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Applying the Analytic Hierarchy Process to Oil Sands Environmental Compliance Risk Management

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This is to certify that the doctoral study by

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Abstract

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MEng, University of Pretoria, 1991

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Doctoral Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Business Administration

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Abstract

Oil companies in Alberta, Canada, invested $32 billion on new oil sands projects in 2013. Despite the size of this investment, there is a demonstrable deficiency in the uniformity and understanding of environmental legislation requirements that manifest into increased project compliance risks. This descriptive study developed 2 prioritized lists of environmental regulatory compliance risks and mitigation strategies and used multi-criteria decision theory for its theoretical framework. Information from compiled lists of environmental compliance risks and mitigation strategies was used to generate a specialized pairwise survey, which was piloted by 5 subject matter experts (SMEs). The survey was validated by a sample of 16 SMEs, after which the Analytic Hierarchy Process (AHP) was used to rank a total of 33 compliance risks and 12 mitigation strategy criteria. A key finding was that the AHP is a suitable tool for ranking of compliance risks and mitigation strategies. Several working hypotheses were also tested regarding how SMEs prioritized 1 compliance risk or mitigation strategy compared to another. The AHP showed that regulatory compliance, company reputation, environmental compliance, and economics ranked the highest and that a multicriteria mitigation strategy for environmental compliance ranked the highest. The study results will inform Alberta oil sands industry leaders about the ranking and utility of specific compliance risks and mitigations strategies, enabling them to focus on actions that will generate legislative and public trust. Oil sands leaders implementing a risk management program using the risks and mitigation strategies identified in this study will contribute to environmental conservation, economic growth, and positive social change.

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Dedication

I dedicate this doctoral study to my wife Elzabe and to my children Izanne, Elandri, and Matt. Above all, this study is in memory of my father, Mr. Pieter Eduard Roux, and my mother, Mrs. Joey Roux, for the foundation and encouragement they gave me.

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Section 1: Foundation of the Study

The oil sands in Canada are the largest region in the world. This region covers an area of 140,000 sq. km, an area larger than England (George, 2012). In the last decade, investment in *in situ* oil sands extraction in Alberta, Canada increased significantly (Government of Alberta, 2010). *In situ* oil sands extraction is technically complex and developed using highly specialized engineers and scientists with expensive equipment resources. The managers of oil companies working in oil sand extraction are charged with ensures environmental regulatory compliance by taking actions to eliminate the impacts of the organization's activities on the environment.

In Alberta, project engineers and executives have to achieve compliance and sustainability throughout a project's life cycle because the success of new projects depends heavily on regulatory compliance and risk management (Rasmussen, 2009). Changes in regulations and compliance requirements force companies to adapt new strategies to manage the imposed risk and policy changes (Aberdeen Group, 2013). Managers should adopt multicriteria decision-making methods for environmental risk management and policy change (Huang, Keisler, & Linkov, 2011). The public demands environmental oversight for oil sands developments in Alberta, unlike in many other oil-producing countries. The environmental compliance risk for oil companies may be higher in Alberta than in the Gulf of Mexico according to a Ceres report, a nonprofit environmental organization in the United States (Nicholls, 2010). Briggs (2010) and Briggs, Tolliver, and Szmerekovsky (2012) reviewed the supply chain risks in the upstream crude oil industry while Enyinda, Briggs, Obuah, and Mbah (2012) studied the Nigerian oil industry. These authors identified environmental and regulatory compliance as one of the six high-risks. During the project life cycle, the environmental requirements may change significantly. In addition, any new regulatory requirement after project definition poses a potential risk to the sustainability of the project. The *in situ* oil plant may not be able to meet new regulatory compliance within the economic framework. The risk management of *in situ* oil sands projects needs a focused, justified, and rigorous approach.

In most cases, risk management focuses on historical data. To stay ahead of federal and international requirements, the government of Alberta reviews environmental regulations on a regular basis. Environmental laws and regulations are more a reflection of public perceptions than of a scientific definition (Schlosberg, 2012). Considerable local and international groups demand that the oil sands developments are not exploiting the environment and increasingly creating more greenhouse gasses (GHG). The Canadian federal government requires new oil sands projects starting production beyond 2011 to implement technologies like carbon capture to reduce GHG emissions (Ordorica-Garcia, Wong, & Faltinson, 2011; Walden, 2011).

Some U.S. states address emissions. The objective of regulations such as the Californian Low Carbon Fuel Standard (LCFS) are to reduce the GHG emission of fuel sold in California (Englander, Bharadwaj & Brandt, 2013). For this reason, oil company leaders and project engineers should not only focus on the present regulations, but also on the concern that these regulations are dynamic and would most likely change before project completion. New oil sands plants have to comply with the regulations of the day. Most *in situ* oil sands projects are a first for a national oil company, which may not have the systems to support risk management frameworks or incorporate lessons learned from previous projects. This lack of systems results in an inconsistent approach to risk identification and inability to prioritize mitigation strategies to meet future regulatory requirements.

The leaders of corporations should consider the current trend in environmental policy changes to predict compliance requirements. The trend in policy changes in Alberta started after the year 2000 with increasing public awareness of environmental issues. In a study on public environmental awareness, Druckman and Bolsen (2011) found the evaluation of available facts as having no basis for initial public opinions; citizens rather base their opinions on less deliberate fact finding. Public environmental awareness in Canada forced the federal and Alberta governments to announce on December 21, 2010 that they would overhaul the environmental policies to ensure sustainable development of the oil sands (McCarthy, 2010). The pace of environmental policy change would have an effect on current and future oil sands projects.

Oil sands projects come with significant environmental risks. Despite the high risks, current body of literature does not sufficiently indicate how executives and project engineers should manage the potential change and influence of environmental regulatory requirements on oil sands projects. Prpich, Dagonneau, Rocks, Lickorish, & Pollard

(2013) analyzed environmental risk management. These researchers concluded that management should pay attention to the change in environmental regulations, and managers should have a sound understanding of environmental risk. This research study would show where difficulties exist for executives and project engineers of *in situ* oil sands projects in understanding the relative importance of environmental risks. Understanding these risks should increase the focus and efforts of project decision makers when they implement environmental and regulatory compliance risk management programs.

Arimura, Darnall, and Katayama (2011) found in their study that an environmental risk management system (e.g., ISO 14000) helped resolve environmental impact in areas such as natural resources and solid waste generation. Edwards and Darnall (2010) identified that the implementation of an environmental risk management plan improves the possibility of an organization complying with environmental regulations. Resolving environmental problems and reducing risks as well as liability are all positive reasons for implementing a risk management system, even before the start of construction (Jafari, Khorasani, & Danehkar, 2010). Integrated risk management is a continuous process of risk assessment on all levels, project and corporate level, and it forms part of the company strategy and culture (Reddy, Govardhan, & Prakash, 2013).

In this quantitative study, I identified the core environmental compliance criteria and the environmental risk mitigation strategies essential to environmental risk management of *in situ* oil sands projects. This study is significant from three points of view. First, the use of a systematic approach is helpful for identifying the importance of compliance risks. Project engineers consider the compliance risks as essential aspects to managing uncertainty due to the changing environmental and regulatory requirements on in situ oil sands projects. Public pressure plays a crucial role in the Alberta government's response to environmental regulatory changes. Governments should implement regulatory policy that would create less uncertainty in the industry (Farahani, R. Z., Baygi, M. B., Mousavi, S. M., 2014). Second, the identification of these key compliance risks (with the actual weight placed on each) provides a consistent approach to environmental risk management of oil sands projects. Last, with the ranking of mitigation strategies, project engineers would be able to implement a successful risk management strategy.

Background of the Problem

Increased demand for oil in the United States and the developing world caused the start of an extensive exploration of the oil sands in northeastern Alberta, Canada (Jergeas & Ruwanpura, 2010). In 2012, Canada exported to the United States 2.3 million barrels of oil per day (Angevine & Green, 2013, National Energy Board, 2011). The provincial government of Alberta can no longer ignore the environmental concerns created by the demand for oil and the large areas needing reclamation because of oil sands mining (Foote, 2012). A growing public perception is that the oil sands exploration and development in Alberta is creating immense environmental damage and perceived health concerns (Kurek et al., 2013).

From 1973 to 1990, puplic awareness of environmental and social issues in the oil sands were barely visible. However, around 1995, public awareness of climate change started to increase, and this caused organizations and corporations to be aware of social and environmental requirements (Carroll & Shabana, 2010; Estévez, Walshe, & Burgman, 2013; Jones & Dunlap, 2010; Orlitzky, Siegel, & Waldman, 2011). Estévez et al. (2013) reviewed 119 papers and confirmed the importance of social impact and human participation in environmental decision-making. Estévez et al. concluded that including environmental stakeholders is neither a homogeneous process nor an easy process. Stakeholders included in environmental decision-making do not necessarily have the technical expertise to understand the risks and consequences (Hendriksen, Tukahirwa, Oosterveer, & Mol, 2012).

Martin (2010) also identified the increasing impact of regulatory compliance in the energy industry. Regulatory compliance is not only about compliance but also about doing business transparently to gain the acceptance of local stakeholders. Martin stated regulatory compliance is about incorporating compliance in corporate decision-making. The Alberta government is focusing on environmental regulatory compliance. In 2007, Alberta became the first region in North America to legislate limits for GHG emissions (Hopper, 2008). The Alberta government prescribed these environmental regulatory requirements on the oil sands industry. The continuous changes in requirements are causing uncertainty as well as financial and technical risks in the industry.

In 2008, Neil Camarta, senior vice-president at Petro-Canada, highlighted that new environmental approval processes are creating bariers to entry for new oil sands projects (Chazan, 2008). Greg Stringham, a vice-president of the Canadian Oil Producers Association (CAPP), identified environmental and regulatory policy changes as the biggest challenges the oil sands industry's leaders must confront (Chazan, 2008). The regulatory policy uncertainty in Alberta has continued to increase the environmental compliance risks for new oil sands projects. Stringham stated that the continual enhancement of environmental performance in the oil sands is an essential part of doing business (Nicholls, 2010).

The extent of *in situ* oil sands projects is enormous: $15 billion in 2012 (CAPP, 2010) and a record $32.7 billion in 2013 (Government of Alberta, 2014). These mega projects have the potential to change the environment due to the size of their environmental footprint. The financial investment in *in situ* projects make it essential for oil sands managers to achieve regulatory compliance.

At the beginning of a project, minimal environmental and process data are available, and future environmental and regulatory requirements have uncertainty. The success of the project and the future sustainability depends on (a) the environmental risk management strategy that decision makers follow and (b) the work with all stakeholders (Álvarez, Moreno, & Mataix, 2013). During the evaluation, design, and execution phases, project engineers and executives of *in situ* oil sands projects have to make decisions that will influence the final environmental impact and compliance with regulations.

Developing a consistent risk management system is thus vital for the duration of the project under the uncertainty of future compliance requirements. Better risk management should improve business sustainability and corporate environmental responsibility.

Epstein and Yuthas (2012) stated that increasing financial sustainability was possible due to financial decisions and investments that allow for future cost of environmental compliance. Epstein and Yuthas proposed that decision makers use decision-making tools for ad hoc decisions and long-term strategic decisions (Eweje, Turner, & Müller, 2012). Zavadskas, Vainiuna, Turskis, and Tamosaitiene (2012) highlighted the required technical skills of project managers and their need to understand the environment and the stakeholders. Engineers and project managers who understood the potential regulatory compliance risks will have a better chance to complete the project successfully.

Problem Statement

According to CAPP (2010), the oil production from the Alberta oil sands will increase from 1.5 million barrels a day in 2010 to 3.5 million barrels a day by 2025. This expansion of oil sands developments is predicted to significantly produce more greenhouse gas emissions and impacts on land and water resources (Jordaan, 2012). This increase will impose environmental risks that will threaten the natural environment and pose a socioeconomic threat to the communities in the province of Alberta, which in turn is a risk to continuous oil production (Foote 2012). Hill and Ferguson-Martin (2010) argued that regulatory policy changes impedes the progress in the energy industry.

Project managers with a better understanding of the criteria influencing future regulatory compliance will be better able to reduce project compliance risks (Kortenkamp & Moore, 2010). The identification and, more importantly, the ranking of risks with associated risk avoidance strategies are challenging to management.

The general business problem investigated by this study is the rate of change of environmental regulations and the ineffective risk management of regulatory compliance among new *in situ* projects that have created environmental damage. The specific business problem investgated by this study is the lack of information available to oil company executives and project engineers on the key environmental regulatory compliance risks and mitigation strategies related to oil sands projects in Alberta, Canada. Such essential information can influence future regulatory compliance of *in situ* oil sands projects.

Purpose Statement

Ayyub, Prassinos, and Etherton (2010) identified three principal risks associated with a project: technical, economic, and financial risks. These principal risks certainly apply to projects such as IT or health services projects. A new principal risk—compliance with environmental regulations—is a risk with large construction projects, including *in situ* oil sands projects. These mega projects have potential effects on the environment.

The purpose of the quantitative descriptive study was twofold:

1. To identify the set of environmental compliance risks and associated mitigation strategies using the Alberta Energy Regulator (AER) database and then validate these risks and mitigation strategies through a pilot survey; and
2. To administer a larger survey to at least 15 SMEs from Alberta oil sands companies, apply the AHP technique to rank the identified environmental compliance risks, and associate mitigation strategies in order of importance.

