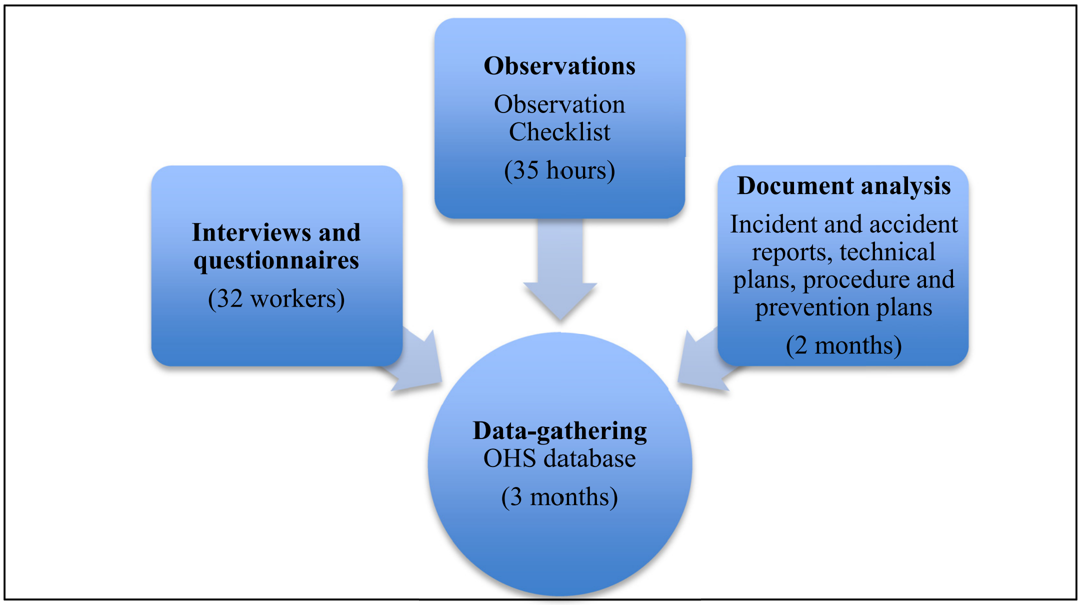

Figure 7.6 Data-gathering tools used in this

Table 7.2 lists some of the hazards noted during the 35-hour observation of the ore extraction process (Figure 7.5). These were categorized in the OHS database as mechanical, electrical, physicochemical, or method/human-related. We included the personnel group affected and the potential zones of impact. The zones of impact depend on the underground architecture of the mine. For example, a major fire or serious problem with the main extraction system (main shaft) could have a major impact on all zones of mining operations. Exposure to silica dust resulting from draw operations has only local impact thanks to various means of isolation put in place by the company (closed cabins, curtains).

Tableau 7.2 Examples of hazards (based on observations)

Hazards	Group affected		Zone of impact	
	Miner in the zone	All miners	Local	General
Cluttered areas (with tools, cables, toolboxes, components, wastes, tool storage, etc.)	x		x	
Dynamic environment (moving, storage, traffic, frequent entry and exit of mobile equipment, interference, changes in architecture, etc.)	x		x	
Slipping or loss of balance (on ground, ramps, stairs and catwalks)	x		x	
Sharp edges, hooks (metal structures, forklifts, tools, etc.)	x		x	
Draw dust (silica, crystalline silica, others), metal filings (grindstone), moisture, cold, heat, draughts, fog, mist, steam	x		x	
Smoke, soot, gases (ammonia, carbon monoxide, sulphur dioxide, nitrogen dioxide)	x	x		x
Accumulation of ice (e.g. on head-frames)	x		x	
Visibility and lighting (control rooms, traffic zones, drilling zones, etc.)	x		x	
Noise (equipment and operations)	x	x		x
Vibrations (equipment and operations)	x		x	
Ground conditions (holes, water, bumps, rocks, slopes, etc.)	x		x	
Harmful and inflammable products near sparks or heat sources, greases, de-greasers, paint (spray and fumes)	x	x		x
Explosives (loading, blasting, residues, ignition and propagation conditions, ignition sensitivity, static electricity, transport, state of packaging, fragment shields)	x	x		x
Traces of explosives in ore and exposure to ammonia after blasting	x	x		x
Flying or falling objects, tools or equipment	x		x	
Collapsing of a roadway or area under stress	x	x		x
Moving elements (cables, conveyers, pulleys, crushers, treadmills, jacks, motors, fans, jackhammer, bolting machine, etc.)	x	x		x
Elements under stress (pipes and ducts, hoists, chains, slings, tires, wear parts, winches, cages, cables, tracks, ore loading and dumping devices, platforms, etc.)	x	x		x
Elements under pressure (hydraulic presses, ducts and pipes, 400-lb pumping station, plumbing, 120-lb compressed air, 80-lb pressurized water, jacks, pistons)	x	x		x
Reservoirs (diesel, gasoline and oil) and water basins	x	x		x
Leaks (water, gasoline, diesel, concrete, oil, compressed air or gas)	x	x		x
Things catching fire	x	x		x
Heavy equipment traffic on slopes (17-18%)	x		x	

Tableau 7.2 (*continued*)

Hazards	Group affected		Zone of impact	
	Miner in the zone	All miners	Local	General
Sources of heat (motors, pumps, oil)	x	x		x
Power supplies and electrocution (600V electrical cabinets, cables, electric motors, transformers)	x	x		x
Electromagnetic hazards (electromagnets, electric motors, electrical breaking, etc.)	x		x	
Control screens (reflections and flashes)	x		x	
Mobile equipment traffic (loaders, borers, trucks, etc.)	x		x	
Truckloads and breaking capability on slopes	x		x	
Interference among mobile equipment (loaders, borers, trucks, etc.)	x		x	
Interference between mobile equipment and workers	x		x	
Remote monitored or controlled equipment (crushers, borers and jackhammers)	x		x	
Equipment and tool ergonomics (standard design, constrained space, vibration, body shield, driving posture, etc.)	x		x	
Procedures ill-adapted to equipment design (e.g. arc-flash in the case of an electrical repair)	x		x	
Improper work posture (standing with little movement, leaning forward, crouching and leaning forward, arms above the shoulders)	x		x	
High-risk tasks (heights, in constrained spaces, enclosed or isolated spaces, in darkness, exposed to cold, dust or dampness, maintenance and inspection of moving elements, loading and transportation of explosives, blasting, drilling, handling and transporting heavy equipment, dislodging ore, worksite repairs, exposed to power sources, proximity of heavy or suspended equipment, gas burners, interference between repair crews, welding, ill-adapted tools and equipment, etc.)	x	x		x
Repetitive manual tasks requiring excessive physical effort	x		x	
Tasks requiring visual effort and prolonged concentration	x		x	
Fatigue and stress	x		x	
Subcontracted teams and tasks (exploration and construction)	x	x		x
Rigour in the use of personal protective equipment (boots, mask, safety glasses and gloves)	x		x	
Respect of procedures and rules (lock-out, maintenance, inspections, chemicals, explosives, environmental safety, blasting zones, blasting plans, sources of ignition, handling and insertion of explosives, wearing protective equipment, driving and parking vehicles, drilling, blasting, emergency measures, etc.)	x	x		x
Respect of laws and regulations (explosives, ventilation, mechanical equipment, gas monitoring, etc.)	x	x		x
Competence (expertise, training, familiarity with the site, reaction capacity, autonomy)	x	x		x
Communication (with monitors, other crews, emergency measures, alarms, radio and interference)	x	x		x

We then compiled the elements of risk by analyzing 975 incident and accident reports filed since 2006. It should be noted that 26% of these reports involved subcontractors (e.g. construction and drilling) during 2011-2012. This is in opposition to the trend recorded previously in the case of the open-pit mine (Badri et al., 2011b) and is explained by the personnel management method adopted by our industrial partner, which favours in-house expertise (within the mining group). Subcontracting is limited to specific cases (cost savings or expertise outside the group of companies). The principal project of the mine has reached the commercial production phase, in which the need for subcontracting is minimal.

During the 32 semi-directed interviews, we discussed and confirmed the hazards identified in the course of observation and document analysis. Discussion with the participants revealed several constraints not noted during observation, brought to our attention by workers very familiar with the site and the nature of the various tasks. The company values this type of data all the more since this highly experienced labour will be replaced over the next few years. We discussed all of the ore extraction zones (main crusher, excavator, maintenance workshop, main extraction system as well as development and production zones). We reported the criticality of these zones in OHS terms as perceived by the workers and identified possible OHS hazards in each extraction process zone. The participants also compared OHS risks to other types of risks (supplier-related, internal organizational, financial, planning-related, personnel-related, logistic and regulatory). Although difficult to evaluate, several OHS-hazard-reinforcing factors were also discussed.

The participants confirmed that mechanical hazards exist in the various process zones studied. Direct-current electrical hazards other than static electricity are also present. Physicochemical hazards are potentially present and human hazards are omnipresent. The workers indicated that harassment and aggressions are currently absent but cannot be ruled out in the future. Figure 7.7 below shows the criticality of the studied zones. Development, production and draw zones and the main mineshaft are the most critical. Interference between workers and mining equipment (loaders, borers, conveyers, etc.) is described as frequent.

Unlike in the open-pit mine situation (Badri et al., 2011b), these workers did not cite the mechanical workshop as the most significant. They felt that maintenance tasks are "organized and safe". They also felt that mobile equipment under repair (loaders, tractors, drills, bolting machines, etc.) were of "limited height" and that the risk of tipping over as well as the risk of falling objects, persons or tools are minimal.

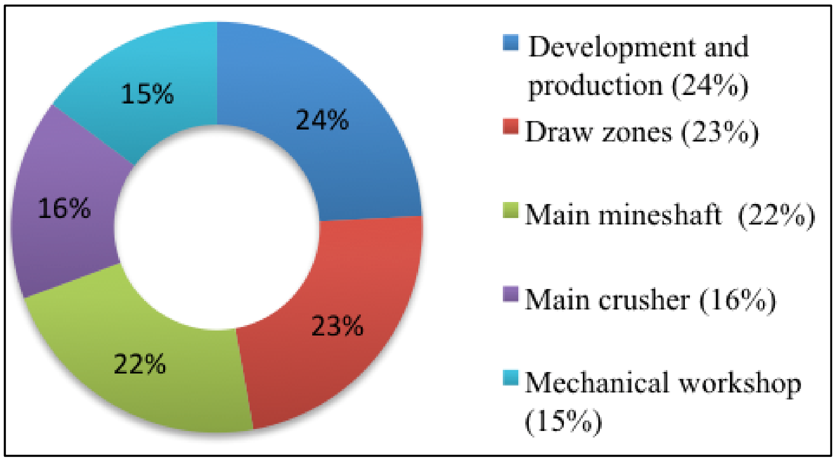

Figure 7.7 Estimation of the criticality of the various zones

Table 7.3 shows the reinforcing factors of the hazards evaluated by most of the workers involved. The presence of these factors can activate or increase the likelihood of the manifestation of risks (indicated by the symbol '+'). The same factors may have no influence (indicated as '0').

Tableau 7.3 Possible effects of some reinforcing factors

Reinforcing factor / Hazard	Heat	Cold	Flooding	Work at night
Mechanical	+	0	0	0
Electrical	+	0	+	0
Physicochemical	+	+	+	0
Human	+	+	+	+

We thus added potential hazards to the approximately 250 entries in the OHS hazards database (see Appendix VI). Before evaluating projects risks, we needed a hazard knowledge base. As mentioned above, the principal focus of the data gathering was identification of OHS hazards, which was undertaken in response to the lack of detailed OHS data available for researchers and practitioners in the goldmine context. By combining "conventional" categories of hazards documented (Badri et al., 2012b) with the results of the open-pit mine study (Badri et al., 2011b), we obtained a summary of hazards judged applicable to underground mines by virtue of encompassing operational, financial, economic, legal and political risks in a macroscopic sense.