As Saaty (2006) noted about calculating priorities, using AHP is possible if the comparison matrices are consistent.

The ultimate goal of this research study was to rank the regulatory compliance risks and mitigation strategies facing oil sands companies operating in Alberta and thereby improve their environmental regulatory risk management process. Oil company executives and engineers applying better risk management of *in situ* oil sands projects will be empowered to promote positive social change through the resultant increase in their understanding of regulatory compliance. Such knowledge would improve the management of the environmental impact of *in situ* oil sands projects and demonstrate the company leaders' commitment to social responsibility, the environment, and the people. Oil sands leaders' increased understanding of environmental risk would enhance their ability to manage sustainable oil sands projects more efficiently. Moreover, their understanding would help protect local communities against potential environmental hazards of oil sands developments and lessen the risk of financial penalties to the oil sands projects' developers.

Nature of the Study

In the quantitative descriptive study, I identified environmental risks that could cause regulatory noncompliance of *in situ* oil sands projects. I used AER archival data and inputs from SMEs. The quantitative research methodology supports the quantifiable ranking of risk mitigation strategies. Obtaining qualitative opinions regarding risk mitigations from SMEs and their perceptions of environmental risks was also possible.

The purpose of the environmental risk management study was not to discover a new risk theory. The goal for the study was to examine and demonstrate a process for identifying and ranking risks and risk mitigation strategies. Therefore, the quantitative ranking of environmental risks and mitigation strategies ruled out the potential lack of trustworthiness and rigor of a qualitative design (Schwandt, Lincoln, & Guba, 2007).

AHP was especially appropriate for the research design because it is often used in the study of risk management and decision-making processes (Briggs, 2010; Deason & Jefferson 2010; Varma, Wadhwa, & Deshmukh, 2008). For example, environmentalists use AHP for environmental sustainability assessments and environmental decision-making (Kara & Köne, 2013; Steele, Carmel, Cross, & Wilcox, 2009; Tegou, Polatidis, & Haralambopoulos, 2010). Researchers in forest management, hazardous waste site selection, water resource management, oilfield selection, and renewable energy have also used AHP as a multicriteria decision-making (MCDM) methodology (Amiri, 2010; Karimi, Mehrdadi, Hashemian, Nabi-Bidhendi, & Tavakkoli-Moghaddam, 2011; Khadka, & Vacik, 2012; Korosuo, Wikstrom, Ohman, & Eriksson, 2011; Yousefpour et al., 2012). AHP has furthermore been used to help make critical long-term decisions such as the selection of hazardous waste sites, long-term irreversible decisions, and long-term investments by the European Union (Křupka, Provazníková, & Švejcar, 2011).

Decision theories constitute aspects through which the decision maker may analyze multiple risks and rank risk mitigation strategies for regulatory compliance. Multiattribute utility theory, an MCDM process, is useful for focusing on the assignment of utility functions to attributes (Gomes, Rangel, & Junior, 2011; Terlikowski, 2008). Assignment of utility functions is only one aspect, howver, in the analysis of alternatives multiattribute utility theory (MAUT) construct interval scales that do not represent the intensity of preference. Intensity of preference is an important aspect, for example, factor A is twice as important as factor B, something MAUT is not addressing (Saaty & Sagir, 2009).

AHP is useful for providing for the intensity of preference and framework the researcher needs to analyze multicriteria problems. With AHP, the user can gather intuitive quantitative and qualitative data (Saaty, 2006; Varma et al., 2008). Saaty (2006) proposed a quantitative survey (using SMEs) to determine the factor weights (using pairwise comparison) and rank the alternatives. The availability of SMEs in a competitive environment such as the oil industry was a problem for me, and it limited the participation of SMEs in the study.

An alternative research methodology to quantitative research is qualitative phenomenological design that includes open-ended SME interviews, which posed a threat to business confidentiality. The second reason was that a qualitative methodology was a disadvantage to the risk management study; it was advantageous to quantify the risks and providing a ranking of the risks and mitigation strategies. The project engineers could use the weights of environmental compliance criteria for risk management to comply with future environmental and regulatory requirements. In the future oil company, executives might use the ranking of risk mitigation strategies to improve project risk management (see Section 2).

Research Questions

The government of Alberta Canada's environmental strategy (Government of Alberta, 2009) defined some environmental compliance criteria that the government considered essential for future environmental conservation. These criteria included natural environment criteria (e.g., land use, water quality, water usage, and air quality), human environmental risks such as community disturbance (socioeconomic), and environmental monitoring system. Oil executives and project engineers do not know the future environmental regulatory requirements at the beginning of a new oil sands project. The regulatory uncertainty at the start of construction sometimes leads to an oil sands plant, which may not be compliant with the latest regulations at the time of production four to five years later. However, the owner would not be able to start operating the plant without complying with environmental regulations. The overarching research question in this study was about the risk management process that project executives and project engineers follow to ensure environmental regulatory compliance under the uncertainty of future regulatory requirements.

The researcher who would define the central research question best defines the goal of the business research study (Cooper & Schindler, 2013). Project executives and project engineers could focus on the existing regulatory compliance requirements and not prepare for the impact of future regulatory change. The broad research questions focused on key environmental compliance risks and mitigation strategies for future oil sands projects in Alberta that would have the greatest impact on future regulatory compliance. The secondary research questions that helped identify risks and mitigation strategies are as follows:

Research Question 1: How do the natural environmental compliance risks relate to human environmental risks in the assessment of future environmental regulatory compliance?

Research Question 2: Which mitigation strategy emerges to be the best strategy to ensure future environmental regulatory compliance?

Research Question 3: Which one of the natural environmental compliance risks (land use, water quality, and water usage or air quality) is the most beneficial for addressing future environmental regulatory compliance?

Research Question 4: How valuable is R&D technology for the mitigation of environmental regulatory compliance risks?

Hypotheses

This risk management study of environmental compliance incorporated the AHP decision-making methodology. Since the study design is quantitative descriptive, I did not define formal statistical hypotheses using statistical analysis, which requires null hypotheses. Therefore, with the AHP, the working hypothesis was the best guide for the study. In Dewey's view (as cited in McGee, 2010), the researcher would generate the working hypothesis, not directly as a testable statement of expectation but as increased understanding that would disclose new information for the original concept.

The AHP is a mathematical decision modeling technique and not a statistical/inferential technique. The purely statistical techniques have adherence to the classical hypothesis definition. Instead, I adopted for the AHP the hypothesis framework that Chamberlain (as cited in Elliott & Brook, 2007) and Railsback (1990) discussed. According to these authors, researchers use a working hypothesis as a proxy to a statistical hypothesis to frame the research study. The working hypothesis is helpful for identifying some facts about the study, but not necessarily in proving the hypothesis. Chamberlain further noted that more than one working hypothesis may describe the research situation. In this study, I focused on the identification of the key risks and the essential mitigation strategies in environmental regulatory compliance risk management.

Null Working Hypothesis 1 (WH1o): In this study, I identified the key risks. The SMEs might consider all risks equally important in the management of environmental risks.

Alternative Working Hypothesis 1 (WH1a): In this study, I identified the key risks. The SMEs might consider certain risks distinctly more relevant than other risks in the management of environmental compliance might.

Null Working Hypothesis 2 (WH2o): Using the AHP, SMEs would be able to identify that all mitigation strategies were equally important to future regulatory compliance of oil sands facilities.

Alternative Working Hypothesis 2 (WH2a): Using the AHP, SMEs would be able to identify that some mitigation strategies were distinctly more relevant to future regulatory compliance of oil sands facilities.

Null Working Hypothesis 3 (WH3o): All the Regulatory Compliance subcriteria for oil sands projects were equally important.

Alternative Working Hypothesis 3 (WH3a): Some of the Regulatory Compliance subcriteria for oil sands projects were more important than other subcriteria.

Null Working Hypothesis 4 (WH4o): Implementing an integrity management program at the start of an oil sands project would be less important than the financial savings for not implementing an integrity management program.

Alternative Working Hypothesis 4 (WH4a): Implementing an integrity management program at the start of an oil sands project would be more important than the financial savings for not implementing an integrity management program.

Null Working Hypothesis 5 (WH5o): A multicriteria risk management approach for an oil sands project used multiple mitigation strategies to ensure future environmental regulatory compliance.

Alternative Working Hypothesis 5 (WH5a): A multicriteria risk management approach for an oil sands project used the most significant mitigation strategy to ensure future environmental regulatory compliance.

Theoretical Framework

In this research study, I focused on environmental risk management and the identification of risks and risk mitigation strategies. Managers and engineers who understand risks and mitigation strategies would be better prepared to ensure future regulatory compliance. The theoretical framework for the study includes the multicriteria decision-making (MCDM) process. MCDM provides a means to make a strong decision in situations where the selection may be extremely complicated, especially if decision makers have to consider many alternatives (Aruldoss, Lakshmi & Venkatesan, 2013). The potential risk to stakeholders due to inconsistent environmental decision-making and the uncertainty of future regulatory requirements were the drivers for the development of the principal research question.

Hey, Lotito, and Maffioletti (2010) evaluated the performance of decision-making models and recommended that decision makers want a simple decision-making model rather than a sophisticated one. Decision makers used the MCDM process to determine the effect of a possible change in the future result based on known information. Terlikowski (2008) created a general definition for the multiple decision-making problems. Terlikowski defined it as a two-stage problem: (a) solving the control problem with the information related to the problem and (b) defining a decision rule for adhering to at all stages. It is the decision maker's responsibility to find a solution to the problem and to select appropriate decisions.

If the decision was time dependent, then the decision maker had to understand what influence the decision would have on the future. Decisions made during the project design phase would affect the final plant layout and potential compliance to future environmental regulations. In a qualitative study, the focus would be on the project definition at the start, the known environmental constraints, possible external influences on the project and the relations or influences among these project criteria. What is missing in this approach is the human factor, the role of the project engineer or an executive in the decision-making process.

Isendahl, Pahl-Wostl, and Dewulf (2010) reviewed the quantified decision-making process in water management and concluded the human factor is important, and the qualitative input from the decision maker is critical in the decision-making process. Isendahl et al. (2010) also identified a relationship between a decision maker, the object, the subject, and the project in a decision-making process. The actions of the decision maker may have an outcome contrary to the decision-making process, as the background, education, and worldview of the decision maker would be influential factors in making decisions (Isendahl et al. 2010). Because of differences among decision makers, they would not consider aspects of the problem or assess the situation the same way.

The incorporation of the human influence in the decision-making process made the AHP a suitable MCDM process for this study. AHP is a decision-making process that combines quantitative data with qualitative judgments (Kaur, Verma & Mahanti, 2010). The AHP allows for integrating the human factor with quantitative data to identify a better decision.

In the literature on qualitative decision-making research, theories such as the fuzzy set theory (Tseng, 2010), decision theory (Dubois & Prade, 2011), or linguistic decision-making (Martinez, Ruan, & Herrera, 2010) are identified as suitable MCDM models. These decision-making theories affect the thinking process of the decision maker. In qualitative decision-making theories, the role of decision makers is as important as their influence on the thinking process. According to Terlikowski (2008), the decision maker has to draw on information realized by measurement or prediction of the elements of the system. Terlikowski further described the decision-making process as a control system. The decision maker would understand the interaction of the elements if defined as part of the system. The interaction of system elements would change the behavior of the system. The system thinking process involves the entire system and the interaction of system elements to generate actions (Skarzauskiene, 2010). Decision makers following a systems thinking process would help identify interactions among environmental, social, and commercial aspects and ways these components fit together in the larger, defined system (Lyons, Long, Goraya, Lu, & Tomlinson, 2012).

Yang and Yeh (2013) proposed project managers recognize the influence of external stakeholders on projects with environmental risks and consider a systems approach, which Fürst, Volk, and Makeschin (2010) supported. I suggested that oil sands project engineers and project executives follow a systems thinking approach to identify the relationships between environmental compliance and certain criteria (e.g., technical, social, and economic risks). A system thinking process is facilitative in providing a definition for the project and the project's environment, as well as in defining the interactions of the elements in the system (Skarzauskiene, 2010).

The methods that researchers use in qualitative decision-making studies follow one of the two approaches. The first approach is to define and test a theory (Tseng, 2010). This approach would include a literature review and exploratory interviews. The second approach is to collect data during the survey and then apply a possible decision-making model or theory based on mental or reasoning process (Martinez et al., 2010) to the data. Dubois and Prade (2011) conducted a qualitative study of the decision-making model. They demonstrated that a decision-making model based on a qualitative decision procedure could be a beneficial approach to decision-making.

Benke, Steel, and Weiss (2011) studied decision-making as it relates to risk assessment for environmental situations. In their study, Benke et al. used qualitative and quantitative methods to research the decision-making problem. Their approach showed that surveys, literature reviews, and inputs from SMEs are part of an appropriate risk assessment process of environmental issues. The goal should be to identify robust qualitative and quantitative risk characteristics.

Li, Wang, Duan, and Hu (2013) applied the same approach to risk assessment of electric transformers. They concluded that the results have practical and theoretical significance. The understanding of openness and endless approach in qualitative research may be helpful for gaining a better understanding of risk management. Shadish (2010) likewise stated that qualitative research methods are useful for attaining in-depth understanding of the research problem. Shadish also promoted the inclusion of qualitative methods in field experiments; qualitative methods are helpful for validating site-specific threats. Environmental compliance on an oil sands site may be specific. The understanding and openness in research would be helpful for accessing the ranking of mitigation strategies with SMEs. Shadish concluded that a qualitative research is less likely than a quantitative research to be useful for providing optimum result or in eliminating subjectivity.

Phenomenological research was another design strategy I considered for this study. The scope of the phenomenological design could include one project team and the manner by which the team approaches risk management. The same possibility could apply to a case study, where reviewing the risk management process in a project team is probable. These designs have the potential to reflect only a single process that one team implemented; therefore, generalization in Alberta and North America would likely be limited. The implementation of phenomenological and case study designs could have caused problems with confidentiality and proprietary information as they encompass the detail of one team and one project only. Confidentiality could have limited openness and not promoted successful research.

Dubois and Prade (2011) considered the potential issues with a qualitative methodology. With the outcome of their studies, Dubois and Prade indicated that a quantitative methodology and quantitative, descriptive design would be most appropriate for the research problem and questions. The purpose is to understand the risk management process and the definition of a risk mitigation strategy. Since the AHP model is a combination of quantitative data and qualitative human input, the model is supportive of the goal's attainment.

The AHP model reflects a decision-making process utilizing quantitative and qualitative data, according to Saaty (2006). Saaty defined AHP as (a) a multicriteria decision-making method using pairwise comparisons, (b) the definition of an eigenvalue matrix to determine relative weights of decision criteria, and (c) the deduction of the final ratings for decision alternatives. I used the AHP to weigh the multiple regulatory risks, using survey data from project engineers and executives.

Siddiqui, Beg, and Fatima (2013) concluded that the AHP may become elaborate, and it takes a long time to complete. I noted and addressed these caveats in designing and implementing this study. The outcome of this study would help project engineers and executives to gain a better understanding of the key environmental compliance risks for an oil sands project. They would be able to identify the risks of future regulatory changes early in the project life cycle.

Definition of Terms

Analytic hierarchy process (AHP). The AHP has a number of definitions:

1. AHP is a decision model that utilizes pairwise comparisons of qualitative and quantitative data to develop ratio scale measurements (Saaty, 2006).
2. AHP is a process, decomposing a complex multicriteria decision problem into a number of irreducible factors (criteria) or subfactors (criteria) and weighing the alternative solutions. Its main contribution is quantifying qualitative criteria and alternatives (Saaty, 2006).
3. AHP is a decision model methodology that decomposes a complex multicriteria decision problem into a number of irreducible factors (criteria), subfactors (subcriteria), and alternative solutions. It utilizes pairwise comparisons to develop ratio scale measurements. Its main contribution is quantifying qualitative factors and alternatives (Saaty & Shang, 2011).

AHP criterion. A factor related to the primary objective of the analyzed decision. Each factor or criterion receives a weight describing its importance with respect to the objective of the decision. When normalized, the weights for all factors or criteria add to 1 (Saaty, 2006). In this study, I used the terms criteria and subcriteria rather than factor and subfactor.

AHP pairwise comparison matrix. A table that includes entries describing the decision analyst opinion (judgment) to which criterion is more (less) important than another in terms of importance to achieving the goal of the decision under review (Saaty, 2006).

AHP scale. This scale ranges from 1 to 9 and 1/9 to 1, representing a numerical presentation of linguistic judgments in the pairwise comparison matrices for the relative importance of factor/criterion or alternative. The interval [1, 9] is for the category more important, and the interval [1/9, 1] is for the category least important (Saaty, 2008).

AHP weighting. Each criterion has a numerical number indicating its importance to the decision (Saaty, 2006).

Decision matrix. A decision matrix A is an (m x n) matrix in which factor a_{ij} indicates the preference of alternative A_i, when evaluated in terms of decision criteria C_j (for $i = 1, 2, 3, \ldots, m$ and $j = 1, 2, 3, \ldots, n$). The entries a_{ij} in the m x n matrix represent the relative value of alternative Ai, when considered in terms of criterion C_j. In AHP, the sum of a_{ij} $i=1$ to n is equal to 1 (Saaty, 2006).

Decision-making. The approach the decision maker uses to make decisions. The approach may include linear programming, analytic hierarchical process, or risk assessments (McCready, 2010).

Decision weight. In most multicriteria decision methods, the decision maker assigns criteria weights of importance relative to achieving the primary objective. Usually, decision makers would normalize the weights to add up to 1; they can use, however, other normalization scales (Saaty, 2006).

Fuzzy sets. Extensions of classical set theory used in fuzzy logic. Contrary to classical set theory, which permits membership in binary form, fuzzy sets allow for gradual membership. The degree of belonging to the fuzzy set ranges within the interval [0, 1] (Labib, 2011).

In situ. In the context of this study, this term refers to the method for oil sands recovery with more than 500 feet of overburden. The steam-assisted gravity drainage (SAGD) process is the most successful recovery process used in the oil sands (Mohebati, Maini, & Harding, 2010).

Intuition. The state of being aware of or knowing something without having to discover or perceive it or the ability to do this. It is something known or believed instinctively, without actual evidence for it (Kusá, 2011).

Oil sands. Oily soil that contains sticky deposits of bitumen mixed with sand and clay that needs industrial processing to extract the oil (NEB, 2006). The oil sands of Alberta cover an area of about 10.8 million acres in the northeastern part of the province. This region's estimated reserves of recoverable oil in place are about 173.2 billion barrels (Giesy, Anderson & Wiseman, 2010; Perry & Saloff, 2011).

Risk. A future event or condition, which can occur and result in positive or negative impacts or consequences (Project Management Institute, Inc., 2013).

Assumptions, Limitations, and Delimitations

Assumptions

For this study, the SMEs providing the survey data were involved in actual *in situ* oil sands projects in Alberta. I did not verify the actual environmental risk management process that project engineers and executives implemented; I only identified the implemented risks and mitigation strategies. For this study, I made the following direct assumptions:

- The project engineers and executives who participated had in-depth knowledge of oil sands. The participants were rational and professional people with integrity, and they made decisions to benefit the project, within the legal, operating parameters, in accordance with the employer and the regulations of the province of Alberta.
- The reports contained in the AER database and filed by oil companies relating to environmental compliance were truthful and accurate.
- The SMEs participating in the survey acted independently. Increasing the number of SMEs participating in the survey would not violate the principle of the independence of alternatives. Luce and Raiffa (as cited in Maskin, 2011) stated that optimizing a decision problem is not possible under uncertainty by adding new acts to the problem.
- The survey was adequate for identifying key risks and mitigation strategies in the risk management of environmental compliance of *in situ* oil sands projects.

- In the allocation of weights (priorities) to alternative criteria, I used the AHP as a *closed system* (Saaty, 2006). In a closed system the sum of the weights (=1) allocated to the alternative criteria on one level in the hierarchy would not increase or decrease when the same level with an additional new alternative. This assumption may cause a reversal in the ranking, which is acceptable if the decision maker adds a new dominant alternative factor.

Limitations

I used archival data from the AER database to identify environmental regulatory noncompliance reported for oil sands projects. I only used information in the public domain for this study. I surveyed an SME group of 15 project engineers and executives from Alberta companies. Using only Alberta SMEs may limit the generalization of the risk management process for projects outside Alberta (Ellis & Levy, 2010). Environmental regulations differ from province to province because it is not a federal matter in Canada. The environmental policies I considered related to Alberta and not necessarily to other provinces or states; this concern may further limit the generalization of the study.

The AHP is the MCDM process I adopted for this study; I reviewed the result of ranking mitigation strategies with a small group of SMEs. The identified mitigation strategies may not be all the possible mitigation strategies. New technologies may help with new mitigation strategies. The unidentified mitigation strategies may limit the outcome of the study, and this limitation may be an opportunity for future research.

Delimitations

The choice of geography (i.e., Alberta, Canada) and the decision to include only oil sands *in situ* projects limited the scope of the study. For the purpose of this study, I considered the Alberta environmental regulations as a guideline for compliance and did not consider international treaties such as the Kyoto protocol. In this study, only SMEs involved in Alberta oil sands projects participated.

I further narrowed the scope of the study by excluding the oil sands mining projects in Alberta, the oil sands in Venezuela, the shale gas in the United States, and the deep-sea exploration in the Gulf of Mexico. Executives and engineers of multinational oil companies not involved with *in situ* projects within the province of Alberta did not participated in this study. I focused on the identification of risks and mitigation strategies known to the SMEs. I did not try to identify those risks and mitigation strategies that may be the result of new technologies implemented in the oil sands and not yet fully accepted in general practice.

Significance of the Study

Reduction of Gaps

The business environment has changed in the last decade. Shareholders expect better financial performance from companies with an environmental management plan (Fisher-Vanden & Thorburn, 2011; Flammer, 2012). Executives of oil sands companies need to understand the shareholders expect them to integrate the goals for environmental compliance within the organizations' business plans. As global environmental requirements for oil sands increase and as technology for extracting oil changes, project engineers and company executives need to understand and support the environmental functions. Such understanding help ensure Alberta oil sands projects would be compliant with the provincial government regulations.

According to the AER's predecessor, Energy Resources Conservation Board (ERCB), the Alberta oil sands industry produced 1.61 million barrels per day (Mb/d) of crude bitumen in 2010 (ERCB, 2011). The oil sands crude production represented 0.86 Mb/d from surface mining and 0.76 Mb/d from *in situ* projects (ERCB, 2011). The crude bitumen production from the Alberta oil sands would more than double by 2020, an increase from 1.6 Mb/d in 2010 to about 3.3 Mb/d (ERCB, 2011). The production from *in situ* projects would exceed production from mining projects within the next few years. Doubling the production of the oil sands would increase the need for better environmental risk mitigation planning to avoid the unfavorable environmental impact.

In 2005, oil sands production (52% or 572,000 b/d) came from open pit mines and from *in situ* with one third using the cold production process and the balance using SAGD (CAPP, 2010). Project engineers of *in situ* oil sands projects have to manage economic, financial, technical, and environmental risks to ensure the successful completion of the project. Risk management strategies for ensuring future environmental compliance of oil sands projects in Alberta are neither widely available nor widely applied. In my literature search, I did not find an SME study on the weighting of risks and the ranking of mitigation strategies. With this study, I hoped to bridge the knowledge gap by (a) identifying the key environmental compliance risks, (b) defining the weights for these risks, (c) recognizing potential mitigation strategies, and (d) ranking the mitigation strategies for *in situ* oil sands projects in Alberta, Canada.

Ranking of mitigation strategies would support Alberta project engineers and company executives in considering the best risk mitigation for their *in situ* oil sands projects, knowing this study considered inputs from a group of SMEs. A risk management process for defining and ranking mitigation strategies could guide executives and engineers to achieve full environmental compliance for new oil sands facilities. An oil sands project can end in financial disaster if the local jurisdiction deemed the project noncompliant with the local regulations; a noncompliant plant would not receive a license to start production. The management of an oil company may spend $500 million on a pilot *in situ* project before the start of production and up to $1.5 billion on a commercial project (Government of Alberta, 2010). The risk management process should help with risk decision-making and result in a consistent risk strategy for the life cycle of *in situ* projects. Providing objective rankings of individual risks and mitigation strategies would be helpful for improving the risk management process.

The French oil company, Total SA (Total), announced on December 8, 2011 that they have received approval for the Joslyn North Mine, a new 9 billion Canadian dollars (8.9 billion U.S. dollars) oil sands mining project (Welsch & Vieira, 2011). This approval process took six years from the date they started the application and approval process, and may take up to five years to get to production (Welsch & Vieira, 2011). In 11 years, the environmental scene may change significantly. Total's project executives and project engineers would be responsible for ensuring that their approved project would be compliant with environmental regulatory requirements throughout the design, construction, commissioning, and production phases.

Implications for Social Change

The increase in production in the oil sands regions affects not only regulations and accountability on the part of the producers and the government, but also requires action by the community. The communities have to consider their environmental footprint and adapt to change. The growth in the oil sands brought economic benefits to local communities, but the boom also had a negative impact on housing, public infrastructure, and services (Kurek et al., 2013). The impact on public infrastructure and services includes increased regional traffic, increased pressures on health care and education systems. These boom communities go through increases in drug and alcohol abuse as well as increased dependence on social service providers (NEB, 2006).

The new prosperity of the oil sands region also brought a change to the traditional way of life and impacts on aboriginal lands. The municipal infrastructure in Fort McMurray area (Wood Buffalo District) lagged behind population growth. The shortage of skilled workers caused an influx of foreign workers, whose presence create social problems in the oil sands communities (NEB, 2006) and change in the communities. Hanan, Burnley, and Cooke (2012) facilitated the involvement of citizens and leaders in the decision-making of their community and environment using MCDM processes not requiring expert inputs. The MCDM process may help community leaders identify solutions to potential problems due to oil sands developments.

The results of this study can contribute to progressive socioeconomic change during the execution of an *in situ* oil sands project. The study would also help executives and project engineers to understand the risk management of environmental compliance in the province of Alberta. Oil company executives and project engineers understanding the risk management process towards regulatory compliance would have a higher chance of success in managing the environmental footprints of their projects. Project engineers accepting the relative weights of the criteria contributing towards regulatory compliance and knowing the ranking of mitigation strategies would be able to have a better plan for environmental regulatory compliance during the execution of their projects.