Figure 7.8 illustrates the hazard hierarchical network for facilitating risk evaluation and use of the "hazard concentration" concept by analysts. Hierarchical levels follow the direction of the arrows. Level 1 is made up of the hazard categories: (1) operational; (2) financial and economic; (3) OHS and (4) societal (legal and political). Each category is made up of one or more "families" of hazards (level 2), while each family is made up of several hazards (level 3). The network is based on the Causal Tree Analysis method (CTA) used to analyze in depth the possible causes of a problem or failure (e.g. workplace accident). The CTA is intended to show the combinations of causes as a whole. We mapped possible hazards by category and by family to determine causal associations between these levels, facilitating both modelling and tabling of the information for the database (MS Access®). To calculate "hazard concentration", we need the number of hazards (level 3) identified per family of hazards. Weighting of each family was obtained by paired comparisons (AHP, Appendix VII) of the families in each category connected to an undesirable event.

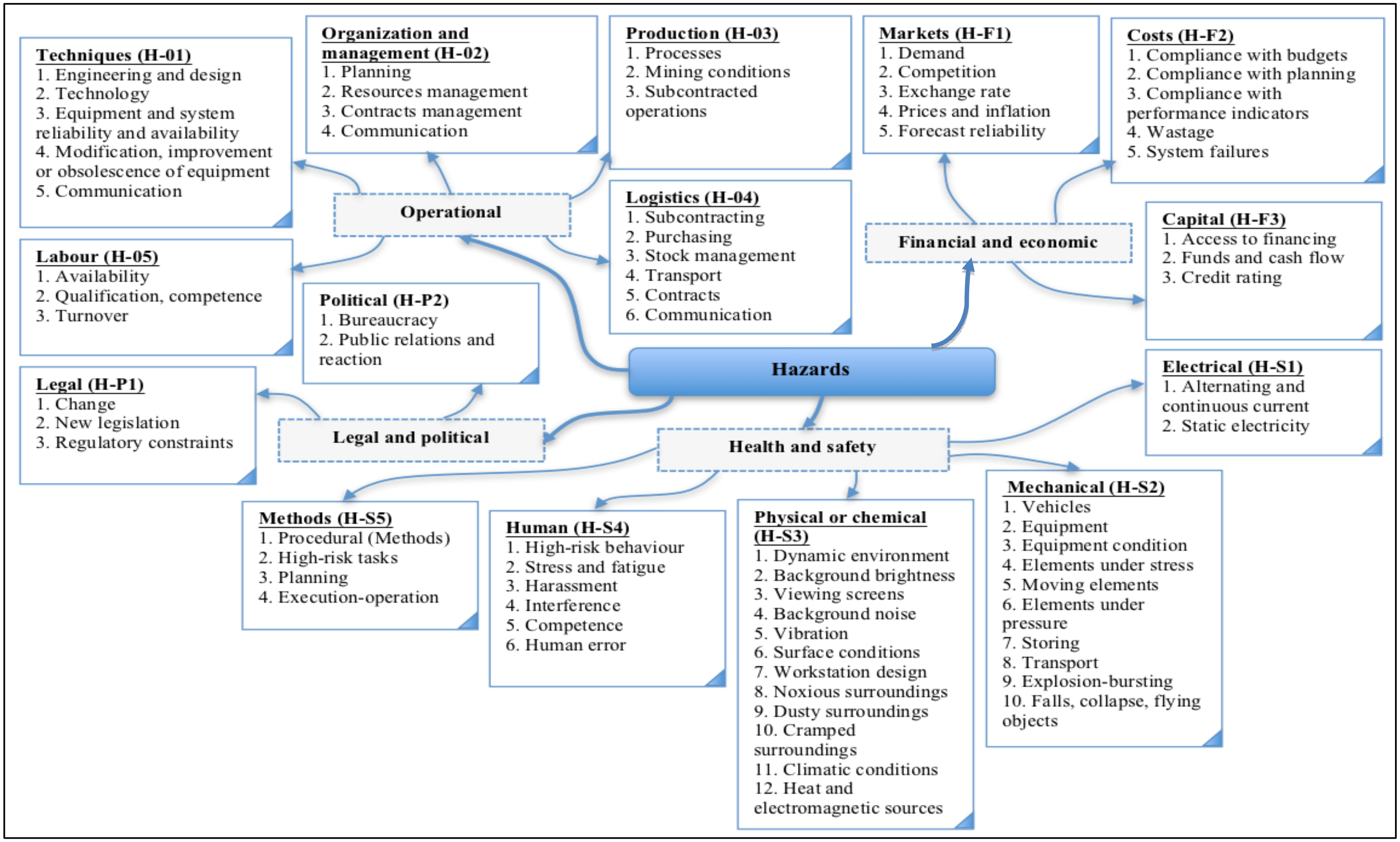

Figure 7.8 Hierarchical network of hazards

7.4.3 A clearer view of risks: elements and causal associations

The risk stemming from a hazard is defined in terms of undesirable events and their impact. These may vary as the project advances. Causal associations must first be drawn, between (1) families of hazards, (2) undesirable events, and (3) the impact or consequences of these events (Figure 7.3). Table 7.4 below models the possible causal associations between these elements, based on the judgment of the team.

Tableau 7.4 Risks and the associations between their constituent elements

Code	**Element**	**Risk**					
		R1	**R2**	**R3**	**R4**	**R5**	**R6**
IE	**Undesirable event**						
DE-1	Major industrial accident	X					
DE-2	Increased business costs		X				
DE-3	External operational difficulty			X			
DE-4	Business stoppage				X		
DE-5	Occupational illness					X	
DE-6	Ecological impact						X
NI	**Negative impact on the project**						
NI-C	Cost increase	X	X	X	X	X	X
NI-D	Delay	X		X	X		
NI-P	Poor performance	X	X	X	X	X	X
HZ	**Hazards**						
H-O	**Operational**						
H-O1	Technical	X	X		X	X	X
H-O2	Organizational and managerial	X	X				X
H-O3	Production-related	X	X		X	X	X
H-O4	Logistic		X	X	X		
H-O5	Labour-related	X	X	X		X	
H-F	**Financial and economic**						
H-F1	Markets			X	X		
H-F2	Costs	X	X		X		X
H-F3	Capital			X	X		
H-S	**Occupational health and safety**						
H-S1	Electrical	X			X		
H-S2	Mechanical	X			X	X	X
H-S3	Physicochemical	X			X	X	X
H-S4	Human	X			X	X	X
H-S5	Procedural	X			X	X	X
H-P	**Legal and political**						
H-P1	Legal		X	X	X		
H-P2	Political		X	X	X		

For example, the risk of occupational illness (R5) is inherent in the undesirable event "occupational illness" (DE-5) and stems from the technical (H-O1), production-related (H-O3), labour-related (H-O5), mechanical (H-S2), physicochemical (H-S3), human (H-S4) and procedural (H-S5) families of hazards. Materializing of this risk has negative impact on project cost (NI-C) and performance (NI-P). The industrial partner views major industrial accidents as those having major destructive impact (e.g. serious fires or accidents with direct impact on work-crew health and safety).

7.4.4 Measurement of threats: evaluation and ranking of risks

To calculate "hazard concentration", a ranking of the families of hazards connected with each undesirable event is obtained using multi-criteria analysis. It is at this stage that the involvement of experienced workers and managers is particularly crucial. As much as possible, the team should also seek external expertise. The exercise can be completed in a single meeting. In our case, Expert Choice® software was used, although a common spreadsheet application could be used. This comparison provides a weighting of the capacity of each family of hazards to lead to undesirable events.

The number of hazards per family (level 3) is taken into consideration at this point. "Hazard concentration" is conceptualised as follows: A family of hazards is more likely to trigger an undesirable event (i.e. increases a risk) when it,

- contains a larger number of identified hazards
- is more heavily weighted by multi-criteria analysis

The concentration concept thus combines the weighting of the family of hazards (perceived likelihood of involvement) with the number of hazards (possibilities). Figure 7.9 below illustrates the comparison of two families of hazards. Family 2 is more likely to lead to the undesirable event.

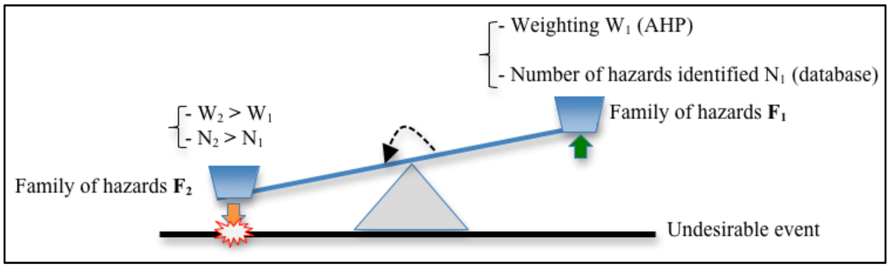

Figure 7.9 The "hazard concentration" concept

According to the team (AHP), the most important "family of hazards" will have the largest weight (disturbance weight). Table 7.5 shows the calculation of the "relative concentration of hazards (rc(i))" for each "family of hazards (i)" using the "disturbance weight" and "number of hazards".

Tableau 7.5 Use of AHP weightings and number of hazards to calculate hazard relative concentration by family

Family of hazards (level 2)	H-O1	H-O2	H-O3	H-O4	H-O5	H-F1	H-F2	H-F3	H-S1	H-S2	H-S3	H-S4	H-S5	H-P1	H-P2
Number of hazards (level 3) $X_{(i)}$	5	4	3	6	3	5	5	3	2	10	12	6	4	3	2
AHP ranking (by paired comparison, Appendix VII)	1	2	4	5	3	8	10	9	13	11	12	7	6	14	15
Disturbance weight $Y_{(i)}$	15	14	12	11	13	8	6	7	3	5	4	9	10	2	1
$X_{(i)}Y_{(i)}$ ($\Sigma X_{(i)}Y_{(i)} = 569$)	75	56	36	66	39	40	30	21	6	50	48	54	40	6	2
Relative hazard concentration by family (i) $rc_{(i)} = X_{(i)}Y_{(i)}/569$	.132	.098	.063	.116	.069	.070	.053	.037	.011	.088	.084	.095	.070	.011	.004

The total of "relative hazard concentration" contributed by all "families of hazards" connected to an undesirable event (j) (RC(j)) is shown in Table 7.6.

Tableau 7.6 Hazard concentration

$Risk_{(j)}$	**Undesirable $event_{(j)}$**	**Concentration $RC_{(j)}$**
R1	DE-1	0.76
R2	DE-2	0.54
R3	DE-3	0.31
R4	DE-4	0.83
R5	DE-5	0.60
R6	DE-6	0.68

Risk is defined as the product of the concentration of hazards and the negative impact connected with an undesirable event. This is the principal innovation described in the present article. We initially converted the concentration to probability in order to combine it with the value of the impact of the undesirable event and thus evaluate risk. In the discussion section, we will explain why we now believe we can use "hazard concentration" directly to evaluate risk.

Estimation of the impact of a risk is based on the highest impact value implied by the causal associations (Table 7.4). The matrix in Table 7.7 shows the levels of impact as established using our approach. In the case of risk R5 and its associated event "occupational illness (E5)", the negative impact will manifest itself as increased cost (NI-C) or poor performance (NI-P). The value of the impact of risk R5 to take into consideration is the higher of the two, in other words,

$$Impact_{(j)} = Maximum\ impact_{(Cost,\ Delays,\ Performance)} \tag{7.1}$$

Tableau 7.7 Impact (consequences) estimation matrix

	+	++	+++
Major	7	8	9
Moderate	4	5	6
Minor	1	2	3

By multiplying the Impact (j) by the "hazard concentration RC(j)", we evaluate and hence rank the risks identified in the course of our study:

$$Risk_{(j)} = RC_{(j)} \text{ x } Impact_{(j)} \qquad (7.2)$$

Given the time constraints on our action research, the present study is limited to ranking of risks. The remaining steps are devoted to implementing appropriate monitoring and control measures, based on this evaluation and ranking of the potential risks.