Huang et al. (2011) concluded sound and consistent decision-making could be helpful for gaining environmental compliance within the financial, technical, and economic framework as well as with local stakeholders. Improving the environmental compliance of *in situ* oil sands projects would facilitate socioeconomic acceptance and demonstration of corporate responsibility. Gil, Beckman, and Tommelein (2008) concluded that knowledgeable managers would improve project decision-making. Improved risk management would reduce the environmental risk, and the probability of environmental disasters would be lower. An environmental responsible oil industry would lead to a better socioeconomic environment in the province of Alberta.

In this study, I identified key risk mitigation strategies applicable in new oil sands projects in Alberta. These risk mitigation strategies would improve the cost effectiveness and sustainability of oil sands projects. Understanding the environmental risks imposed by an *in situ* oil sands project would be supportive of oil companies to (a) reduce their ecology footprint, (b) reduce water usage, (c) improve air quality, (d) improve water quality, (e) reduce stress on local infrastructure, and (f) improve support to and communications with local communities. The focus and domain of the study were about regulatory compliance in Alberta. The identified risks and the mitigation strategies could be helpful to oil company executives and engineers elsewhere as they prepare to manage project environmental compliance.

A Review of the Professional and Academic Literature

I have focused the review of the professional and academic literature on four main themes supportive of this research study. The themes are: (a) oil sands as an energy resource and its extraction process, (b) risk management of oil sands extraction, (c) an overview of MCDM processes, and (d) a review of the literature on AHP. Reviewing the spectrum of MCDM processes was necessary because I used an MCDM process to rank the environmental risks associated with oil sands extraction projects. I used AHP as the MCDM process for this study for a number of reasons. I reviewed the last two themes to explain specific reasons.

Literature Review, Search Methods, and Search Instruments

In the literature review, I used resources from the academe, the industry, and the government. I retrieved most of the academic resources through the Walden University library. The databases and other resources used included ABI/INFORM, Academic Search Premier, Business Source Alumni Edition, EBSCOhost, Emerald Management Journals, Google Scholar, OnePetro, ProQuest Central, ProQuest Dissertations & Theses, SAGE Journals Online, Science Direct, and Alberta government publications on the oil sands. Keywords or subject terms used (including a combination of words) in the literature search were *Alberta, analytical hierarchy analysis (AHP), Delphi, environmental regulations, environmental risks, in situ process, multicriteria decision-making (MCDM), oil sands, ranking, regulatory compliance, risk, risk management, risk process, Saaty, and SAGD process.* The listed subject terms are common descriptors of the four themes I described in this literature review. In Table 1, I recorded a summary of the number of references I used in the study.

Table 1

Summary of References

Scope	No.	%
All references	302	-
Recent references (since 2010)	270	89
Peer-reviewed references	262	87
Recent and peer-reviewed references	244	81

For oil sands *in situ* oil extraction literature, I used sources from Alberta research institutes (the University of Alberta and Alberta Research Institute) and industry associations (CAPP and Pembina Institute). The intention was to provide an understanding of the oil sands as a natural resource requiring a technically advanced extraction process. The provincial government, local research institutions, and industry supported the development of the *in situ* oil extraction processes. Moreover, exploring the government of Alberta's regulatory publications, environmental strategy publications, and energy strategy publications provided the background information to realize the potential risk in regulatory compliance. The focus of this study was the identification of those risks and mitigation strategies that would assist project managers in their attempt to comply with environmental regulations. I collected this information in four themes and presented them in the literature review.

Specifically, in the first theme of the literature review, I addressed (a) the complexity of oil extraction from oil sands, (b) the extraction methods used, and (c) the potential impact of *in situ* oil sands projects to change the environment in the boreal forest. The second theme includes a focus on the environmental regulatory processes dictated by the Alberta government and the risks associated with such regulatory process as imposed on the oil sands industry. The third theme is a description of MCDM processes and their limitations that may be useful for ranking multiple criteria. AHP is just one of the MCDM processes. The study covers a perspective on the MCDM process as an analytic framework for assessing the importance of environmental risk and mitigation strategies. The fourth and final literature review theme points to the AHP technique. As I explained in the theoretical framework subsection of this study, AHP is a robust MCDM process similar to the Delphi method. However, the Delphi method is more rigorous in quantifying the votes of the participants, and AHP is supportive of consensus decision-making better than the Delphi method.

Oil Sands as an Energy Resource and Its Extraction Process

The oil sands in Alberta are an energy resource in environmental sensitive part of the province. In 2008, ducks (1,600) drowned in the Syncrude Aurora tailings pond (Stewart, Archer, & Trynacity, 2010). Syncrude is a leading Alberta oil sands producing company. Syncrude paid $3M in penalties and much more in loss of image, which gave the company a reputation for producing dirty oil (Stewart et al., 2010). The incident of the dead ducks should be a reminder to all oil sands executives. The preservation of the environment is a serious issue, and managers of future oil sands projects must consider the environment during project execution.

History of the oil sands in Alberta. The First Nations in Northern Alberta used outcrops of oil sands (bitumen) to seal their boats. The trappers of the Hudson Bay Company found bitumen near the Athabasca River in Alberta (NEB, 2006) in the early part of the 19th century. The first hot water extraction of bitumen from oil sands was at Carpentaria, California in 1895 (NEB, 2006). Sydney Ellis, an engineer with the Department of Mines, was the first to suggest commercial use of the oil sands, using hot water to separate the bitumen (Humphries, 2010). In 1925, Karl Clark of the Alberta

Research Council perfected a process using hot water and caustic soda, which is still the basis of processes currently used in the oil sands (Humphries, 2010). In 1927, R.C. Fitzsimmons started the first open pit mine at Bitumont, 80 km north of Fort McMurray. Fitzsimmons founded the International Bitumen Company in 1927 and built a small plant to produce bitumen for roofing and road surfacing (NEB, 2006).

Later, with research support from the provincial government of Alberta, the University of Alberta developed an extraction process to remove the bitumen from the oil sands. The University of Alberta research led to the first pilot plant in the 1950s. In 1967, the Great Canadian Oil Sands Company (GCOS) started the first commercial operation north of the town of Fort McMurray in Alberta (Humphries, 2010). Since 1970, five oil companies have established commercial open pit extraction operations in northeastern Alberta. These operations have a daily production of one million barrels of oil equivalent (Welsch & Vieira, 2011).

Oil has innumerable forms. Oil produced in the Middle East is light crude, medium crude produced in Texas and Brent crude produced in the North Sea. The bitumen or heavy crude is from the oil sands (Perry & Saloff, 2011). Venezuela and Western Canada have oil sands a well as California and Russia. The biggest deposits are in Canada: the equivalent of 950 to 1,600 billion barrels of oil, about 175 billion barrels of which are recoverable (Owen, Inderwildi, & King, 2010). Great Canadian Oil Sands Ltd (later Suncor) began production of the oil sands north of Fort McMurray, Alberta, Canada in 1967 (George, 2012). The Alberta oil sands are the largest deposit of oil available in a democratic country, second to the oil reserves in Saudi Arabia (George, 2012; Owen et al., 2010). The oil sands (80%) in northeastern Alberta are at depths of more than 150 m, too deep for open pit mining and suitable for *in situ* extraction (George, 2012).

Oil sands processing methods. *In situ* oil sands, extraction is technically complex and involves highly specialized individuals, expensive equipment resources, and registered patents (CAPP, 2011). The extraction of oil sands bitumen deposits involves the application of underground steam in large quantities. The steam increases the viscosity of the bitumen and pumps extract the oil to a processing plant on the surface (Mohebati et al., 2010). *In situ* projects are in an environmentally sensitive area, the boreal forest with vast areas of open water; therefore, project engineers need to implement project planning and risk management carefully.

The SAGD process is an *in situ* method most companies use. Butler was the first to introduce steam as a means to move bitumen to a production well (Mohebati et al., 2010). Butler's steam process developed into the modern SAGD process (Mohebati et al., 2010). The SAGD process has some distinctive characteristics that are advantageous, compared to other *in situ* processes (Mohebati et al., 2010). The main advantages are the use of gravity to drain the oil, lower energy consumption, and relative high recovery efficiency (between 70–75%; CAPP, 2011). The *in situ* process requires 0.6 to 0.9 barrels of water per barrel of bitumen produced compared to two to four barrels of water to upgrade bitumen from open pit mining (Bedair, 2013; Nicholls, 2010). The *in situ* process and open pit mining depend on water and therefore there is a strain on local water resources if not managed well.

In situ plants have a small land footprint similar to the footprint of conventional oil well operations, and *in situ* plants have no need for tailings ponds. For *in situ* projects, the steam-to-oil ratio (SOR) is a measure of the energy efficiency of bitumen recovery. Most owners of new *in situ* plants specify an SOR of 2.5 (NEB, 2006).

Environmental impact. **The government of Alberta measures the environmental impact of the oil sands in terms of several factors or indicators (Government of Alberta, 2009):**

1. Land use or footprint – The area of boreal forest cleared for operations, all affected land reclaimed and biodiversity maintained (regulated by Alberta Environment). The government would certify reclaimed land before oil companies return the land for public use (Perry & Saloff, 2011). Only 3% (4, 800 km^2) of the oil sands surface area used for open pit mining. The other 97% (138, 000 km^2) of the oil sands area covers the reserves that are too deep for mining, but are suitable for *in situ* recovery (Alberta Environment, 2010). For comparison, the oil sands surface mining area (4,300 km^2) is as large as the metropolitan area of Los Angeles, California.
2. Air pollution – GHG emissions from the oil sands totaled 45 million tons in 2009 (McCarthy, 2010), and these GHG emissions represented 6% of Canada's GHG emissions and 0.1% of global emissions. The Alberta

provincial government introduced in 2007 a 12% mandatory reduction in GHG emissions. These mandatory reductions are for all large industrial facilities, including oil sands (Alberta Environment, 2008; Charpentier, Kofoworola, Bergerson, & MacLean, 2011). The Wood Buffalo Environmental Association (WBEA) continuously monitors air quality throughout the oil sands area around Fort McMurray. The Alberta Clean Air Strategic Alliance (CASA) also benchmarks the air quality in the oil sands region.

3. Water use – The Alberta government regulates all fresh water resources in the province. Project managers of oil sands projects must apply for a permit and submit hydrogeological measurements to demonstrate the sustainability of the proposed project water resource (Miall, 2013). In 2009, irrigation and agriculture represented 44% of the provincial water usage allocations; the provincial regulator allocated 7% of the water usage to oil sands industry. *In situ* projects require about 0.5 barrels of fresh water per barrel of oil, and SAGD facilities use 80–90% recycled water (CAPP 2010; Miall, 2013). Most oil sands projects drill for water and use salt water unsuitable for agriculture or human consumption. The oil sands production, mining and *in situ*, used 1.1 billion barrels of fresh water in 2009 (CAPP, 2010). This high consumption of water put a strain on local water resources and may have a considerable impact on the environment.

4. Water quality – The Alberta Environment (Alberta government agency) regulates the release and the quality of all water. All water must conform to the water quality standards of Alberta environment (Hurley, Sadiq, & Mazumder, 2012). Water, in the form of steam, is vital to oil sands development and oil recovery. During the extraction, steam is helpful for reducing viscosity of bitumen during upgrading and extraction, and the well drilling and completion operations need water (CAPP, 2010).
5. People – The oil sands developments have an effect on the communities. New developments disturb the community, change the lifestyle, and the new labor force has an impact on local community services and infrastructure (Lopez, 2013). Consulting with local stakeholders and communities is a regulatory requirement (Government of Alberta, 2009).
6. Cumulative environmental impact – Future research should study the effect of accumulated environmental changes to air, land, and water. Jordaan (2012) examined the land disturbance due to *in situ* oil sands projects and considered the effect of not only the land disturbance but also the effect of fragmentation and peripheral use. This unknown effect would increase the environmental compliance to risk pending the result of scientific studies and their impact on compliance requirements the provincial government of Alberta imposed (Government of Alberta, 2009).

Project engineers should consider these six environmental criteria. The oil sands company executives should carefully factor all the environmental indicators to create an oil sands project culture. Such a culture should be environmentally and economically conscious, responsible, and viable. The Alberta government monitors these environmental indicators for oil sands projects ensuring proof of compliance by the project owner throughout the project construction and production phases. In the upcoming years, oil companies would spend billions of dollars on oil sands projects, and all these projects would require an environmental risk management program.

The government of Alberta set an energy strategy. The focus was on sustainable development and growth of the oil sands as well as the enhancement of the quality of life of all Albertans with full consideration of the environment (Government of Alberta, 2009). The Alberta government worked on an integrated approach between the energy strategy and land use framework to improve the environmental protection (Alberta Environment, 2010). The Alberta Provincial Energy Strategy described the following elements as essential to the protection of the environment and the development of the oil sands: (a)environmental footprint, (b) adding value to Alberta's energy industry, (c) change how energy is consumed, (d) innovation related to energy technology, (e) development of people, (f) development of electrical supply, (g) awareness of energy issues, and (h) alignment of *Provincial Energy Strategy* with other initiatives (Government of Alberta, 2009).