It was anticipated of course that the company would set its own criteria or levels of risk acceptability based on its in-house strategy. These criteria must treat federally or provincially regulated risks independently of their ranking. Risk acceptability depends principally on criteria set by decision-makers (ISO/IEC Guide 73: 2002). In the case of our industrial partner, the criteria were the result of the ranking of the risks and the value of their impact (or consequences). Table 7.8 shows the evaluation and ranking of the potential risks. We emphasize the feasibility of evaluating all categories of project risks using the proposed approach. The company is now able to integrate OHS into its management of risks associated with projects. It is able to update its risk evaluation as a function of project phase or following changes to processes, procedures, strategies, follow-up indicators or managerial methods.

Tableau 7.8 Evaluation and ranking of potential risks

Risk	**Concentration $RC_{(j)}$**	**$Impact_{(j)}$**	**Value of the risk**	**Rank**
Major industrial accident (R1)	0.76	9	6.84	1
Increased business costs (R2)	0.54	5	2.70	4
External operational difficulty (R3)	0.31	7	2.17	5
Business stoppage (R4)	0.83	7	5.81	2
Occupational illness (R5)	0.60	3	1.80	6
Ecological impact (R6)	0.68	4	2.72	3

7.5 Discussion

It should be noted that the OHS database created for the underground mine is almost identical to the one used for the open-pit mine. This suggests that the identified hazards are applicable, with a few adjustments, to goldmines in general. There were some discrepancies due to process and procedure characteristics and to the type of mine as well as to differences in perception of the consequences of hazards by the workers. The managers and workers in the underground mine feared fire the most. In general, they were not afraid of mine collapses. In the open-pit mine, the workers' worries were related to traffic and interference with mobile equipment during ore loading operations and maintenance activities. They also expressed apprehension regarding high-risk behaviours. These behaviours are among the preoccupations of underground miners (e.g. Xia, 2010). Vibrations are viewed among underground miners as a long-term problem and have been examined in several studies (e.g. Kumar, 2004; Pal and Dewan, 2009). Hazards are entered into the database without evaluation or measurement of the perceived degree of associated danger. The perceived seriousness of the hazard becomes apparent only after the ranking procedure (weighting) or evaluation of impact is completed.

The database is thus used to store as many potential hazards as can be identified in the mine. The data are updated as projects advance, as processes and procedures evolve, as new strategies are implemented, as new indicators or new managerial methods are adopted, and so on. The database thus serves as a knowledge base potentially adaptable to other companies as well as new mining projects. The challenges currently facing mines in terms of demand pressure, labour shortages and the use of new means of production have a direct impact on control of project risks. With the present work, we are trying to limit the negative impact of these factors by providing companies with solid fundamental knowledge in the area of risk management. This study has also provided OHS and project management researchers with the opportunity to apply their knowledge in the context of goldmines. Much literature is focused on risks in coalmines (e.g. Torma-Krajewski et al., 2007; Guo et Wu, 2009; Larry

Grayson et al., 2009). To the best of our knowledge, the OHS database established in the present study is the first of its kind for goldmines in the Canadian Shield. Once the proposed approach has been integrated into the company risk management process, we believe it will make a significant contribution to the protection of mining personnel. Sharing this evolving know-how should have a sparing effect on both human and material resources.

Integration of OHS reveals a limitation of conventional risk analysis and evaluation tools. These tools are generally derived from the analysis of the safety of technical systems. To evaluate a risk, a probability is combined with a consequence. Probability is generally estimated indirectly using measurable variables such as frequency of breakdown or failure/incident rate. In socio-technical system risk management, the challenge is often taking into consideration workers and their interactions with the technical, social and organizational sub-systems of the business under study. It should be noted that human influence is dominant. Human behaviour, thought, reaction and decision-making are all difficult to define in terms of probability (Badri et al., 2011a,b). The behaviour of a worker depends to a large degree on his perception of danger and is influenced by personal or professional goals and by the nature of his relationships within the organization (Nadeau, 2001). The risk management system also has a direct influence on risk evaluation. Even when rules or algorithms are applied, evaluation will always be affected by feelings, intuition, experience and the evaluator’s acceptance of the risk. It is clear that the attitude of individuals towards risk evolves with the established common symbolic referential in the workplace (Duclos, 1991). Referring to the theories of modern cognitive psychology, Slovic et al. (2004) proposed two possible systems of risk appreciation. The first of these is the “analytical system”, which applies rules and standard models such as stochastic calculation. The second is the “experimental system”, which focuses on human intuition and emotions. In the case of simultaneous application of these two systems, the second naturally influences the first.

We attempted accordingly to find a compromise between these two systems to increase the reliability of risk evaluation, especially for cases in which different types of risks are integrated. The “hazards concentration” concept begins by identifying all rational concerns.

Paired comparison of the families of hazards by the AHP method allows the reaching of a compromise among the evaluators and reduces disparities in risk appreciation. As is required by the AHP method, we kept a watch on the consistency indexes of hazard family weighting to ensure reliability. This weighting and hence the value we have called “concentration” replaces the term probability used in conventional risk evaluation formulas. “Concentration” is by design proportional to the likelihood of occurrence of an undesirable event and the final value of each risk remains proportional to the total number of potential hazards. Whether probability or “concentration” is used has no impact on the ranking of risks, given the linear relationship between these two variables (Badri et al., 2011a,b).

In spite of several logistical constraints, we were able to involve mining operational crews in order to adapt and improve the proposed risk management technique as well as obtain an OHS database potentially applicable to other goldmines in Quebec. Using the “hazard concentration” concept and multi-criteria analysis, all forms of risk can be evaluated simultaneously and no threat to a project need be neglected. More comprehensive evaluation of risk should allow more enlightened and rational decision-making.

The proposed approach nevertheless has several limitations, which we will attempt to resolve in future research. Action-research affects the practices observed in the participating companies. This may influence the course of subsequent discussions and the risk evaluation exercise. Our presence may have modified behaviours and the manner in which tasks were performed or hazards were assessed. We did not choose the risk management team. Participation in data gathering was free and voluntary. The company did make a point of involving its most experienced miners. The hazards identified were generally known to the researchers and the workers beforehand and have been cited in numerous studies. Since changing the number of hazards per family could influence the calculated concentrations, the evaluation must be updated if the hazards profile is changed. We believe that this problem will be minor as long as the data gathering process remains rigorous. When sharing the knowledge gained in the present study with new mines, effort should focus in each case on verifying the presence of the elements compiled in the database.

7.6 Conclusion

This article presents a novel practical approach to risk management applicable to mining projects. The aim of the study is to begin the gradual introduction of such an approach into goldmines throughout the province of Quebec. The study was carried out within a comprehensive research program intended to devise a method of managing practically all risks in mining projects and involved adapting new concepts developed in the context of open-pit gold mining to the underground context.

Thanks to extensive data gathering by several methods, including interviews, questionnaires, collaborative observation and document analysis, we were able to identify a wide range of hazards that provided reliable evaluation of potential risks. Using the new concept of “hazard concentration” and multi-criteria analysis (AHP), it is now possible to evaluate simultaneously practically all types of risks in mining projects and thus avoid neglecting possible threats to the success of a project.

In spite of several limitations, this study involved operational crews in the mine in order to adapt and improve the procedure. Action research made possible exchanges with experienced miners, whose contribution and know-how increased the value of the study. In addition to evaluating potential risks, we have begun the development of a useful OHS database. This database is adaptable and could be applicable throughout the Quebec mining sector with adjustments to accommodate the unique character of each new mining project.

CONCLUSION

Les travaux de cette thèse avaient essentiellement pour but d'intégrer la SST dans la gestion des risques de projets miniers. Dans le cadre de cette thèse, une démarche de gestion des risques, interdisciplinaire et pratique, a été mise en place au sein de deux entreprises minières québécoises. Cette démarche fait appel à un concept novateur d'évaluation des risques identifiés. Ce concept est basé essentiellement sur le calcul des « concentrations des sources de dangers » estimées à l'aide du nombre des sources de dangers identifiées, en lien avec des évènements indésirables, et le résultat de leur comparaison multicritère (méthode AHP).

Pour atteindre les objectifs de la thèse, nous avons adopté une démarche de recherche partenariale. Nous avons commencé par vérifier la pertinence de nos questions de départ par l'exploration de la littérature (chapitres 3). Une fois la recension des écrits est réalisée, nous avons élucidé la problématique de la prise en compte de la SST dans la gestion des risques de projets industriels. Par la suite, nous avons construit le modèle conceptuel de la démarche proposée (chapitre 4) à l'aide des hypothèses générales de recherche, sur la base des objectifs de la thèse et des éléments principaux de la problématique (chapitres 1 et 2). Nous avons pu adapter et améliorer le modèle conceptuel de référence au gré de l'avancement de nos travaux et par le biais d'une recherche-action impliquant deux partenaires industriels du secteur minier québécois (chapitres 5, 6 et 7). Cette recherche-action a permis aux chercheurs d'évaluer le modèle conceptuel par la collecte et l'utilisation des données et l'appréciation des améliorations apportées. En contrepartie, les entreprises impliquées ont profité des résultats de recherche pour améliorer des situations et éliminer des problèmes en lien avec l'identification des sources de dangers et la priorisation des risques.

Le chapitre 3, consacré à la recension des écrits, consiste en l'examen de la littérature pertinente et présente un résumé de la mesure dans laquelle les risques de SST sont pris en compte dans les pratiques de gestion de projets industriels. Nous avons procédé à une exploration des travaux de recherche et nous avons tracé un aperçu de quelques outils, méthodes et approches mis au point ou adaptés afin d'intégrer la SST. Notre revue a démontré la nécessité d'identifier les risques de SST en lien avec un projet et de planifier adéquatement leur gestion dans le but d'éviter les dangers et les pertes menaçant les entreprises. Nous avons souligné que les publications identifiées sont principalement issues de l'industrie de la construction. Enfin, nous avons confirmé que l'intégration de la SST dans la gestion des risques n'est pas systématique dans tous les secteurs industriels, malgré le changement et l'amélioration des lois et des référentiels de gestion de la SST.

Cette recension des écrits a montré la pertinence de la problématique abordée dans la thèse et a servi de référence pour identifier et discuter des pratiques et des outils pouvant servir à notre secteur industriel cible. Nous avons complété cet aperçu général par d'autres revues dédiées à l'industrie minière afin de justifier le besoin d'une intégration systématique de la SST dans la gestion des risques de projets miniers (chapitres 5, 6 et 7). Ces revues ont confirmé le besoin d'une solution novatrice permettant la prise en considération des risques de SST tout au long du cycle de vie des projets miniers. Cette solution doit prendre en considération plusieurs facteurs en lien avec cette industrie, tels la complexité des projets, le caractère dynamique des mines, l'apport dominant de l'humain dans les opérations minières, l'évolution des technologies et des équipements et l'émergence des nouvelles entreprises minières dans un contexte économique en pleine effervescence.

Grâce au nouveau concept de « la concentration des sources de dangers » et l'évaluation multicritère (AHP), la démarche proposée permet d'identifier les sources de dangers et de calculer une concentration de ces sources relative à chaque évènement indésirable identifié. Cette concentration donne plus de réalité au poids de perturbation de chaque « famille de dangers » en lien avec des évènements indésirables. Le concept de « la concentration des sources de dangers » combine donc le poids de la « famille de dangers » à perturber un état et sa concentration en « sources de dangers ». Avec ce concept, les évaluateurs ne considèrent plus les sources de dangers identifiées comme des entités ayant la même influence.

Notre présence sur le terrain a été décomposée en deux mandats. Ces mandats ont impliqué deux partenaires miniers québécois. Le but de notre présence était de compléter les étapes du cadre pratique prévues dans notre devis méthodologique (section 2.1), afin de proposer à la communauté scientifique et celle des praticiens une démarche pratique intégrant la SST dans la gestion des risques de projets miniers. Cette démarche ne doit pas se limiter à une modélisation théorique et une simulation d'un cas (chapitre 4), mais elle doit plutôt être mise en oeuvre dans un contexte industriel réel (chapitres 5 et 7) de manière à ce que l'on puisse mesurer sa pertinence par l'appréciation concrète de ses solutions apportées.

Le premier mandat engagé dans une nouvelle mine d'or à ciel ouvert (chapitre 5) a permis d'adapter la démarche proposée au contexte d'un projet au démarrage. Cette démarche a permis de constituer une base de données de SST facilitant la gestion des risques pour les experts. L'analyse des incidents et des accidents, les entrevues et les observations partenariales, nous ont aidés à constituer cette base de données de SST, d'environ 200 sources de dangers, exploitable pour le cas de cette mine. Nous avons pu confirmer la présence de plusieurs de ces sources de dangers identifiées dans d'autres travaux de recherche. Durant ce travail, nous avons identifié quelques effets de renforcement entre les familles des sources de dangers et nous avons pu prioriser l'ensemble des risques potentiels identifiés par l'équipe.

Par la suite, nous avons établi un portrait préliminaire des risques rattachés aux projets miniers (chapitre 6). Nous avons jugé cette étape nécessaire afin d'alimenter notre démarche de gestion des risques miniers. Pour effectuer ce travail, nous avons principalement utilisé les résultats des travaux de recherche réalisés sur le terrain. Nous avons complété ce portrait par les résultats d'identification des risques que nous avons menée dans une mine à ciel ouvert (chapitre 5). Les risques et les incertitudes identifiés ont été catégorisés de façon hiérarchique en montrant leurs influences et leurs apparitions possibles en fonction des phases du projet minier. Ce travail a également comblé le déficit, dans la littérature, d'un portrait complet des risques miniers et a permis de bâtir un cadre de connaissances indispensables afin de compléter une évaluation fiable et systématique des risques miniers.

Par la suite, le deuxième mandat est venu compléter nos travaux et améliorer la démarche proposée en s'inscrivant dans une mine d'or souterraine (chapitre 7). Dans cette étape, la méthode d'évaluation et de priorisation des risques a évolué davantage. La conversion des « concentrations des sources de dangers » en probabilités a été remplacée par une estimation directe de la valeur du risque, en fonction de ces concentrations. Une nouvelle notion du « poids de perturbation » a été ajoutée lors de la comparaison des sources de dangers. Une étape de planification de la mission de gestion des risques a été ajoutée à la démarche afin de se conformer à la plupart des référentiels de gestion de projets. La base de données de SST a été également adaptée au contexte de la mine souterraine. Cette base de données évolutive a été constituée d'environ 250 sources de dangers identifiées dans la mine souterraine. Une évaluation plus étendue des risques a été réalisée en utilisant le portrait préliminaire des risques de projets miniers (chapitre 6). Ce portrait a été adapté aux particularités de l'entreprise et de la phase d'exploitation du projet minier en cours.

Finalement, nous avons élaboré le concept de « la concentration des sources de dangers » qui dépend essentiellement d'une collecte rationnelle des dangers. La comparaison multicritère à l'aide de la méthode AHP permet d'atteindre un compromis entre les évaluateurs et de réduire la disparité dans les appréciations individuelles des risques. Pour atteindre plus de fiabilité durant le processus d'évaluation des risques, nous avons veillé à suivre les indices de consistance de l'appréciation des « poids de perturbation » des familles de dangers. Les outils de collecte de données sont choisis de manière à se compléter et dans le but de permettre l'extraction d'un maximum d'informations au cours d'une période de temps relativement courte.

Les travaux de cette thèse ont pour potentiel de favoriser une convergence vers la prise en considération de la SST, ce, dans toutes les activités opérationnelles des entreprises minières impliquées. Le travail collaboratif et interdisciplinaire des équipes a permis de résoudre rapidement plusieurs problèmes. Nous avons contribué à la mise en place progressive d'une base de données de SST évolutive et possédant le potentiel d'être généralisable à d'autres mines d'or au Québec. Grâce à la nouvelle démarche proposée, il est maintenant possible d'évaluer simultanément presque tous les risques de projet et d'éviter de négliger diverses menaces possibles au projet. Une évaluation étendue des risques permettra certainement de prendre des décisions plus éclairées et fondées !

RECOMMANDATIONS

À l'issue de cette thèse, nous considérons que la nouvelle démarche proposée et les contributions réalisées constituent des résultats probants permettant la prise en compte systématique de la SST dans la gestion des risques de projets miniers. Les travaux de cette thèse s'inscrivent dans les initiatives engagées depuis plusieurs années par des groupes de travail réunissant des professeurs, des chercheurs, des ingénieurs et des experts afin d'améliorer la prise en compte de la santé, de la sécurité et du bien-être en milieu de travail. Malgré les efforts, ces travaux présentent plusieurs limites parmi lesquelles on retrouve certaines que nous nous proposons de résoudre à l'avenir. Ces limitations seront présentées ci-après sous forme de perspectives et de recommandations de recherche.

Les deux premières versions de la démarche (chapitres 4 et 5) utilisent une échelle de conversion des « concentrations des sources de dangers » en probabilités afin d'évaluer et de prioriser les risques en lien avec chaque évènement indésirable. Comme discuté dans les chapitres 4 et 5, la conversion des concentrations mesurées (qui sont la base de l'estimation des probabilités) ne fausse pas les calculs et ne change pas la philosophie de l'estimation du risque. Elle offre, pour l'organisation, l'avantage d'agir en fonction de leur tolérance aux risques (Ewing, 1994 ; Frank, 2010 ; Hallowell, 2010 ; Marszal, 2001). Nous avons amélioré la méthode de l'évaluation des risques par la prise en compte des valeurs des concentrations en lien avec chaque risque (chapitre 7). Telle que « la concentration des sources de dangers » est conçue, la probabilité de causer un évènement indésirable est proportionnelle à la valeur de cette concentration. La valeur finale de chaque risque reste une quantification proportionnelle au nombre total des risques potentiels. Utiliser une valeur de probabilité ou une « concentration des sources de dangers » n'a pas un impact sur la priorisation des risques, vu la linéarité entre les deux variables. Dans cette perspective, il est important de souligner la remarque des pairs recommandant de valider les échelles par des experts. Cet effort donnera plus de fiabilité à la conversion, mais il demande un historique d'évaluation des risques par la démarche proposée. Il est donc envisageable d'utiliser la méthode Delphi pour atteindre le consensus des experts afin de fixer une échelle de conversion. Ce consensus pourra également prendre en compte la tolérance aux risques de l'entreprise.

Comme discuté dans le chapitre 4, le choix initial de AHP comme outil principal d'évaluation multicritère est fait sur la base de son succès dans les industries nord-américaines. AHP présente plusieurs avantages, mais aussi certaines limites qui sont, en grande partie, communes à d'autres méthodes. « *AHP n'est pas une formule magique qui trouve la réponse exacte. Il s'agit plutôt d'un processus qui aide les décideurs à trouver la meilleure réponse* » (Forman et Selly, 2002, p. 14). Nous avons limité la démarche proposée à l'utilisation de la méthode AHP pour laisser la même référence d'évaluation des risques dans tous nos travaux. Nous recommandons, dans le futur, de comparer l'efficacité d'autres méthodes multicritères (par exemple, MACBETH, ELECTRE, PROMOTHEE et Théorie des ensembles approchés [Rough set]) (Bana e Costa et Chagas, 2004 ; Boudreau-Trudel et Zaras, 2012). Cette ouverture permettra de comprendre et de généraliser davantage l'utilisation de la démarche proposée.

La démarche proposée est basée sur le nombre des sources de dangers identifiées. Ces sources de dangers sont généralement reconnues par les chercheurs et les travailleurs dans le contexte des deux mines étudiées (chapitres 5 et 7). Elles sont également citées dans les différentes recherches que nous avons détaillées dans la recension des écrits ou les discussions des résultats. Le changement du nombre de ces sources de dangers (par famille) pourra influencer le calcul des concentrations. Nous recommandons d'explorer les possibilités d'ajouter d'autres techniques de collecte de données plus adaptées aux problématiques étudiées. Nous soulignons l'exemple de l'identification des problèmes ergonomiques en lien avec les postures et les postes de travail qui peuvent être mieux détaillés en utilisant des outils de type OWAS (The Ovako Working posture Analysis System) ou EAWS (European Assembly Worksheet).

La démarche proposée repose sur l'adhésion et la motivation de l'équipe pour fixer convenablement les liens de causalité possibles entre les éléments de risques. Dans cette étape, la démarche ne prévoit pas une méthodologie pour atteindre le consensus. Durant nos travaux (chapitres 4, 5 et 7), nous n’avons pas rencontré de difficultés, mais le problème reste possible et nous oblige à trouver une solution. La démarche pourra faire appel à une approche appropriée afin de mieux structurer les discussions et de converger vers une décision unique (par exemple, mini-Delphi ou Estimate-Talk-Estimate [ETE]).

Finalement, il est important de souligner que la démarche proposée et ses nouveaux concepts sont mis en place dans deux entreprises minières. Ces deux cas précis sont issus de l’industrie minière québécoise. Cette industrie est parmi les plus développées et règlementées en matière de SST dans le monde. Ce secteur a également une culture industrielle particulière. Les entreprises minières sont aussi des systèmes sociotechniques uniques. Toutes ces contraintes posent des limites quant à la généralisation des résultats de cette recherche (chapitres 5 et 7). La méthodologie de recherche-action adoptée présente aussi des limites de généralisation étant donné que ses résultats sont très influencés par la culture de l’entreprise impliquée (Lavoie et al., 1996). Il est donc important d’étendre les interventions dans d’autres mines et de continuer à suivre de près les deux partenaires industriels. Ces actions ont pour but d’améliorer et de généraliser progressivement cette démarche et de la mettre à la disposition des mines d’or de toute la province de Québec.

ANNEXE I

AHP SCALE OF BINARY COMBINATIONS

Tableau-A I-1 AHP scale of binary combinations
(Saaty, 2000)

Numerical scale	Definition	Verbal explanation
1	Equal significance of the two elements	Two elements contribute equally to the property
3	**Low** significance of one element compared to another	Experience and personal assessments favor one element slightly over another
5	**Strong** significance of one element compared to another	Experience and personal assessments favor one element strongly over another
7	**Confirmed** dominance of one element over another	One element is strongly favored and its dominance is borne out in practice
9	**Absolute** dominance of one element over another	The evidence favoring one element over another appears irrefutable
2, 4, 6, 8	**Intermediate values** between two neighboring levels	The assessment falls between two levels
Reciprocals (1/x)	A value attributed when activity *i* is compared to activity *j* becomes the reciprocal when *j* is compared to *i*	

ANNEXE II

DETAILS OF RISK FACTORS

Tableau-A II-1 Mechanical factors contributing to OHS risk

Mechanical factors (F1)	
Code	**Designation**
F11	Moving elements: Chucks, tools, robots, turntables, grinders, conveyer belts
F12	Handling: Bridge crane, forklift, stacker, motorized trailer
F13	Physical explosions: Dust, gas, vapor, tank depressurizing, liquid on very hot surfaces
F14	Heights: Ladders, staircases, catwalks
F15	Movement: Obstacles on the ground, slopes, openings in the ground
F16	Devices and elements under pressure: Compressors, gas cylinders, hydraulic or pneumatic lines
F17	Elements under strain: Structures, slings, pulleys, loaded racks, piping

Tableau-A II-2 Electrical factors contributing to OHS risk

Electrical factors (F2)	
Code	**Designation**
F21	DC or AC electrical current: Electrical room, electrical cabinet, transformer, wiring, overload of outlets
F22	Static electricity: Accumulation of charge on insulating materials; sparks in the presence of inflammable liquid transfer operations.