The Alberta government defined the vision for the oil sands and the environment as follows (Government of Alberta, 2009):

> Alberta is a global leader in the innovative, responsible, and collaborative development of oil sands. The benefits of development continue to support clean, healthy, and vibrant communities for Albertans and future generations. Communities and development reside together in a manner that balances progress with environmental stewardship. This vision will guide implementation of the strategies, as well as ongoing decision-making for oil sands development today and in the future. (p. 2)

The vision of the Alberta government focuses on four principles: (a) healthy environment and communities, (b) balanced growth, (c) collaboration, and (d) public interest and accountability. All of these principles connect the stakeholders, the public, and communities to the sustainable management of the environment. It is also important to understand the community and who represents the community; this would avoid future problems when engaging the community (Spoel & Den Hoed, 2014). This link between environmental responsibility and people opens the door for continuous focus on environmental compliance and the impact of public pressure. The public in Alberta is becoming aware of the importance of the environment. The Alberta government stated in the Provincial Energy Strategy that the outcome should be a smaller environmental footprint and enhanced accountability by all involved in the energy industry (Government of Alberta, 2009). The Provincial Energy Strategy provides clear indicators that future environmental requirements would continue to change and would only become more stringent. Oil company executives and project engineers should be aware of this direction assumed by the Alberta government. The Alberta government's vision recognized the global awareness on the environment. The vision statement is a strong indication to the oil industry to ensure environmental compliance of oil sands projects is a requirement for future oil extraction.

The Alberta Government published the *Provincial Energy Strategy* (Government of Alberta, 2009a), a *Climate Change Strategy* (Alberta Environment, 2010) in conjuction with the Federal government's *Turn the Corner* plan (Alberta Environment, 2010; Ordorica-Garcia et al., 2011). These strategies and the federal plan provide guidance to the oil sands companies as for the future environmental expectations and requirements of the Alberta Government (Government of Alberta, 2009b). The regulating agency, AER, monitors the environmental compliance of the oil companies in the oil sands.

The AER is the decision-making authority on the approval of all new oil sands projects based on environmental and public interest issues, and the Oil Sands Conservation Act with defined technical requirements, directives issued by the AER. Compliance to these technical requirements is the key responsibility of the project engineers throughout the project life cycle. Approvals in accordance with the Water Act, Alberta Environment Environmental Protection and Enhancement Act and Public Lands Act follow the approval by the AER. These approvals are helpful for ensuring oil sands project managers adhere to the protection of the environment and manage the environmental risks.

The environmental criteria are of prime importance to oil sands projects, optimizing these environmental criteria would minimize the effect on the environment, and the plant would be compliant with the environmental regulations. Metaxas and Tsavdaridou (2013) examined the importance of environmental issues and corporate responsibility. They concluded that environmental criteria have an impact on management decision-making. Metaxas and Tsavdaridou also recognized the impact of communities and other stakeholders and stated that communities and stakeholders would make management recognize their influences as part of the future decision-making process. Management would have to develop better working relationships with communities. Management also needs to engage in participative decision-making with their stakeholders; stakeholder involvement would reduce the oil company's environmental risk (Metaxas & Tsavdaridou, 2013). Environmental compliance is an integral part of future management actions.

According to Huque and Watton (2010), the federal constitution of Canada, the British North America Act of 1867, gave the provincial governments the responsibility for and management of public land. Section 109 gives the provinces ownership of all lands, mines, minerals, and royalties. The Canadian federal government owns about 55% of all land, and this includes the boreal forest in northeastern Alberta, the oil sands. Huque and Watton emphasized that the government of Alberta has the responsibility to regulate environmental issues, and the federal government is responsible for the governance of waterways (rivers). The Canadian federal government does not have responsibility for environmental policy, but they have some jurisdiction over water. Huque and Watton clarified that the federal government sets standards such as the Canadian Environmental Assessment Act and applies political pressure to change provincial environmental policies because of international pressure.

Environmental policy trends. Environmental policy based on economic theory may not always be a popular choice with the public (Schlosberg, 2012). According to Gattig and Hendrickx (as cited by Arbuthnott 2010), policies and regulations are in most instances the product of public awareness of environmental risk. When environmental risk is at stake, most people take into account future considerations of how commercial development would affect the environment. Therefore, society's long-term approach to human impact on the environment would be an influencing factor on environmental policy (Arbuthnott 2010). The principles of self-regulation, corporatization, and marketization have been a prominent environmental policy change in the US and Canada since the Reagan administration (Arimura, Darnall, & Katayama, 2011; Hsueh, & Prakash, 2012). Arimura et al. (2011) stated that governments in the implementation of environmental policies could use command-and-control and voluntary approaches concurrently. The trend reported by Gattig and Hendrickx (as cited by Arbuthnott, 2010) has changed policies from a command-and-control approach towards the control of the effects of pollution on the environment (Huque & Watton, 2010). A disadvantage of command-and–control policy is the negative influence on innovation and the development of new technology towards the environment (Rennings, & Rexhauser, 2011). This trend in policy is a change that oil company executives should be aware off as it increases the company's risk in managing oil sands facilities.

National and multinational companies should be aware of the change in environmental policies, and the influences these policies have on business strategy and future profits. If there is a high demand for energy, then there would be a high potential for conflict with environmental protection (Foote, 2012; Wagner & Armstrong, 2010). In the 1970s, there developed an awareness for damage to the ozone layer. This awareness started to change the emphasis of environmental policies to prevention rather than cure. Multinational companies have to deal with diverse environmental policies that cause inconsistency. Changing policies may cause conflict with energy, social, and economic goals of governments and corporations, the periods between economic, political, and ecological actions are not always aligned (Foote, 2012).

The major trends in environmental policy identified by Wagner and Armstrong (2010) were integration of environmental, energy, social, and resource policies. Wohl, Gerlak, Poff, and Chin (2013) described in their study the importance of core issues of environmental policy and regulations. Core regulatory topics include decision-making, people in the environment, accountability, and feedback systems. The trend in environmental policies is to implement a holistic approach to policymaking. This trend recognizes the complexity of the environment and that changes to the environment may have influences on people and other systems. It is a matter of everything influencing everything else. The holistic approach in environmental policy would affect the life cycle of an oil sands project.

Holzinger, Knill, and Sommerer (2008) further recognized that pressures to change environmental policies are coordinated through not only local organizations but also international organizations. There is little social tolerance on local and international levels (Foote, 2012). Environmental policies and regulations have been through a period of change. Some researchers think those internal organizational factors such as risk management policy and not legislative or regulatory design would ensure regulatory compliance (Huising & Silbey, 2011). Janicke and Lindemann (2010) stated that the globalization, the leadership role a country has in the international community, and the influence of international trade and labor agreements influenced the trend of environmental policies. Janicke and Lindemann identified that the economic competition requires markets, and political competition among countries applies pressure on environmental policies. The province of Alberta needs new markets for its oil, and the American environmental policies, environmentalists, and governments in other parts of Asia and Europe are applying pressure to political and environmental policy. These pressures restrict Alberta oil exports, and the Keystone XL pipeline is an example of environmental and political pressure on the approval process.

The economic and political pressures are applying constant pressure on the Alberta government to be a trendsetter in environmental policy. For example, Alberta was the first government that adopted CO_2 regulations in 2007; however, change would remain constant. In 2011, Alberta government also changed the reclamation regulations. The new regulations focus on the performance of reclamation by the oil sands companies (Perry & Saloff, 2011). Environmental policies would have to keep up with the international trends to ensure acceptance of the product in the international market. Open economies would see strong environmental policies to which they would need to adapt to and correspond with international trends (Janicke & Lindemann, 2010).

In contrast to what Huque and Watton (2012) reported, Schlosberg (2012) found the international shift in policymaking. Schlosberg identified three policy approaches: (a) the polluter pays, (b) fair share and equal allocations, and (c) right-based approach. These strategies focused on a framework of prevention and mitigation. Schlosberg recognized the new approach as close to the relationship between human beings and the environment. The involvement of the public is becoming essential. Lopez (2013) supported this in his study of American policies based on Canadian oil sands lessons learned.

Schlosberg also observed that policies changed rapidly since the energy crisis of 1973 and created conflict with the energy, social, cultural, and economic goals of communities, governments, and corporations in industrial countries. Research on environmental policies in Europe found that there is a high degree of international environmental policy convergence among 24 industrial nations (Holzinger et al., 2008). The impact of globalization is creating changes and is influencing international trade and labor agreements. For example, Alberta was the first government to adopted CO_2 regulations in 2007 (Hopper, 2008). The environmental policies of Alberta are changing to stay ahead of the global trend in environmental policy.

Janicke and Lindemann (2010) identified environmental policy change as a stimulus to technology innovation, and this caused a new mega trend in environmental technology. The Pew Research Center published a report in 2007, on their Global Attitudes Project, focusing on the public environmental opinion in different countries (Cetron & Davies, 2010). There is a high awareness among the public for environmental issues in the surveyed countries (Cetron & Davies, 2010). This public awareness would also influence the environmental policies and regulations adopted by the jurisdiction in those countries. There are also unstable circumstantial factors such as change in government (Reagan vs. George W. Bush) or economics (recession or prosperity) that could cause a sudden change in environmental policy (Huque & Watton, 2010). Circumstantial factors may also include environmental damage in the oil industry such as a major oil spill (e.g., the March 24, 1989 Exxon Valdez spillage in Alaska; the April 10, 2010 BP Deepwater Horizon oil spill in the Gulf of Mexico; or the July 26, 2010 Enbridge pipeline rupture, spilling oil into the Kalamazoo River near Marshall, Michigan). Environmental policy is more likely to change in developed countries because of global leadership and perceived capacity to change than in developing countries. The factors are present in Alberta, and they make the likelihood of continuous environmental change possible in Canada (Huque & Watton, 2010). The new policies and public awareness would create a responsibility with industry leaders to manage the potential environmental risk and regulatory compliance.

Risk Management

The International Environmental Risk Management system (ISO 14000) is a standard that defines a systems approach to environmental risk management. This ISO system focuses on a general framework applicable to all industries (Arimura et al. 2011). At the beginning of a project, minimal environmental and process data may be available, and there is uncertainty about future environmental and regulatory requirements (Hill & Ferguson-Martin, 2010). The success of engineering project depends on the risk management strategy and the anticipation of future risks due to potential changes in the project environment (Bali & Apte, 2014). Oil sands projects include trends of uncertainty such as changing regulatory requirements and oil economics. These uncertainties create risks and a risk management strategy (Elahi, 2013). Therefore, the success of the project and the future sustainability of the oil sands facility would depend on the environmental risk management strategy followed by decision makers. Sato (2012) supported the strategy on risk management. Sato used the AHP to define a risk management strategy, and she identified priorities to support sustainability in a manufacturing plant under budget constraints.

Risk management of *in situ* oil sands projects. The BP Deepwater Horizon oil spill in the Gulf of Mexico that happened in April 2010 demonstrated how a company with a long-term environmental strategy could still have an environmental incident. This incident was also catastrophic to the CEO and the company's image (Cherry & Sneirson, 2011). The BP Deepwater Horizon drilling rig was an ultra-deep-water, dynamically positioned, semi-submersible offshore oil drilling rig. The rig cost $365 million to build and the BP Deepwater Horizon oil spill caused $36.9 billion in damages to the Gulf of Mexico coast environment (Smith, Smith, & Ashcroft, 2010). The oil company executives need to ensure an environmental risk management process is in place, and that the company complies with the environmental, health and safety regulations. Risk management is the process of selecting risk mitigation actions based on the information gathered in the risk assessment process (Gregory et al., 2012). Regulatory compliance risk management is the process of establishing mitigation measures that would help to (a) protect the company image, (b) protect the company wealth, (c) execute successful oil sands projects, (d) provide a safe workplace, (e) protect the environment, and (f) maintain close relationships with local communities.

Risk management is a structured approach towards the management of risk and uncertainty and is essential in any business decision-making environment. Risk management is a fundamental part of any project in the oil industry. Investors are at risk and project managers have to manage risk finding the best feasible alternative within the project definition. Risk management is important throughout the life cycle of the project. Project executives and project engineers must consider the attributes of the project (parameters, factors, criteria) to be able to reduce the risk (Zavadskas, Turskis, Ustinovichius, & Schevchenco, 2010). The risk attributes can be qualitative and quantitative. Environmental risk management should be a framework for continuous improvement and mitigation of risks. Project managers could group risks in three source groups those are internal environment, external environment, both with predictable sources of risk and external environment with unknown uncertainties (Bali & Apte, 2014). This approach would help management to reduce the environmental impact and to go beyond compliance. In the case of new oil sands projects, engineers would have to work towards regulatory compliance.

Regulatory compliance is possible, if project engineers manage the identified risks. These risks include (a) operational risk, (b) compliance and legal risk, (c) reputation risk, (d) social risk, (e) environment, health, and safety or EHS risk, (f) geologic risk, (g) political risk, (h) financial risk, and (i) economic risk (Andersen & Mostue, 2012; Wagner & Armstrong, 2010). Enyinda et al. (2012) and Briggs et al. (2012) recognized social risk, economic risk, financial risk, technological risk, and environmental and regulatory compliance risk as high-level risks in the oil industry's supply chain.. Gas supply networks, similar to the oil industry, experience risks related to political issues, environmental, technology, and regulatory uncertainty (Farahani, Baygi, Mousavi, 2014). In a Nigerian oil industry study by Enyinda et al. (2012) the primary risks identified were geological and production risk, environmental and regulatory risk, transportation risk, oil availability risk, geopolitical risk, and reputation risk. Most of these risks (i.e., social risk, economic risk, financial risk, technological risk, environmental risk, and regulatory compliance) the researchers identified in the oil industry may also apply to oil sands projects (Ayyub et al., 2010; Briggs, 2010; Enyinda et al., 2012; Government of Alberta, 2009). Project managers and engineers in the oil sands sector should understand these risks. These engineers should have a constant risk assessment and decision-making process in place; they should ensure regulatory compliance, smooth operations, and avoid damaging the company's reputation or the environment.