Tableau-A II-3 Human factors contributing to OHS risk

Human factors (F3)	
Code	**Designation**
F31	High-risk behavior: Alcohol, narcotics, tobacco, ignoring safety measures, ignoring safe limits/protection.
F32	Stress: Work pace, work overload
F33	Harassment

Tableau-A II-4 Physical ambience factors contributing to OHS risk

Physical ambience and other nuisance factors (F4)	
Code	**Designation**
F41	Ambient lighting Work station lighting, glare, luminosity
F42	Video screens
F43	Ambient noise Infrasound, ultrasound, blowers, machinery
F44	Vibrations Machines, motorized trailers
F45	Contact temperature Hotplates, composting machine, Bunsen burner, hot surfaces, piping
F46	Work station design Work posture, repeated movements, human-machine interface, station arrangement
F47	Hostile environments Asphyxia caused by displacement of air by gas, work in isolation, physical aggression

ANNEXE III

CASE STUDY: THE PAIRED COMPARISON MATRICES

Work-related illnesses (E1)

	F1	F2	F3	F4
F1	1	5	3	0.50
F2	0.20	1	0.50	0.13
F3	0.33	2	1	0.14
F4	2	8	7	1

Drop in productivity (E2)

	F1	F2	F3	F4
F1	1	3	0.25	0.50
F2	0.33	1	0.11	0.14
F3	4	9	1	2
F4	2	7	0.5	1

Drop in quality (E3)

	F1	F2	F3	F4
F1	1	4	0.33	2
F2	0.25	1	0.13	0.50
F3	3	8	1	7
F4	0.50	2	0.14	1

Inadequate design (E4)

	F1	F2	F3	F4
F1	1	2	4	7
F2	0.50	1	3	5
F3	0.25	0.33	1	2
F4	0.14	0.20	0.50	1

Pollution (E5)

	F1	F2	F3	F4
F1	1	6	8	2
F2	0.17	1	3	0.33
F3	0.13	0.33	1	0.17
F4	0.50	3	6	1

Explosion and fire (E6)

	F1	F2	F3	F4
F1	1	0.33	3	4
F2	3	1	5	7
F3	0.33	0.20	1	2
F4	0.25	0.14	0.20	1

ANNEXE IV

OHS DATABASE (OPEN-PIT GOLDMINE)

Tableau-A IV-1 OHS database (open-pit goldmine)

Category (Level 0)	Subcategory (Level 1)	Details of hazards (Level 2)
Mechanical (MC)	MC-1	Mobile park: Excavator, drill, bulldozer, articulated haulers, truck, pickup, scraper, leveler, loader, crane
	MC-2	Equipment: Non-compliant safety equipment, dangerous equipment, ladder, stairs, gateway
	MC-3	Maintenance and installation of equipment Preventive, mechanical wear, wiring, installations
	MC-4	Moving parts: Tools, trailers, grinder, conveyor belt, working basis, moving or unstable part, vibrating object
	MC-5	Under pressure devices and elements: Compressors, gas cylinders, hydraulic or pneumatic circuits
	MC-6	Constrained elements: Structures, slings, racks loaded, pipes, tank
	MC-7	Handling: Traveling crane, pallet truck, cart, conveyor
	MC-8	Shifting and oversight: Obstacle on the ground, slope, high walls, open ground
	MC-9	Explosion-bursting: Leak, fire, smoke, dust, fuel, gas, enclosures in depression, explosives, sparks, electric arc, blasting, friction, chemical products, tires, battery
	MC-10	Fall, collapse, projection or reversal, slip: Rocks, load, object, worker, structure, open ground, blasting
Electrical (EL)	EL-1	DC or AC power: Electrical room, electrical cabinet, transformer, cable, isolation, electrical outlets overloaded, battery, electrical equipment, measurement tool
	EL-2	Static electricity: Charge accumulation on insulating materials, spark during unloading of flammable materials
Ambient physical factors (PA)	PA-1	Light environment: Lighting of work stations, glare, brightness
	PA-2	Display screen: Computer, control interface
	PA-3	Soundscape (noise): Gussets, machines, mobile park, blasting, crushing, radio
	PA-4	Vibration: Machines, vehicles, blasting, crushing
	PA-5	Contact temperature: Heater, hot surface, gel and ice
	PA-6	Design of the workstation: Working posture, repetitive gesture, Man-machine interface, job location, ergonomics
	PA-7	Hostile environments: Asphyxia, diesel particulate, chemicals, explosives
	PA-8	Dusty environment: Ventilation, crusher, blasting, transport ore, loading, unloading, excavation

Tableau-A IV-1 (*Continued*)

Category (Level 0)	**Subcategory (Level 1)**	**Details of hazards (Level 2)**
Ambient physical factors (PA)	PA-9	Limited areas: Confined space, debris, waste, obstacles, traffic patterns, parking, garage, loading area, unloading area, jamming against an object
	PA-10	Climatic condition: Frost and ice, bad weather, wet temperature, maneuver in high winds, rain and flood, snow, heatstroke, chill, fog
Human (HM)	HM-1	Risk behaviours: Alcohol, drug, tobacco, non-compliance with safety measures, non-compliance with instructions/protection, unsafe driving
	HM-2	Stress and fatigue: Work pace, overwork, inattention, lack of concentration, to sleep
	HM-3	Harassment
	HM-4	Interference: Several subcontractors, competition, cultural differences, languages, integration, pedestrian-equipment
	HM-5	Competence: Expertise, training, local knowledge, capacity for action, autonomy
	HM-6	Human error: Conduct, parking, order, working methods, safety instructions, oversight, manipulation, access to hazardous areas, decision, safety equipment (belts, harness, *etc*.)
Working methods (WM)	WM-1	Methods: Posture problems, excessive effort, sudden movement, lack of signaling, non-adapted conduct, communication, reactivity, safety equipment, lifting or moving a heavy load, improper handling, exploration
	WM-2	Risk tasks: Driving, loading shovel, drop operation, blasting, near area excavated by blasting, near a power source in the pit, near the vehicles, intervention in height, intervention in a confined space, repairing, preventive maintenance
	WM-3	Planning: Monitoring, communication, overtime, organization of work at risk, division of labor, interference
	WM-4	Execution: Tasks control, layers and ground control, site examination, emergency procedures, communication

ANNEXE V

THE PAIRED COMPARISON MATRICES (OPEN-PIT GOLDMINE)

E1 : Job-related illness

	MC	EL	PA	HM	WM
MC	**1**	8	4	6	3
EL	1/8	**1**	1/8	1/8	1/8
PA	1/4	8	**1**	3	1
HM	1/6	8	1/3	**1**	1
WM	1/3	8	1	1	**1**

E2 : Drop in productivity

1	8	2	1/4	1/2
1/8	**1**	1/8	1/8	1/8
1/2	8	**1**	1/2	1/3
4	8	2	**1**	2
2	8	3	1/2	**1**

E3 : Drop in quality

1	2	1/8	1/8	1/8
1/2	**1**	1/8	1/8	1/8
8	8	**1**	1/4	1/3
8	8	4	**1**	2
8	8	3	1/2	**1**

E4 : Industrial accident

1	6	6	3	4
1/6	**1**	4	2	3
1/6	1/4	**1**	1/2	1/2
1/3	1/2	2	**1**	2
1/4	1/3	2	1/2	**1**

ANNEXE VI

OHS DATABASE (UNDERGROUND GOLDMINE)

Tableau-A VI-1 OHS database (underground goldmine)

Family of hazards (level 2)	**Details (level 3)**
Electrical H-S1	**1. Direct or alternating current** Electrical room, cabinet, transformer, cable, insulation; overloaded outlets, batteries, electrical equipment
	2. Static electricity Accumulation of charge, sparks
Mechanical H-S2	**1. Vehicles** Borer, truck, tractor, loader, interference with equipment or workers
	2. Equipment Substandard safety devices, dangerous devices, ladders, stairs, catwalks
	3. State of equipment Mechanical wear, age, reliability, operation, suspension
	4. Elements under stress Structures, pipes and ducts, hoists, chains, slings, tires, wearing parts, winches, cages, cables, tracks, ore loading and dumping devices, tanks and reservoirs, floors or roadways under stress
	5. Moving elements Tools, turntables, crusher, treadmill, work base, moving or unstable parts, vibrating objects, conveyers, pulleys, jacks, motors, fans, rock borer, jackhammer, bolting machine
	6. Devices and elements under pressure Compressors, hydraulic press, pipes and ducts, pumping stations, plumbing, jacks, pistons, tanks
	7. Material handling Rolling bridge, forklift, dollies, conveyer
	8. Transport Obstacles on ground or floors, uneven ground, openings, puddles, bumps, rocks, clutter, loading and breaking capacity, slopes
	9. Explosion/bursts Leaks, fire, smoke, dust, fuel, gases, tanks under pressure, explosives, sparks, electric arcs, dynamiting, friction, chemicals and inflammable liquids, tires, batteries
	10. Falls, collapses, splashes, spills, slipping Rocks, loading, tools, objects, workers, structures, openings in ground, dynamiting, oil, water, roadways
Physicochemical H-S3	**1. Dynamic environment** Transport, material handling, traffic, frequent entry/exit of mobile equipment, interference, changes in architecture
	2. Ambient lighting Workstation lighting; flashes, brightness
	3. Viewing screens Computer, control panel
	4. Ambient noise Equipment, vehicles, crusher, wireless, operations, blasting
	5. Vibration Equipment, vehicles, dynamiting, operations
	6. State of contact surfaces Hot or cold surfaces, ice accumulation
	7. Workstation design Man-machine interface, station surroundings (clutter), ergonomics
	8. Noxious surroundings Gases, diesel fumes and soot, chemicals, explosives

Tableau-A VI-1 (*Continued*)

Family of hazards (level 2)	**Details (level 3)**
Physicochemical H-S3	**9. Dusty surroundings** Ventilation, draw, drilling, crusher, dynamiting, ore loading and dumping
	10. Cramped surroundings Enclosed spaces, debris, wastes, obstacles, traffic routes, parked vehicles, workshop; tools or materials stuck between objects
	11. Climatic conditions Ice and frost, dampness, draughts, flooding, fog
	12. Sources of Heat (motors, pumps, oil), electromagnetic fields (electromagnets, electric motors, electric breaks)
Human H-S4	**1. High-risk behaviour** Alcohol, drugs, tobacco, unsafe driving, access to danger zones, compliance with procedures and rules (lockout, maintenance, inspections, residual energy, chemical and explosives storage; securing areas, blast zones, blast plans and ignition sources; handling and insertion of explosives; wearing protective devices; driving and parking; handling materials; drilling, blasting, emergency measures), compliance with laws and regulations (explosives, ventilation, mechanical equipment, gas monitoring, etc.)
	2. Stress and fatigue Work pace, work load, inattention, poor concentration, drowsiness, visual effort, manual tasks
	3. Harassment Bullying, physical aggression
	4. Interference Numerous subcontractors, competition, cultural differences, integration, pedestrian-equipment conflicts
	5. Competence Experience, training, knowledge of the site, capacity for action, autonomy
	6. Human error Driving, parking, controls, work methods, safety procedures and rules, omissions, improper handling
Work methods H-S5	**1. Procedural (Methods)** Challenging posture (standing with little movement on cement floor, leaning forward while standing or crouching, arms above shoulders), excessive effort, sudden movement, lack of signalling, ill-adapted behaviour, poor communication or responsiveness, poor use of safety equipment, lifting or moving heavy loads, improper handling, repetitive tasks, procedures ill-adapted to equipment design
	2. High-risk tasks Vehicle driving, draw, working on slopes, at heights, in closed or cramped spaces or darkness, repairs, exposure to cold, dust or dampness, maintenance and inspection of moving elements, loading and transport of explosives, blasting, drilling, handling or moving heavy equipment, dislodging ore, worksite repairs, exposure to flashes and electric arcs, proximity of heavy or suspended equipment, work with gas burners, interference between repair crews, welding, ill-adapted tools and equipment, remote monitored or controlled equipment (crushers, drillers and jackhammers)
	3. Planning Follow-up, communication, overtime, organization of high-risk work, task distribution, interference, subcontracting
	4. Execution-operation Task monitoring, site inspection, emergency procedures, communication (with control rooms, other crews, emergency measures, alarms, radio and interference)

ANNEXE VII

THE PAIRED COMPARISON MATRICES (UNDERGROUND GOLDMINE)

DE-1: Major industrial accident

Paired comparison of hazards: H-O1, H-O2, H-O3, H-O5, H-F2, H-S1, H-S2, H-S3, H-S4, H-S5.

$$\begin{bmatrix} 1 & 7 & 5 & 3 & 5 & 7 & 7 & 5 & 3 & 3 \\ 1/7 & 1 & 1 & 1 & 3 & 2 & 2 & 3 & 5 & 3 \\ 1/5 & 1 & 1 & 1 & 3 & 5 & 5 & 5 & 4 & 4 \\ 1/3 & 1 & 1 & 1 & 5 & 7 & 7 & 7 & 4 & 3 \\ 1/5 & 1/3 & 1/3 & 1/5 & 1 & 5 & 5 & 5 & 2 & 3 \\ 1/7 & 1/2 & 1/5 & 1/7 & 1/5 & 1 & 1 & 1 & 2 & 2 \\ 1/7 & 1/2 & 1/5 & 1/7 & 1/5 & 1 & 1 & 1 & 3 & 2 \\ 1/5 & 1/3 & 1/5 & 1/7 & 1/5 & 1 & 1 & 1 & 2 & 1 \\ 1/3 & 1/5 & 1/4 & 1/4 & 1/2 & 1/2 & 1/3 & 1/2 & 1 & 1 \\ 1/3 & 1/3 & 1/4 & 1/3 & 1/3 & 1/2 & 1/2 & 1 & 1 & 1 \end{bmatrix}$$

DE-2: Increased business costs

Paired comparison of hazards: H-O1, H-O2, H-O3, H-O4, H-O5, H-F2, H-P1, H-P2.

$$\begin{bmatrix} 1 & 1 & 5 & 2 & 2 & 7 & 5 & 5 \\ 1 & 1 & 1 & 7 & 5 & 7 & 5 & 5 \\ 1/5 & 1 & 1 & 1 & 1 & 5 & 5 & 5 \\ 1/2 & 1/7 & 1 & 1 & 2 & 2 & 2 & 2 \\ 1/2 & 1/5 & 1 & 1/2 & 1 & 7 & 5 & 5 \\ 1/7 & 1/7 & 1/5 & 1/2 & 1/7 & 1 & 2 & 2 \\ 1/5 & 1/5 & 1/5 & 1/2 & 1/5 & 1/2 & 1 & 1 \\ 1/5 & 1/5 & 1/5 & 1/2 & 1/5 & 1/2 & 1 & 1 \end{bmatrix}$$

DE-3: External operational difficulty

Paired comparison of hazards: H-O4, H-O5, H-F1, H-F3, H-P1, H-P2.

$$\begin{bmatrix} 1 & 2 & 2 & 2 & 5 & 5 \\ 1/2 & 1 & 7 & 5 & 3 & 2 \\ 1/2 & 1/7 & 1 & 1 & 2 & 2 \\ 1/2 & 1/5 & 1 & 1 & 2 & 2 \\ 1/5 & 1/3 & 1/2 & 1/2 & 1 & 2 \\ 1/5 & 1/2 & 1/2 & 1/2 & 1/2 & 1 \end{bmatrix}$$

DE-4: Business stoppage

Paired comparison of hazards: H-O1, H-O3, H-O4, H-F1, H-F2, H-F3, H-S1, H-S2, H-S3, H-S4, H-S5, H-P1, H-P2.

$$\begin{bmatrix} 1 & 5 & 6 & 3 & 3 & 2 & 5 & 5 & 4 & 3 & 6 & 6 & 6 \\ 1/5 & 1 & 4 & 3 & 3 & 2 & 4 & 4 & 5 & 5 & 4 & 5 & 5 \\ 1/6 & 1/4 & 1 & 2 & 2 & 2 & 2 & 4 & 2 & 4 & 5 & 5 & 6 \\ 1/3 & 1/3 & 1/2 & 1 & 4 & 2 & 4 & 5 & 3 & 3 & 4 & 6 & 7 \\ 1/3 & 1/3 & 1/2 & 1/4 & 1 & 4 & 3 & 4 & 3 & 2 & 4 & 6 & 5 \\ 1/2 & 1/2 & 1/2 & 1/2 & 1/4 & 1 & 3 & 5 & 5 & 4 & 3 & 4 & 4 \\ 1/5 & 1/4 & 1/2 & 1/4 & 1/3 & 1/3 & 1 & 4 & 3 & 2 & 2 & 4 & 4 \\ 1/5 & 1/4 & 1/4 & 1/5 & 1/4 & 1/5 & 1/4 & 1 & 2 & 1 & 1 & 3 & 4 \\ 1/4 & 1/5 & 1/2 & 1/3 & 1/3 & 1/5 & 1/3 & 1/2 & 1 & 1 & 2 & 3 & 4 \\ 1/3 & 1/5 & 1/4 & 1/3 & 1/2 & 1/4 & 1/2 & 1 & 1 & 1 & 2 & 2 & 4 \\ 1/6 & 1/4 & 1/5 & 1/4 & 1/4 & 1/3 & 1/2 & 1 & 1/2 & 1/2 & 1 & 4 & 3 \\ 1/6 & 1/5 & 1/5 & 1/6 & 1/6 & 1/4 & 1/4 & 1/3 & 1/3 & 1/2 & 1/4 & 1 & 2 \\ 1/6 & 1/5 & 1/6 & 1/7 & 1/5 & 1/4 & 1/4 & 1/4 & 1/4 & 1/4 & 1/3 & 1/2 & 1 \end{bmatrix}$$

DE-5: Occupational illness

Paired comparison of hazards: H-O1, H-O3, H-O5, H-S2, H-S3, H-S4, H-S5.

$$\begin{bmatrix} 1 & 1 & 3 & 5 & 3 & 2 & 2 \\ 1 & 1 & 4 & 5 & 5 & 3 & 3 \\ 1/3 & 1/4 & 1 & 3 & 3 & 4 & 3 \\ 1/5 & 1/5 & 1/3 & 1 & 2 & 2 & 2 \\ 1/3 & 1/5 & 1/3 & 1/2 & 1 & 3 & 2 \\ 1/2 & 1/3 & 1/4 & 1/2 & 1/3 & 1 & 1 \\ 1/2 & 1/3 & 1/3 & 1/2 & 1/2 & 1 & 1 \end{bmatrix}$$

DE-6: Ecological damage

Paired comparison of hazards: H-O1, H-O2, H-O3, H-F2, H-S2, H-S3, H-S4, H-S5.

$$\begin{bmatrix} 1 & 5 & 3 & 6 & 5 & 5 & 7 & 3 \\ 1/5 & 1 & 2 & 4 & 6 & 5 & 3 & 3 \\ 1/3 & 1/2 & 1 & 7 & 6 & 5 & 4 & 4 \\ 1/6 & 1/4 & 1/7 & 1 & 2 & 2 & 1 & 2 \\ 1/5 & 1/6 & 1/6 & 1/2 & 1 & 2 & 2 & 2 \\ 1/5 & 1/5 & 1/5 & 1/2 & 1/2 & 1 & 3 & 1 \\ 1/7 & 1/3 & 1/4 & 1 & 1/2 & 1/3 & 1 & 1 \\ 1/3 & 1/3 & 1/4 & 1/2 & 1/2 & 1 & 1 & 1 \end{bmatrix}$$

APPENDICE A

CERTIFICATS D'ÉTHIQUE (MINE D'OR À CIEL OUVERT)

Université du Québec
École de technologie supérieure
1100, rue Notre-Dame Ouest
Montréal (Québec) H3C 1K3
Téléphone : (514) 396-8800
Télécopieur : (514) 396-8950

29 juillet 2010

Mme. Sylvie Nadeau
M. André Gbodossou
M. Adel Badri
Département de génie mécanique

Objet : Approbation de votre projet de recherche intitulé « *Gestion des risques dans la conduite des projets industriels : Développement de méthodes et outils pour intégrer les risques de santé et de sécurité du travail.* »

Messieurs,

Les modifications et précisions demandées par le CÉR dans sa lettre du 18 juin 2010 ayant été apportées adéquatement, votre projet peut aller de l'avant.

Veuillez toutefois noter que cette approbation n'est valable que pour une année. Vous devrez donc annuellement demander le renouvellement de l'approbation au Comité, sans quoi le projet sera considéré comme terminé. Également, nous attendons le rapport final de votre projet pour le **31 décembre 2010**. Vous trouverez le formulaire nécessaire à l'adresse suivante :

http://www.etsmtl.ca/zone2/administration/decanats/recherche/humains/formulaire_rapport.doc

Veuillez agréer, messieurs, l'expression de mes sentiments les meilleurs.

Liliana Guédez, M.Env.
Secrétaire
Comité d'éthique de la recherche

cc.Claude Bédard, Doyen à la recherche et au transfert technologique

Université du Québec en Abitibi-Témiscamingue
445, boul. de l'Université, Rouyn-Noranda (Québec) J9X 5E4
Téléphone: (819) 762-0971 Télécopieur: (819) 797-4727

Le 8 septembre 2010

Madame Sylvie Nadeau, Ph.D.
Département de génie mécanique
École de technologie supérieure

Monsieur André Gbodossou, Ph.D.
UER en sciences de la gestion
Université du Québec en Abitibi-Témiscamingue

OBJET : Évaluation éthique
Projet : *« Gestion des risques dans la conduite des projets industriels : Développement de méthodes et outils pour intégrer les risques de santé et de sécurité du travail »*

Madame, Monsieur,

Il me fait plaisir de vous informer que, suite aux modifications que vous avez apportées au protocole et au formulaire de consentement du projet de recherche cité en rubrique, le Comité d'éthique de la recherche de l'UQAT est heureux de vous délivrer le certificat attestant du respect des normes éthiques

En vous souhaitant tout le succès escompté dans la réalisation de votre projet, je vous prie de recevoir, Madame, Monsieur, l'expression de mes sentiments les meilleurs.

Manon Champagne, Ph.D.
Présidente
Comité d'éthique de la recherche impliquant des êtres humains
/dc
p.j. :

Université du Québec
en Abitibi-Témiscamingue

COMITÉ D'ÉTHIQUE DE LA RECHERCHE IMPLIQUANT DES ÊTRES HUMAINS

CERTIFICAT D'ÉTHIQUE

Le Comité d'éthique de la recherche impliquant des êtres humains de l'Université du Québec en Abitibi-Témiscamingue certifie avoir examiné le protocole de recherche soumis par :

Sylvie Nadeau, Ph.D. et André Gbodossou, Ph.D.

et intitulé (titre de la recherche) :

Gestion des risques dans la conduite des projets industriels : Développement de méthodes et outils pour intégrer les risques de santé et de sécurité du travail

DÉCISION DU CÉR :

☒ Accepté

☐ Refusé : Suite aux dispositions du 1er alinéa de l'article 5.5.2. « Évaluation complète » de la Politique d'éthique de l'Université du Québec en Abitibi-Témiscamingue

☐ Autre (voir commentaires ci-dessous)

Surveillance éthique continue :

Rapport annuel	Date : ______
Rapport d'étape	Date : ______
Rapport final[1]	Date : à la fin du projet
Autres (expliquez) : ______	

[1] Le rapport final consiste à envoyer une lettre au Comité annonçant la fin du projet. Cette lettre doit être accompagnée d'un résumé du projet d'au plus 250 mots et préciser tout événement de nature éthique survenu en cours de projet.