Risks and mitigation strategies for environmental regulatory compliance. On April 20, 2010, the BP Deepwater Horizon disaster occurred; 11 people died, and 17 workers injured while 13,000 gallons of crude oil per hour leaked into the sea (Grant, 2011). In 2008, the Syncrude Aurora tailings pond killed 1,600 ducks (Stewart et al., 2010). Saturday morning, May 5, 2007, a steam pipeline burst on the *in situ* plant site of MEG Energy Corporation at Christina Lake, Alberta, destroying 1.4 km of steam pipeline and causing localized spillage of bitumen (ERCB, 2008). If a disaster strikes, it can have several consequences such as the loss of life, killing of innocent birds, significant equipment damage, local spillage or an environmental disaster. The BP Deepwater Horizon spilled oil for 100 days at a rate of about 13,000 gallons of crude oil per hour into the Gulf of Mexico (Grant, 2011). The mentioned disasters have one common thread that is the corporations all operated these facilities under government environmental regulations and in a certain way, they were noncompliant.

All *in situ* oil sand projects have to be compliant with the environmental regulatory requirements from day one to the last day. When the oil company returns the *in situ* site to the government and the local community at the end of the project, they shall reclaim and restore all land. An environmental compliance mitigation strategy is unique for every project; therefore, a systems approach or holistic approach to regulatory compliance would help an oil sands company to comply. The potential risks define the mitigation strategies. Gregory et al. (2012) investigated environmental decision-making and risk management. Gregory et al. concluded that the risk assessment of resource development (i.e., oil sands) is not only about the probability of environmental events but also about the risk mitigation strategies. Gregory et al. (2012) stated risk management should combine the probability of events that may affect the environment with socioeconomic and political factors. Hanewinkel and Oehler (2012), as well as Yousefpour et al. (2012), found in their study that in complex environmental studies (i.e., forest management), scientific (geological) and economic (financial) factors should be considered with uncertainty and the views of different stakeholders. Estévez et al. (2013), as well as Gregory et al. (2012), confirmed the importance of stakeholder participation.

Wagner and Armstrong (2010) alluded to the importance of social and environmental risks alongside political and economic risks. The mitigation of the high-level risks is part of the risk assessment process (Ayyub et al., 2010; Briggs et al., 2012). In risk management, the manager should consider four generic mitigation strategies; risk acceptance, risk avoidance, risk reduction, and risk transfer (Reddy, Govardhan, & Prakash, 2013). The risk management strategy is the first step in risk mitigation.

In the European study on risk management strategies, Cortes, Figerio, Schenato, Pasuto, and Sterlacchini (2013) identified four mitigation strategies: (a) prevent damages to people, properties and infrastructure, (b) ensure people are prepared and trained to manage risks, (c) improve technology to respond to risk, (d) enhance public awareness. The second step in the risk management strategy is to develop mitigation strategies, similar to the proposal of Cortes et al., for the risks identified on the lower hierarchy, the physical, quantifiable risks. The environmental regulations define most of the physical environmental requirements.

The U.S. Federal Clean Air Act amendments of 1990 were the first to address environmental risk assessment. Risk management is a process that depends on the risk manager understanding the steps of risk management. These steps are (a) the vulnerability and risk; (b) analyzing internal and external factors; (c) identifying the timing for risk assessment; (d) identifying the real and potential impacts; (e) identifying threat and opportunity, (f) and identifying the probability of the risk (Măzăreanu, 2011). Gregory et al. (2012) described risk management as the combination of risk mitigation and risk assessment. Gregory et al. then described the risk assessment process in four steps:

1. Define the problem.
2. Identify the hazards and boundaries.
3. Assess the exposure paths and potential effects.
4. Characterize the risks and their probabilities of occurrence.

Jaskowski and Biruk (2011) considered risk assessment for construction projects and defined a four-step process similar to Gregory et al. (2012) but with a different focus. Jaskowski and Biruk's four-step process focuses on the identification of the risk activities, estimates the effect on project duration, reviews mitigations, and defines a final project duration distribution. Decisions for managing the risks need clear communication, not only from engineers and managers, but also with the community. Managers and engineers practicing risk management would have a high rate of successful environmental compliance if they make decisions in a collaborative manner. Practicing environmental risk management is the action that could close the regulating compliance gap for *in situ* projects. It is the responsibility of engineers to address these compliance issues. It is up to the management and project engineers to develop policies as part of their mitigation strategies to ensure the oil sands projects would be compliant. Hopkins (2011) studied risk management in the oil industry and recommended that a technical rule-based compliance mitigation strategy be essential to ensure minimum regulatory compliance. Gibbs (2011) stated that risk analysis and adopting a risk assessment tool are the fundamental approach to environmental management, and Hopkins (2011) added *value of rule compliance* to the risk management process. The risk management process also requires consideration for local and cumulative impact of projects on the environment, the need for technology transfer, and adaptive risk mitigation (Gibbs, 2011).

To ensure compliance to the environmental regulations, the AER requires oil sands companies to develop an environmental management plan (EMP). The EMP should allow for reporting and assessment of the project's current compliance, as well as projecting the future environmental compliance of the plant in operation. A project EMP should include compliance monitoring as a mitigation strategy; compliance monitoring would allow an adaptive approach to risk management (Gibbs, 2011).

The AER and Alberta government focus also on the physical environmental risks described in the Alberta government oil sands strategy (Government of Alberta, 2009). The physical risks include natural environmental risks (i.e., land use, water quality, water usage, and air quality), human environmental risks (i.e., community disturbance, socioeconomic changes), and implementation of a local environmental monitoring system. Air quality is a key focus of the environmentalist. Thus, the Alberta government implemented a GHG level objective in 2007 to limit GHG emissions with the goal to reduce GHG by 12% (Hopper, 2008). *In situ* oil sands projects have an advantage with lower GHG emissions compared to open pit mining (Bergerson, Kofoworola, Charpentier, Sleep & MacLean, 2012; Brandt, 2012; Yeh et al., 2010). The engineers need to implement a plan to improve *in situ* plant designs and to eliminate the GHG emitted into the air. The second mitigation strategy is to reduce the carbon dioxide (CO_2) emissions by participating in a carbon capture and storage program or reduce emissions using steam solvent processes (Charpentier et al., 2011).

A third risk mitigation strategy should focus on water quality and quantity. *In situ* projects require less water usage compared to the open pit mine. The mines have a water usage of two to four barrels of water per barrel of oil (Bedair, 2013; Nicholls, 2010) compared to *in situ* projects that currently use about 0.6 to 0.9 barrel of water per barrel of oil (Kim, Hipel, & Bowman, 2013; Mannix, Dridi, & Adamowicz, 2010). The strategy, according to Mannix et al., is to recycle more water; up to 90% to 95% for new projects. The second strategy is to use no fresh water or water from local rivers and creeks and to use only treated underground saline water in the SAGD process. Water quality suffers due to an increase in polycyclic aromatic hydrocarbons (PAH) levels. The increase in PAH levels is a risk for surface water, ground water, and aquatic ecosystems (Giesy et al., 2010). A further aspect to consider for new *in situ* projects is water security: no water pollution (Kim et al., 2013). Kim et al. (2013) proposed project managers should balance water security with environmental, economic and social impacts. The AER fined Suncor Energy Ltd, an oil sands producer, for water pollution by kitchen staff, a subcontractor at an *in situ* oil sands workers campsite (Bertels, Cody, & Pek, 2014). The ISO 14000 environmental risk management system focuses on risk mitigation with the implementation of a systems approach. A robust mitigation strategy implemented by ISO 14000 is documentation management as a method to reduce or control risk.

In summary, the mitigation strategies should focus on the avoidance of the potential cause of the environmental risk (e.g., no emissions). The second option is to reduce the risk to an acceptable and safe level, and the third option is to share the risk with others (e.g., buy insurance or get a project partner). Documentation control, enhanced technology, and R&D would further improve the mitigation strategies. The implementation of ISO 14000 as a formal environmental risk management system may also contribute to regulatory compliance.

Influence of Alberta environmental policies on risk management. The influence that regulations and government actions have on the risk level of new projects may determine the final compliance of the project. In Alberta, the provincial government has changed the policies regulating the royalty payable by oil and gas companies a few times since 2007 (Perry & Saloff, 2011; Plourde, 2012). The royalty changes cause uncertainty and increase the project compliance and sustainability risk. Ayyub et al. (2010) defined the risk decision-making process for new projects.

Compliance requirements and their impact on projects may have a significant influence on how executives see the future compliance issues and corporate social responsibility as measures of project success (Wagner & Armstrong, 2010). Monitoring and enforcement of regulations by the regulator have a significant impact on how operations conduct themselves. Gray and Shimshack (2011) emphasized the importance of enforcement and the effect it has on the reduction of emissions and regulatory enforcement has a direct influence on over compliance by plant managers. The importance of enforcement is an indication that management respond positive to regulatory enforcement (Gray and Shimshack, 2011). Most Canadian plant managers (70%) stated that regulatory enforcement has the biggest impact on their environmental compliance, more than community organizations and environmental pressure groups

(Gray & Shimshack, 2011). Gray and Shimshack did not report the influence of political decision-making in the study, and it is outside the power sphere of the project engineer or manager. For instance, McLinden et al. (2012) reported on the trend of air quality measurements in the oil sands and compared with the air quality in Alberta cities. However, it is the regulator and politicians that need to take action based on this scientific evidence. Project decision makers should consider a multicriteria decision-making model for environmental risk management.

An Overview of MCDM Processes

MCDM has developed into an accepted method to support the decision maker (Mota, Campos, Neves-Silva, 2013).Researchers and practitioners may use MCDM processes to rank the environmental risks associated with oil sands extraction projects. For this environmental regulatory compliance study, I focused on a quantitative approach towards decision-making. Therefore, I examined various quantitative decision-making theories and techniques to show why the AHP is appropriate for this study. Deciding which MCDM method to use is important because different methods may give different rankings (Stanujkic, Djordjevic, Djordjevic, 2013). In their study, Huang et al. studied more than three hundred environmental project papers and concluded that there is an increase in the application of MCDA. Huang et al. identified the methods used the most in environmental analysis; analytic hierarchy process (Saaty, 2006), MAUT (Beccacece & Borgonovo, 2011; Brito, de Almeida, & Mota, 2010; Gomes et al., 2011; Liu, Walshe, Long, & Cook, 2012), and outranking (Jajimoggala & Karri 2013). Geng and Wardlaw

(2013) identified the MCDMs most used in environmental management are compromise programming (Zarghami & Szidarovszky 2010), goal programming (Liao & Kao, 2010), and AHP (Saaty, 2006).

A weak problem structure or definition in an MCDM process is a problem in determining the optimum decision (Zavadskas et al., 2010). In construction projects similar to oil projects, environmental risk assessment and decision-making have become more complex. The quality of data and SME inputs become essential criteria in the decision-making strategy (Zavadskas et al., 2010). Decision-making is possible depending on two aspects of data: the availability of data (qualitative or quantitative data) and the certainty of data. In this study, I used data available from a government agency database and a survey. Most MCDM approaches include three primary elements: (a) definition of alternatives that SMEs will rank, (b) rules to enable the measurement of the alternatives, and (c) performance measures for each alternative with respect to each criterion (Geng & Wardlaw, 2013).

The decision-making theory under uncertainty used in most studies is the probability theory as defined by Savage (cited in Pothos & Busemeyer, 2013). Probability theory uses a Bayesian measurement of the possible occurrence of a future event (Karni, 2011). Quantitative decision-making under uncertainty uses a judgmental approach or an intuitive approach, also called a heuristic approach (Kusá, 2011). A heuristic approach may be a safe effort, as for many decisions not all the information may be available (Gigerenzer & Gaissmaier, 2011). A heuristic approach is to estimate the possibility that something may happen or the likelihood of occurrence. Lee and Newell (2011) considered the heuristics approach to MCDM and included a hierarchical Bayesian method in decision-making, which may lead to improvement in heuristic decision-making. Golmohammadi, Afshari, Hasanzadeh, and Rahimi (2010) suggested applying heuristic decision-making models to business applications such as supply design and optimization. An MCDM process facilitative of considering or managing the human aspect of decision-making was beneficial in this study on environmental compliance and risk management. Understanding the openness and endless approach in qualitative research helped to get a better understanding of decision-making.

Janssen et al. (2009) developed a quantitative method to evaluate multidisciplinary projects and combined different models to define new decision–making criteria for use in future agriculture and environmental project assessment. Janssen et al. used the integrated assessment and modeling (IAM) method to study the decision-making options in defining agricultural and environmental policy in Europe. The policies had to consider multiple stakeholders, agriculture, the environment, and the criteria in assessing contributions to sustainable development. Janssen et al. obtained help from more than 100 participants to define and evaluate their IAM models. The IAM approach has the potential of an MCDM process to work in a quantitative manner with members from the oil sands industry. The said approach could have helped to define an environmental regulatory compliance strategy. However, attracting a large group of SMEs posed a problem. There are not that many SMEs in Alberta, therefore, I did not consider the IAM method as a viable methodology for the study.