Membres du comité :

Nom	Poste occupé	Département ou discipline
Manon Champagne	Professeure	UER en sc. de la santé
Nancy Julien	Professeure	UER en sc. de la santé
Bruno Sioui	Professeur	UER sc. dév. humain et social

8 septembre 2010
Date

Manon Champagne, Ph.D., présidente CÉR

APPENDICE B

CERTIFICATS D'ÉTHIQUE (MINE D'OR SOUTERRAINE)

ÉTS
Le génie pour l'industrie

9 juin 2011

Mme Sylvie Nadeau
M. Adel Badri
Département de génie mécanique

Objet : Approbation de votre projet «Gestion des risques dans la conduite de projets industriels: développement de méthodes et outils pour intégrer les risques de santé et de sécurité du travail»

Madame Nadeau,

Les précisions demandées par le CÉR dans sa lettre du 30 mai 2011 ayant été apportées adéquatement, votre projet peut aller de l'avant.

Veuillez toutefois noter que cette approbation n'est valable que pour une année. Vous devrez donc annuellement demander le renouvellement de l'approbation au Comité, sans quoi le projet sera considéré comme terminé. Également, nous attendons le rapport final de votre projet pour le **31 décembre 2012**. Vous trouverez le formulaire nécessaire sur la page Internet du Décanat à la recherche et au transfert technologique.

Veuillez agréer, Madame, l'expression de mes sentiments les meilleurs.

Caroline Chartrand
Secrétaire
Comité d'éthique de la recherche

Université du Québec en Abitibi-Témiscamingue

COMITÉ D'ÉTHIQUE DE LA RECHERCHE IMPLIQUANT DES ÊTRES HUMAINS

CERTIFICAT D'ÉTHIQUE

Le Comité d'éthique de la recherche impliquant des êtres humains de l'Université du Québec en Abitibi-Témiscamingue certifie avoir examiné le protocole de recherche soumis par :

André Gbodossou, Ph.D. et Sylvie Nadeau, Ph.D.

et intitulé (titre de la recherche) :

> *« Gestion des risques dans la conduite des projets industriels : Développement de méthodes et outils pour intégrer les risques de santé et de sécurité du travail »* - Mine [redacted]

DÉCISION DU CÉR :

☒ Accepté

☐ Refusé : Suite aux dispositions du 1er alinéa de l'article 5.5.2. « Évaluation complète » de la Politique d'éthique de l'Université du Québec en Abitibi-Témiscamingue

☐ Autre (voir commentaires ci-dessous)

Surveillance éthique continue :
Rapport annuel Date : 2 mai 2012
Rapport d'étape Date : ______
Rapport final[1] Date : à la fin du projet
Autres (expliquez) : ______________________

[1] Le rapport final consiste à envoyer une lettre au Comité annonçant la fin du projet. Cette lettre doit être accompagnée d'un résumé du projet d'au plus 250 mots et préciser tout événement de nature éthique survenu en cours de projet.

Membres du comité :

Nom	Poste occupé	Département ou discipline
Manon Champagne	Professeure	UER en sc. de la santé
Nancy Julien	Professeure	UER en sc. de la santé
Bruno Sioui	Professeur	UER sc. dév. humain et social

Date : 2 mai 2011

Manon Champagne, Ph.D., présidente CÉR

APPENDICE C

DOCUMENTS : COLLECTE DE DONNÉES

Questionnaire-Entrevue

Projet de recherche universitaire

Gestion des risques de SST dans la conduite des projets industriels

Entreprise : ………………………..

Université du Québec École de technologie supérieure — Université du Québec en Abitibi-Témiscamingue

En nous permettant de recueillir des données, vous contribuerez à l'élimination, la diminution ou le contrôle des risques de santé-sécurité dans la gestion des nouveaux projets.
Ce questionnaire sera également une opportunité unique pour réfléchir à vos pratiques SST[11].

Instructions

Veuillez remplir tous les champs cités ci-après du questionnaire. Il devrait prendre environ 20 minutes pour le compléter. Avant de répondre, vous aurez une explication détaillée.
En fonction de votre disponibilité, le questionnaire pourra faire l'objet d'une entrevue. La durée de l'entrevue est variable en fonction de la nature de vos responsabilités.

Code du participant :

Informations personnelles

Quelle est votre fonction ?

……………………………………………………………………

Depuis combien de temps travaillez-vous dans cette entreprise ?

……………………………………………………………………

Depuis combien de temps travaillez-vous dans l'industrie minière ?

………….Années ………….. mois

Quel est votre niveau scolaire ?

☐ Collégial ☐ Universitaire

☐ Autre …………………………………………………

Quel est votre plus haut diplôme ?

……………………………………………………………………

Quelle spécialité ?

……………………………………………………………………

Avez-vous déjà été blessé au travail ?

☐ Oui ☐ Non

Avez-vous déjà été impliqué dans un accident de travail ?

☐ Oui ☐ Non

Avez-vous eu une formation en santé-sécurité ?

☐ Oui ☐ Non

Si oui, avez-vous une certification en santé et sécurité ?

☐ Oui ☐ Non

Précisez

……………………………………………………………………

……………………………………………………………………

[11] Santé et sécurité du Travail

Description des tâches par zone

Précisez vos principales tâches ou interventions dans les zones suivantes de la mine :

❑ Zone .... :
1...
.... Fréquence/sem ....
2...
.... Fréquence/sem ....

❑ Zone .... :
1...
.... Fréquence/sem ....
2...
.... Fréquence/sem ....

❑ Zone .... :
1...
.... Fréquence/sem ....
2...
.... Fréquence/sem ....

❑ Zone .... :
1...
.... Fréquence/sem ....
2...
.... Fréquence/sem ....

❑ Zone .... :
1...
.... Fréquence/sem ....
2...
.... Fréquence/sem ....

Criticité des zones

Veuillez encercler votre meilleure estimation. D'après vous et durant vos interventions, quel est le niveau de danger dans ces zones ?

Zone .... :

Faible I Moyen I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

❑ Je ne peux pas répondre

Zone .... :

Faible I Moyen I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

❑ Je ne peux pas répondre

Zone .... :

Faible I Moyen I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

❑ Je ne peux pas répondre

Zone .... :

Faible I Moyen I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

❑ Je ne peux pas répondre

Zone .... :

Faible I Moyen I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

❑ Je ne peux pas répondre

Présence des facteurs de risques par zone

Veuillez cocher la case correspondante si vous jugez qu'au moins une des sources de dangers mentionnées est présente dans une telle zone de la mine. Pour plus de précision, veuillez barrer simplement la source que vous jugez non présente dans toutes les zones.

Sources de dangers mécaniques :

Zones / Sources de dangers					
Éléments en mouvement : Broches, outils, robots, plateaux, broyeur, Tapis roulant.	☐	☐	☐	☐	☐
Manutention : Pont roulant, transpalette, Gerbeur, chariot, automoteur.	☐	☐	☐	☐	☐
Explosions physiques : Poussières, gaz, vapeur, enceintes en pression, liquide sur surface très chaude.	☐	☐	☐	☐	☐
Intervention en hauteur : Échelles, escaliers, passerelles.	☐	☐	☐	☐	☐
Déplacement : Obstacle au sol, dénivellation, ouverture au sol.	☐	☐	☐	☐	☐
Appareils et éléments sous pression : Compresseurs, bouteilles de gaz, circuits hydrauliques ou pneumatiques.	☐	☐	☐	☐	☐
Éléments sous contrainte : Structures, élingues, racks chargés, tuyauteries.	☐	☐	☐	☐	☐
Autres : ……………………………………… ……………………………………… ……………………………………… ………………………………………	☐	☐	☐	☐	☐

Sources de dangers électriques :

Zones / Sources de dangers					
Électricité à courant continu ou alternatif : Local électrique, armoire électrique, transformateur, fil, surcharge des prises électriques.	☐	☐	☐	☐	☐
Électricité statique : Accumulation de charges sur matériaux isolants, étincelle lors de dépotage de matières inflammables.	☐	☐	☐	☐	☐
Autres : ……………………………………… ……………………………………… ……………………………………… ………………………………………	☐	☐	☐	☐	☐

Sources de dangers d'ambiances physiques :

Zones / Sources de dangers					
Ambiance lumineuse Éclairage des postes de travail, éblouissement, luminosité.	☐	☐	☐	☐	☐
Écran de visualisation	☐	☐	☐	☐	☐
Ambiances sonores Sources sonores, Soufflettes, machines.	☐	☐	☐	☐	☐
Vibrations Machines, chariot automoteur.	☐	☐	☐	☐	☐
Températures de contact Plaque chauffante, surface chaude, canalisation.	☐	☐	☐	☐	☐
Conception du poste de travail Postures de travail, gestes répétitifs, interface homme-machine, implantation du poste.	☐	☐	☐	☐	☐
Milieux hostiles Asphyxie en cas de substitution de l'air par un gaz, travail isolé	☐	☐	☐	☐	☐
Autres : ……………………………… ……………………………… ………………………………	☐	☐	☐	☐	☐

Sources de dangers humaines :

Zones / Sources de dangers					
Comportements à risque : Alcool, drogue, tabac, non-respect des mesures de sécurité, non-respect des consignes/protections, conduite non sécuritaire.	☐	☐	☐	☐	☐
Stress te fatigue : Rythme de travail, surcharge de travail.	☐	☐	☐	☐	☐
Harcèlement	☐	☐	☐	☐	☐
Interactions : Présence de plusieurs sous traitants, différence de cultures, plusieurs langues, intégration dans l'équipe.	☐	☐	☐	☐	☐
Compétence : Expérience, formations, connaissances des lieux, capacité d'action, autonomie.	☐	☐	☐	☐	☐
Autres : …………………………… ……………………………	☐	☐	☐	☐	☐

Présence des effets de renforcement

Veuillez identifier les facteurs qui influencent les sources de dangers. Veuillez cercler le (+) dans le cas d'une augmentation possible du risque, le (-) dans le cas d'une diminution possible du risque ou le (0) dans le cas d'absence d'influence.

Facteurs de renforcement / Sources de dangers	Chaleur	Froid	Pluie/ Inondation	Travail de nuit
Mécanique	+ 0 -	+ 0 -	+ 0 -	+ 0 -
Électriques	+ 0 -	+ 0 -	+ 0 -	+ 0 -
Ambiances physiques	+ 0 -	+ 0 -	+ 0 -	+ 0 -
Humaines	+ 0 -	+ 0 -	+ 0 -	+ 0 -

Les risques de SST et les autres types risques de projet

Veuillez encercler votre meilleure estimation. D'après vous, quel sera le niveau de l'impact (négatif) de chaque typologie de risques à l'atteinte des objectifs du projet ?