Quantitative decision-making methods require adequate data, and these methods need inputs from experts. Qualitative methods for decision-making under uncertainty such as believe function theory (Fan & Nguyen, 2011) or fuzzy set theory are closer to human decision-making or problem solving (Huang, Zhang, Liu, & Sutherland, 2011; Wu, Zhang, Wu, & Olson, 2010). Fuzzy set theory is a decision-making method that represents environmental knowledge, control knowledge, vagueness, and linguistic imprecision (Karimi et al., 2011; Wu et al., 2010). Decision makers may use a decision-making model that has characteristics such as fuzzy theory, qualitative probabilistic reasoning, or scenario-based reasoning. Decision makers use these theories to identify the influence of future policy or environmental requirements on the risk of the project (Durbach & Stewart, 2012). These characteristics define the criteria for selecting an MCDM process for this study.

Business leaders and project engineers should address several criteria related to decision-making, socio-political influences, economic impact and environmental compliance (Huang, et al., 2011; Yousefpour et al., 2012). These criteria include environmental risks, uncertainty in the data, the decision-making models used, as well as ethics (Pimentel, Kuntz, & Elenkov, 2010). Pimentel et al. (2010) reviewed ethical decision-making in business and identified four characteristics of ethical decision-making. Decision makers should consider the stakeholders, the law and regulations, the environment, and the organization's values and norms. Executives should also consider self-efficacy and their non-compliance when making decisions (Shacklock, Manning & Hort, 2013). Ethical decision-making imposes on the culture, strategy and goals of the organization (Pimentel et al., 2010). A final important aspect of ethical decision-making in risk management is the impact of current decisions on the future and the opinion of the public on the future (Pimentel et al., 2010).

If managers observe a trend in environmental regulations, then it would be beneficial to consider the potential changes in their risk management strategy. Pimentel et al. (2010) proposed decision-making should include ethical aspects of decision-making in business. Lotila (2010) identified corporate response to social pressure as a factor in ethical decision-making. Lotila further stated that social pressures related to environmental matters create a functional and a moral relationship with the community. Lotila's views are similar to the views of Pimentel et al. that focus on management responsibilities, and their impact on the community. Therefore, for environmental regulatory compliance the impact of the oil sands on the community is part of the risk management plan.

Decision-making depends on the decision maker who may be individuals or a group of people. Group decision-making in project management is quite common (Jaskowski, Biruk, & Bucon, 2010). Kimbrough, Kunreuther, Baron, Gong, and Xiao (2010) studied decision-making in economics and psychology. Kimbrough et al. identified three factors of importance when considering a decision-making framework:

uncertainty, cooperation, and group decisions. The integration of these elements allows decision makers to make better decisions and to cooperate with stakeholders. The understanding of group decision-making is an influencing factor on the selection of an appropriate decision-making method; some methods may be too conservative or over-optimistic (Tavares, 2012). Group decision-making techniques often used by researchers and management are the Delphi technique and multicriteria methods such as AHP (Saaty & Vargas, 2012). AHP is an MCDM that is well suited for group decision-making, and it translates human judgments into quantitative values (Basak, 2011; Grošelj, Pezdevšek Malovrh, & Zadnik Stirn, 2011; Ramanathan & Ramanathan, 2010; Wu, Kou, Peng, & Ergu, 2012).

The Delphi method may be attractive for defining project goals in a group as it allows for inputs and balancing of opinions from all members (Cole, Donohoe, & Stellefson, 2013). Dalkey and Helmer (as cited in Hsu & Stanford, 2007) developed the Delphi method in the1950s. Decision makers use the Delphi technique as a method for consensus decision-making with a group of experts. Decision makers use most group decision-making techniques for goal setting or predicting the occurrence of future events, asking the question, “What” (Hsu & Stanford, 2007). The Delphi technique has a different approach, using questionnaires and tries to find answers from SMEs to *what could/should be* (Hsu & Stanford, 2007). The Delphi method focuses on the knowledge and opinions drawn from a group of SME with validity based on an iterative process with a group of SMEs (Cole, Donohoe, & Stellefson, 2013). The SMEs will respond independently to a question within a designated period (Dalkey and Helmer as cited in Hsu & Stanford, 2007). The Delphi method focuses on consensus; it uses multiple iterations and encourages participants to reassess their original judgments.

The Delphi method makes conclusions based on statistical analysis of the data and may still indicate different opinions by showing the spread in the participant's opinions (Hsu & Stanford, 2007). The statistical analysis provides for an objective and impartial analysis. A Delphi study can be time consuming in comparison with other group decision-making and MCDM processes. Yeung, Chan, Chan, Chiang, & Yang, 2012) did four rounds of Delphi surveys to select ten key performance indicators (KPIs) for construction projects. For my study, there were more than eight risks related to environmental compliance, and that would require large blocks of time for SMEs to complete the questionnaires. The process might require three or four rounds of Delphi surveys (Yeung et al., 2012). Repeated rounds of questionnaires make the Delphi technique impractical. SMEs are full-time industry executives and practitioners with limited time in their busy schedules to participate in various surveys. The multiple rounds of questions discourage participation and limit the sample size. A small sample size will not be representative (Hsu & Sandford, 2007). Therefore, multi rounds of questions with a large sample size of SMEs caused difficulty in obtaining data for this study because there are a limited number of SME in Alberta involved in oil sands projects. Some researchers overcome this problem by combining the Delphi method with AHP (Cho & Lee, 2013).

Executives responsible for risk management have to deal with the uncertainty or probability of a possible future scenario, therefore making decisions under uncertainty depend on their experience and training. They may also request the opinions of SMEs. Cooke published the TU Delft database, an expert judgment database in 2005 for the validation of decisions made by experts with the classic model (Cooke, 2014; Lin & Huang, 2012). Various researchers used the TU Delft database to explore new validation models, for example; Clemen proposed the Remove-One-At-a-Time (ROAT) method (Cooke, 2014; Lin & Huang, 2012). However, these validation models using expert judgment require further development when applied to probabilistic scenarios (Cooke, 2014). Eggstaff, Mazzuchi and Sarkani (2014) questioned the validity of the Cooke's classic model for expert judgment aggregation based on critic reported by researchers. Risk management in the oil industry had to deal with probabilistic scenarios, possibilities of equipment failure or incidents that might happen; therefore, the Cooke classic model and a ROAT validation might not be a suitable decision-making model. Technology would influence decisions made under uncertainty (Bobtcheff & Villeneuve, 2010). Bobtcheff and Villeneuve showed that if the choice is between two options under uncertainty, the best outcome is not easy to identify, and there may be a need for more SMEs to provide opinion on the subject. The known decision-making criteria determined the choice of the decision-making framework for environmental regulatory compliance in Alberta. The multiple criteria influencing the choice of MCDM process selected include the following: group decisions, risk (uncertainty), data available, probabilities, and inputs from SMEs.

The environmental policy uncertainty in the oil and gas industry in Alberta influences the decision-making in this industry and the framework most suitable for decision-making. Huang et al. (2011) studied decision-making in environmental studies and found that there is a trend towards the use of MCDM methods for environmental policy management. Similarly, in studies in decision-making, in the civil engineering and construction industries researchers found that vague and incomplete information cause uncertainty and plagued decision-making (Abdelgawad & Fayek, 2010). In Alberta oil sands, project managers also experience vague and uncertain data (Zavadskas et al., 2010; Zou, Liu, Liu, & Guo, 2010). Zou et al. (2010) proposed the use of a modified interval linear programming (ILP) decision-making model, defined as a risk explicit ILP (REILP). Conversely, Nieto-Morote and Ruz-Vila, (2011) reviewed the decision-making process in power plants using the fuzzy AHP with subjective weighting criteria. Nieto-Morote and Ruz-Vila also presented an evaluation of several plant systems to show the effectiveness of the AHP process.

Decision-making is a broad subject that influences the project, executives, project engineers, and the organization (Akdere, 2011), It is therefore essential to identify typical decision-making models used for multicriteria decisions-making (MCDM), as required for environmental decision-making. The applicability of different decision-making models may require further review to identify any relevance to making project decisions under uncertainty. Reviewing the literature regarding the decision-making process used in other industries where most of these criteria occur, I found that researchers and decision makers often used the AHP as an MCDM (see section under AHP).

Multicriteria decision-making (MCDM). Decision-making is a process of making a decision between two or more possibilities. Multiple possibilities introduce the possible choice of one solution to another, and there is an uncertainty of which decision may be a better decision. The multicriteria decision-making process applies to engineering, management, marketing, human relations, IT, and any other part of the organization. Decisions become intricate if the interface is with internal criteria and external criteria. For example, regulatory compliance or jurisdictional policy changes may require a review of several policy factors in pursuit of making the best decision (Tjader, Shang, & Vargas, 2010). MCDM applications are expanding with the growing of the internet, computing power, and availability of web-based software. Decision makers are applying MCDM further in disciplines like engineering, e-Commerce, and finance (Bragge, Korhonen, Wallenius & Wallenius, 2012). The reviews of other decision makers and researchers are influencing the growth in MCDM applications (Sipahi & Timor, 2011). Researchers identified and described several MCDM theories in the literature (Aruldoss, Lakshmi & Venkatesan, 2013); these theories include for example heuristics, goal programming, MAUT, and AHP. The AHP has the widest application for construction, engineering, finance, internet, politics, and project management (Saaty, 2006, 2012).

Decision-making, where multiple criteria and multiple objectives exist, requires a structured approach or framework to obtain a decision. The decision maker has to learn how to deal with a variety of factors and the different dimensions of these factors (Saaty & Vargas, 2013a). Multiattribute theory, an MCDM theory, is focusing on the decomposition of complex problems into irreducible criteria and sets of actionable solutions (Gomes et al., 2011). Multiattribute decision models focus on single decision-maker models and group decision-maker models such as AHP and step matrix method.

MCDM requires human input. However, the human mind finds it difficult to consider or weight across multiple criteria. The human mind works in a systematic way, and hierarchy structures are a systematic form for the definition of complex decisions (Saaty & Sagir, 2009). The hierarchy structure forms the backbone of the AHP. Decision-making, where multiple criteria and multiple objectives exist, requires a structured approach or framework to obtain a decision by a single decision maker or a group of decision makers.

Researchers described a number of MCDM models in the literature, such as (a) outranking methods, (b) linear weighted point, (c) judgmental modeling, (d) interpretive structural modeling, (e) categorical method, (f) fuzzy sets, and (g) AHP (Beck, & Hofmann, 2012; Turskis, & Zavadskas, 2011; Zavadskas, Turskis, & Kildienė, 2014). Greco, Matarazzo, and Sowiski (2010) described a time-based decision-making model; they examined the decision-making models under uncertainty for those situations where the outcome was time sensitive. Greco et al. (2010) based their decision-making model on a combination of time dominance and stochastic dominance; their model is also suitable for qualitative ordinal distributions. Additive models and weighting models for multiattribute decision-making based on AHP were reviewed and found acceptable (Shang, Zaiyue, & Cungen, 2010; Sarabando & Dias, 2010). Labib (2011) used a fuzzy AHP model for a supply chain selection with the ability to check consistency in decision-making. Ordoobadi's (cited by Labib, 2011) motivation for using an AHP model with fuzzy sets is the accommodation of subjectivity and imprecision associated with perceptions and not forcing decision makers to use numerical scales. Ishizaka and Nguyen (2013) applied fuzzy AHP for the same reasons, uncertainty and imprecision, in a bank account selection study. In this study, I determined the rankings without the inclusion of subjective impressions or perceptions of decision makers.

A Review of the Literature on AHP

The world is a complex environment, a system influenced by many interacting factors from the environment and people and industry. The interactive environment or system requires decision-making methodologies capable of system decision-making following a holistic and analytical approach. AHP is an MCDM methodology suitable for complex systems that allow for the interpretation of qualitative and quantitative aspects of decisions (Saaty & Sagir, 2009). Saaty and Shang (2011) stated that the AHP is suitable for comparisons where the magnitudes are either very small or very large. The pairwise comparison techniques used in AHP is better suited for these small and large magnitudes than a rating system that considers one alternative at a time. AHP reduces a complex decision or problem to a hierarchy and to a series of pairwise comparisons (Saaty, 2006). Saaty (2006) stated that the AHP is an MCDM process that allows the use of quantitative data, experience, intuition, and insight. AHP is easy to understand by decision makers, as well as non-experts, who can participate in the decision-making process. Therefore, AHP is a preferred MCDM framework by many practitioners (Aydin & Arslan; 2010; Podvezko, Mitkus, & Trinkūnienė, 2010). Another advantage of the AHP is its ability to resolve multi-objective decision situations (Saaty, 2006). At the end of the process AHP not only allows the researcher to manage different types of data it is also possible with AHP to evaluate the consistency of the inputs from decision makers (Dong, Zhang, Hong, & Xu, 2010; Machiwal, Jha, & Mal, 2011; Stoklasa, Jandová, & Talasová, 2013). Dong et al. (2010) and Stoklasa et al. (2013) emphasized the importance to measure consistency in consensus and group decision-making. Stoklasa et al. proposed to do a preliminary ranking of priorities before doing a pairwise comparison, a way to improve consistency with a group of SMEs. Kravchenko and Seredenko (2011) evaluated the AHP and concluded the importance to establish alternatives to the problem that lead to an increase in the decision-making efficiency. The AHP is a methodology suitable for the modeling of uncertainty and risk as it is capable of quantifying subjective and intuitive data.