Risques de SST :

Faible I Moyen I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

☐ Je ne peux pas répondre

Risques de fournisseurs :

Faible I Moyen e I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

☐ Je ne peux pas répondre

Risques organisationnels internes :

Faible I Moyen I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

☐ Je ne peux pas répondre

Risques financiers :

Faible I Moyen e I Élevé

1 2 3 I 4 5 6 I 7 8 9 I

☐ Je ne peux pas répondre

Risques de planification :

Faible	I	Moyen	I	Élevé

1 2 3 **I** 4 5 6 **I** 7 8 9 **I**

☐ Je ne peux pas répondre

Risques de ressources humaines :

Faible	I	Moyen	I	Élevé

1 2 3 **I** 4 5 6 **I** 7 8 9 **I**

☐ Je ne peux pas répondre

Risques logistiques :

Faible	I	Moyen	I	Élevé

1 2 3 **I** 4 5 6 **I** 7 8 9 **I**

☐ Je ne peux pas répondre

Risques législatifs et règlementaires :

Faible	I	Moyen	I	Élevé

1 2 3 **I** 4 5 6 **I** 7 8 9 **I**

☐ Je ne peux pas répondre

Les risques de SST comparées aux autres risques de projet

Veuillez comparer les autres types de risques aux risques de SST.

Veuillez cercler le (+) dans le cas d'une typologie de risques ayant plus d'impact (négatif) à l'atteinte des objectifs de projet, le (-) dans le cas d'une influence moindre ou le (E) dans le cas d'une équivalence.

Risques de SST / **Autres types de risques**		**Risques de SST**	
Risques de fournisseurs	-	E	+
Risques organisationnels internes	-	E	+
Risques financiers	-	E	+
Risques de planification	-	E	+
Risques de ressources humaines	-	E	+
Risques logistiques	-	E	+
Risques législatifs et règlementaires	-	E	+

Accidents

Selon vous, quel est le risque qui survient le plus fréquemment à l'intérieur de l'entreprise ? Précisez la zone

1……………………………………………………………………
……………………………………………………………………….

2……………………………………………………………………
……………………………………………………………………….

Selon vous, quel serait l'accident le plus grave pour votre entreprise ?

1……………………………………………………………………
……………………………………………………………………….
….

2……………………………………………………………………
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Quel est l'accident que vous craignez le plus personnellement ?

1……………………………………………………………………
……………………………………………………………………

2……………………………………………………………………
……………………………………………………………………

D'après vous, quelles sont les causes majeures des accidents ? (inattention, mauvaise formation, rythme de travail, prise de risque, etc.). Vous pouvez citer des exemples des sources de dangers présentées dans le questionnaire.

1……………………………………………………………………
……………………………………………………………………

2……………………………………………………………………
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Gestion des risques

Durant la mise en place d'une nouvelle installation ou un nouveau moyen, avez-vous remarqué l'existence de certains risques d'utilisation pouvant être évités avant sa mise en service ? Si oui, précisez des exemples.

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Avez-vous discuté de ces problèmes avec votre responsable ?

❑ Non

❑ Oui

Si oui, avez-vous remarqué une réactivité et une solution mise en place❑ ❑ Oui Non

Évaluation des risques

Au travail, dans quelle situation vous sentez-vous en danger ?

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……………………………………………………………………
……………………………………………………………………

Comment vous prémunissez-vous contre les situations dangereuses ? (instrument de protection, rythme de travail ralenti, communication, etc.)

……………………………………………………………………
……………………………………………………………………

Questions réservées aux Gestionnaires

Avez-vous des méthodes de gestion systématique des risques de SST dans la gestion de projet ?

❑ Non

❑ Oui, lesquelles ?

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Prenez-vous en compte l'historique des accidents et des incidents dans l'évaluation des risques de SST ?

❑ Non

❑ Oui

Comment hiérarchisez-vous les impacts (négatifs) des risques ?

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En fonction de quel critère (financier, retard, qualité, etc.) ?

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Quels sont les moyens souvent utilisés pour éviter les risques de SST ?

……………………………………………………………………
……………………………………………………………………

Adel Badri
Stagiaire
Poste téléphonique :

Grille d'observation		
1	**Entreprise**	
1.1	Recenser les incidents ayant eu lieu dans l'entreprise. (consulter les bases de données de l'entreprise)	
1.2	Analyser les incidents : lieux, fréquences, impacts, causes, actions de prévention, etc.	
1.3	Recenser les accidents ayant eu lieu dans l'entreprise. (consulter les bases de données de l'entreprise)	
1.4	Analyser les accidents : lieux, fréquences, impacts, causes, actions de prévention, etc.	
1.5	Les solutions apportées sont-elles généralisées dans d'autres secteurs d'activités ou sont-elles prises en compte dans de nouveaux projets ?	
2	**Atelier de production**	
2.1	**Ligne de production**	
2.2	Date de mise en service.	
2.3	Produit fabriqué.	
2.4	Nombre de travailleurs.	
2.5	Cadence théorique// Cadence réelle.	
2.6	Documentation à la ligne : implantation, consignes de sécurité générales, etc.	
3	**Poste de travail**	
3.1 3.2	Documentation aux postes : mode opératoire, fiche de poste, consignes de sécurité, etc. Quels sont les écarts entre le travail prescrit et le travail réel ? Discuter et détailler les commentaires des travailleurs.	

3.3	Analyser et commenter les écarts identifiés : tâches ajoutées, problème de capacité, problème d'ergonomie au poste, modifications produits, etc. Tracer le graphique d'opération, identifier et analyser les tâches à risque.	
3.4	Moyens de protection de l'opérateur : Lister les moyens (dispositifs provoquant l'arrêt de tout ou une partie de la machine, protection contre les risques d'électrocution, de chute, de brûlure, etc.)	
3.5	Conditions de travail dans le poste : Lister les problèmes identifiés. Exemple : espace de travail, vision, éclairage, bruit, ambiance thermique, circulation, manutention, etc. (en absence des moyens de contrôle, discuter avec les opérateurs leurs avis)	
4	**Risques de SST en production**	
4.1	Lister les risques identifiés et le poste concerné.	
4.2	Exposer les risques identifiés au Responsable de production et détailler ses commentaires.	
4.3 4.4	Quels sont les risques pouvant être éliminés dès la conception ? Vérifier la prise en compte de ces risques dans la documentation projet : Cahiers des charges, AMDEC, etc.	
4.5	Analyser les risques identifiés, commentaires du Responsable de production et les résultats de la consultation de la documentation projet : risque confirmé ? Les éléments du risque ? Les moyens de correction de la situation actuelle ? La possibilité de prise en compte au futur ?	
5	**Risques de SST en changement d'équipe**	
5.1	Lister les risques identifiés et le poste concerné lors d'une reprise de production. (état de la ligne après la première production est aussi à décrire).	
5.2	Exposer les risques identifiés au Responsable de production et détailler ses commentaires.	

5.3	Analyser les risques identifiés et les commentaires du Responsable de production.	
6	**Risques de SST en opérations de maintenance**	
6.1	Lister les risques identifiés et le poste concerné lors d'une opération de maintenance (corrective ou préventive).	
6.2 6.3	Exposer les risques identifiés au Responsable de maintenance et détailler ses commentaires. Quels sont les risques pouvant être éliminés dès la conception ?	
6.4	Vérifier la prise en compte de ces risques dans la documentation projet : Cahiers des charges, AMDEC, etc.	
6.5	Analyser les risques identifiés, commentaires du Responsable de maintenance et les résultats de la consultation de la documentation projet : risque confirmé ? Les éléments du risque ? Les moyens de correction de la situation actuelle ? La possibilité de prise en compte au futur ?	
7	**Communication**	
7.1	Assister aux réunions opérationnelles et exposer les problèmes de SST discutés.	

APPENDICE D

LISTE DES PUBLICATIONS EN LIEN AVEC LA THÈSE

Articles publiés ou acceptés dans des revues scientifiques avec comité de lecture

1. Badri, A., Gbodossou, A., Nadeau, S. 2012. « Occupational Health and Safety risks: towards the integration into project management ». *Safety Science*, vol. 50, n° 2, p. 190-198.
2. Badri, A., Nadeau, S. et Gbodossou, A., 2012. « A mining project is a field of risks: a systematic and preliminary portrait of mining risks ». *International Journal of Safety & Security Engineering* (accepté pour publication).
3. Badri, A., Nadeau, S., Gbodossou, A. 2012. « Proposal of a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation ». *Accident Analysis and Prevention: Construction and Engineering*, In Press.
4. Badri, A., Nadeau, S., Gbodossou, A. 2011. « Integration of OHS into risk management in an open-pit mining project in Quebec (Canada) ». *Minerals: Safety & Health in Mining,* vol. 1, n° 1, p. 3-29.

Articles en révision ou soumis à des revues scientifiques avec comité de lecture

1. Badri, A., Nadeau, S. et Gbodossou, A., 2012. « A new practical approach to risk management for underground mining project in Quebec ». *Safety Science* (soumis, avril).

Conférences avec comité de lecture

1. Badri, A., Nadeau, S., Gbodossou, A. 2012. « Une nouvelle approche multidisciplinaire pour intégrer la SST dans la gestion des risques d'un projet minier ». *Congrès AQHSST*, 16 au 18 mai, Gatineau, Canada. (Récipiendaire d'une bourse de participation et d'un Prix pour la meilleure présentation).

2. Badri, A., Nadeau, S., Gbodossou, A. 2012. « Vers une intégration novatrice des risques de SST dans la conduite de projets miniers ». *Les conférences scientifiques de l'ÉREST*, École de technologie supérieure, Travail et santé, vol. 28, n° 1, p. 25.
3. Badri, A., Nadeau, S., Gbodossou, A. 2012. « Overcoming the OHS risks of a mining project: case of an new open-pit mine in Quebec ». *Gesellschaft für Arbeitswissenschaft (GfA)*, 22 au 24 février, Kassel, Allemagne, p. 153-157.
4. Badri, A., Nadeau, S., Gbodossou, A. 2011. « Gérer les risques de santé et de sécurité du travail : une nouvelle démarche appliquée à un projet minier québécois ». *Congrès AQHSST*, 11 au 13 mai, Trois-Rivières, Canada. (Récipiendaire d'une bourse).
5. Badri, A., Nadeau, S., Gbodossou, A. 2011. « A New Paradigm for Integrating Occupational Health and Safety into Project Risk Evaluation ». *Gesellschaft für Arbeitswissenschaft (GfA)*, 23 au 25 mars, Chemnitz, Allemagne, p. 123-128.
6. Badri, A., Nadeau, S., Gbodossou, A. 2010. « Intégrer les risques de santé et de sécurité du travail dans la gestion des projets industriels ». *Congrès AQHSST-RRSSTQ*, 12 au 14 mai, Lévis, Canada. (Récipiendaire d'une bourse).

Publications dans des revues sans comités de lecture (articles de vulgarisation)

1. Badri, A., Nadeau, S., Gbodossou, A. 2011. « Intégrer la santé et la sécurité du travail dans la gestion de projets industriels ». *Travail et Santé*, vol. 27, n° 2, p. 28-29.

Conférences sans comités de lecture

1. Badri, A., Nadeau, S., Gbodossou, A. 2010. « Intégrer les risques de santé et de sécurité du travail (SST) dans la gestion des projets industriels ». *Assemblée générale du RRSSTQ*, 10 décembre, Longueuil, Québec.
2. Badri, A., Nadeau, S., Gbodossou, A. 2010. « Démarche de modélisation et d'évaluation par facteurs de risques pour intégrer les risques de santé et de sécurité du travail dans la conduite de projets ». *Les conférences scientifiques de l'ÉREST*, École de technologie supérieure, 16 septembre, Montréal, Québec.

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1. Badri, A., 2012. « Le génie pour la santé et la sécurité dans les mines ». *Concours de l'ÉREST*, École de technologie supérieure. Montréal, Québec. (Récipiendaire d'un Prix).
2. Badri, A., 2011. « Vers l'intégration de la santé et la sécurité du travail dans la gestion des risques de projets industriels ». *Concours de l'ÉREST*, École de technologie supérieure. Montréal, Québec. (Récipiendaire d'un Prix).

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