Background to AHP. Thomas L. Saaty (2006) developed the AHP, which proved a valuable technique for multicriteria decision-making. Saaty developed the AHP as an MCDM process that can change subjective probabilities from uncertainty to a framework of measurable criteria and ratio measures that culminate to a single measure. The reviewed literature identified several applications of AHP in social science, management, and engineering. AHP is suitable for MCDM where many SMEs may be involved reviewing several variables or criteria influencing the decision (Amponsah, 2011; Dong et al., 2010; Wu et al., 2012). The variables may be quantitative or qualitative (Saaty, 2006), tangible or intangible (Saaty, 2011), subjective or unquantifiable variables (Ramanathan & Ramanathan, 2010). Saaty (2006) worked to define the supporting axioms after early criticism against the validity of the AHP (Dyer as cited in Steele et al., 2009). Saaty did not only work on improving the theoretical basis of the AHP, but also on the group decision-making advantages of AHP, and said it works well for a group of SMEs to evaluate qualitative criteria. In a group decision-making study by Grošelj et al. (2011), they showed the importance of not violating the reciprocal property that is a requirement of the AHP for consistent group decision-making. Other group decision-making models causing inconsistent group decision-making violate the reciprocal property (Grošelj et al., 2011). Saaty (2006) and Grošelj et al. (2011) demonstrated that AHP has advantages as a group decision-making framework, but with caution by the decision maker.

Saaty (2006) identified and summarized the advantages in the application of AHP as an MCDM framework for group decision-making as follows:

1. AHP constitutes a one-stop solution for unstructured problems.
2. It processes the ability to resolve complex problems.

3. It can connect the dots between interdependent elements in a complex mode.
4. It is capable of breaking down complex problems into simple elements distributed over multiple levels of the hierarchy.
5. It allows pairwise comparisons for items on the same hierarchical level to derive priorities.
6. It converts intangible judgments into measurable scales.
7. It allows the verification of consistency in data.
8. AHP provides an overall/decomposed priority of alternatives in relation to the problem.
9. AHP derives a conclusion from diverse opinions.
10. AHP allows modifications, and repetition to improve results.

These advantages make it possible for researchers and practitioners to use AHP in many applications.

Applications of AHP. Saaty (2006, 2012) has used AHP since its introduction in 1980 for a large number of MCDM projects, industries, and applications. Saaty used the AHP for applications such as setting priorities, risk management, quality management, project management, and strategic decision-making. The AHP is suitable for hardware and software related decisions, as well as using inputs from literature reviews, databases and experts (Talib, Rahman, & Qureshi, 2011). Badizadeh and Khanmohammadi (2011), as well as Pun, Chin, and Yiu (2010), used the AHP in assessing the risk in new product development. Practitioners used AHP to identify the priorities for product development strategies and the associated risk of the chosen strategy. The use of pairwise comparison shortens the time to identify and prioritize risks, and it helps participants to avoid confusion in answering survey questions (Ishizaka, 2012; Ishizaka & Labib, 2011a). For these reasons, researchers used AHP in economic modeling, environmental management, forest management, water resource management, energy, and renewable energy planning (Aragonés-Beltrán, Chaparro-González, Pastor-Ferrando, & Pla-Rubio, 2014; Grošelj et al., 2011; Imam & Tesfamichael, 2013; Giri & Nejadhashemi, 2013; Kara & Köne, 2013; Khadka, & Vacik, 2012; Kravchenko & Seredenko, 2011; Rodríguez-Bárcenas & López-Huertas, 2013; Steele et al., 2009; Tegou, Polatidis, & Haralambopoulos, 2010; Yousefpour et al., 2012). The application of AHP in environmental studies is widespread and applied to climate change (Promentilla, De la Cruz, Angeles, & Tan, 2013) and bioenergy sustainability (Kurka, 2013). These broad applications of AHP provide confidence to practitioners and researchers when they consider AHP as an MCDM process.

Yousefpour et al. (2012) selected the AHP as the decision-making process to integrate public preferences in complex forestry decisions and Piran, Maleknia, Akbari, Soosani, and Karami, (2013) used AHP for urban forest site selection. Grošelj et al. (2011) found that using AHP improved transparency, group decision-making with multiple objectives, and forest management credibility. Although Huang, et al. (2011) found MCDM, including AHP, extremely valuable for environmental applications. Steele et al. (2009) cautioned in their study that using the AHP in environmental decision-making might have severe consequences if not used with discretion. Steele et al. criticized the use of relative normalization rather than using absolute normalization. They argued that rescaling the criteria could lead to rank reversal and criteria weights should change accordingly. Steele et al. proposed the use of absolute scoring scales, scales with minimum and maximum endpoints.

Maleki and Zahir (2012) did more work on prioritizing scales and normalizing, and they found that, in most AHP case studies, decision makers used relative normalizing, and they checked for possible rank reversal. The application of AHP in environmental studies is widespread. It would be useful to examine the prioritizing scales and evaluate the potential rank reversal in-group decision-making applications.

The AHP application in supply chain management. Many practitioners and researchers used AHP in supply chain management and in managing supply chain risks (Tao, 2012 Tavana, Fazlollahtabar, & Hajmohammadi, 2012). Various researchers used AHP for the evaluation of suppliers (Alireza, Meysam, & Seyyed, 2013; Antil, Singh, & Kumar, 2013; Ong & Salim, 2014; Varma et al., 2008). Ong and Salim replaced a previous selection method using a Likert scale with the AHP. Researchers combined the AHP with the balanced scorecard (BSC) to build decision models for the evaluation of supply chain management (Tjader, May, Shang, Vargas, & Gao, 2013; Varma et al., 2008). With the help of SMEs, using pairwise comparisons, Varma et al. determined the relative weights of the criteria influencing the supply chain performance. Alireza et al. and Varma et al. applied AHP successfully in the evaluation of supplier’s risks, and De

Felicea, and Petrillo (2012) used the AHP to rank the logistic factors of an international supply chain. Cho, Lee, Ahn, and Hwang (2012) and Cooper, Tadikamalla, and Shang (2012) used AHP to assess the performance of service providers. Varma et al. summarized the advantages of AHP. The AHP allowed for the quantification of the qualitative data, and the AHP was a useful methodology.

The AHP method is stable and flexible; it allows for small changes and the addition to the hierarchy (Varma et al., 2008). The second reason for using the AHP was the ease of use by the SMEs (Saaty, 2006; Varma et al., 2008). A third reason Varma et al. (2008) stated for using AHP was its ability to determine the relative importance of criteria, which was significant in this regulatory compliance risk management study. Varma et al. noted that the accuracy and the handling of dynamic situations with AHP might improve by defining more levels in the hierarchy; however, this would be at the cost of simplicity. The management of a large number of criteria and alternatives for complex systems can become cumbersome. The use of available AHP software packages makes this cumbersome process less labor intensive (Jayant, Gupta, & Garg, 2011). These relative complex decision-making models using the AHP still provided a decision framework with flexibility and systematic design.

The selection of the best suppliers involves tangible and intangible criteria. These criteria make the AHP a suitable framework for the selection or the ranking of vendors (Bindu & Ahuja, 2010; Kaur et al., 2010; Yücenur, Vayvay, & Demirel, 2011). Kaur et al. (2010) stated the primary reason for selecting the AHP in ranking of suppliers was its capability to measure the consistency of the pairwise decisions of SMEs. Pochampally and Gupta (2008) used the AHP for a supply chain study. Pochampally and Gupta identified seven criteria for selecting the AHP for their study: (a) ability to provide a realistic description of the problem, (b) possibility to do group decision-making, (c) ability to structure the decision-making process, (d) ability to define relative weights of criteria, (e) ability to analyze alternatives, (f) easy to understand, and (g) applicability of the decision-making process.

For the management of supply chain risks in the pharmaceutical industry, Asamoah, Annan, and Nyarko (2012) used the AHP to identify superior risk mitigation strategies. The study by Asamoah et al. is helpful to pharmaceutical executives in selecting the appropriate measures for the management of supply chain risks. The application of the AHP was successful to aspects of supply chain management (Asamoah et al., 2012; Bindu & Ahuja, 2010; Kaur et al., 2010; Varma et al., 2008; Yücenur et al., 2011). Project managers can use the AHP with confidence in supply chain management.

The AHP application in construction. Construction project managers tend to base their risk assessments on experience or qualitative assessments, and that can lead to project failure. The literature clearly indicate that the AHP is an acceptable model for managing risk in new construction projects (Abdelgawad & Fayek, 2010; Aminbakhsh, Gunduz, & Sonmez, 2013; Cebi, 2011; Nandi, Paul, & Phadtare, 2011; Podvezko et al., 2010). Project managers in construction management used AHP where personal judgment is subjective and nonlinear (Nandi et al., 2011). Nandi et al. (2011) used the

AHP to identify and select the best construction project. Aydin and Kahraman (2010), Cheng, Ma, and Sun (2012), Kargi and Ozturk (2012), and Podvezko et al. used the AHP to select and manage the risk in selecting contractors. For supplier selection, Ho, Xu, and Dey (2010) identified metrics of 101 criteria and used the AHP to help with the multicriteria decision-making process. Cebi (2011) used AHP in a housing construction project to identify the risk likelihood and severity of project risk. Aydin and Arslan (2010) also used AHP to determine the best site for a new hospital. Betrie, Sadiq, Morin, and Tesfamariam (2013), as well as Deepa and Krishnaveni (2012), selected remedial alternatives for industrial and mining sites. Aydin and Arslan (2010) selected the AHP for its simplicity and flexibility. Aydin and Arslan found that if the researcher improves on the criteria selection and increases the number of alternatives, then the accuracy of the AHP outcome would improve.

Ramanathan and Ramanathan (2010) used the AHP to prioritize qualitative criteria in the equipment selection process of a construction project. The AHP was helpful for structuring the decision-making process, providing a systematic framework, and applying the method to quantify soft intuitive criteria. Ramanathan and Ramanathan applied the soft intuitive principles with quantitative criteria in the decision-making process. In a complex situation like the oil sands, decision makers do not depend on intuition or pure logic but rather on systematic MCDM (Saaty & Zoffer, 2012; Tavana & Hatami-Marbini, 2011; Vidal, Marle & Bocquet, 2013).

Nandi et al. (2011), as well as Zou and Li (2010), promoted the use of the AHP in construction projects to provide a logical and rational project assessment method. Nandi et al. suggested that avoiding rank reversal, which a potential problem found in AHP applications (Maleki & Zahir, 2012), is possible by including all criteria, even those that have a very low weight factor. The method of measurement and the assumption of independence are the two main causes of rank reversal (Zhu, Cooper, & Yang, 2012). Decision makers can avoid the rank reversal by adhering to consistent judgments and ensuring independence of all elements. Shin and Lee (2013) avoided rank reversal with the use of the least squares method to drive the priority vectors of alternatives. However, Zhu et al. (2012) proposed to use the weighted geometric mean aggregation rule as the primary aggregation rule to avoid rank reversal. Despite the potential issue of rank reversal, Aydin and Arslan (2010), as well as Podvezko et al. (2010) concluded that a decision-making methodology such as AHP is useful for avoiding subjective decision-making and is easy to interpret.

The AHP application in project management. Risks, such as, technical, financial, environmental, and commercial influence engineering and construction projects. Some of these risks are uncertain and difficult to control (Jaskowski & Biruk, 2011). Jaskowski and Biruk (2011) developed a risk model and used AHP to evaluate and rank risks. Using the AHP was helpful to project managers to improve the project scheduling and evaluation of risk mitigation strategies.

Again, the AHP allowed the decision maker to combine quantitative risk data with subjective risks such as human error and environmental issues. Labib (2011) compared the results from AHP with those of fuzzy logic using linguistic expression to determine the ranking of suppliers. Labib showed that AHP has similar outcomes and that it is possible to express opinions in the form of linguistics terms. Labib also demonstrated that with the AHP, performing a sensitivity analysis is possible for better understanding of the relationships in the assessment terms. Risks and uncertainty in construction projects are high contributors to failure (Abdelgawad & Fayek, 2010; Zou & Li, 2010). Abdelgawad and Fayek (2010) combined AHP with the failure mode and effect analysis (FMEA) to solve the multicriteria decision-making problem in construction risk management. FMEA is just another technique to help identify risks for a project compared to data analysis or brainstorming or SWOT analysis. Amiri (2010) used AHP in oil field project selection. Amiri (2010) identified technical and financial criteria for oil field project selection. Amiri then used the AHP to calculate the criteria weights and applied the fuzzy TOPSIS method to determine the final ranking. When using the TOPSIS method, rank reversal may occur. The decision maker should be aware of the possibility of rank reversal when combining AHP with fuzzy TOPSIS. Amiri concluded that project managers could use the AHP with linguistic and technical preferences to make decisions in uncertain situations.

The AHP application in transportation. In the transportation industry, the AHP is widely useful for assessing the feasibility and investment of transportation projects.

The projects include airports, public road works, vulnerability of highway systems, and shipping selection. Some of these applications considered risk and uncertainty with incomplete data (Arabameri, 2014; Kaya, Öztayşi, & Kahraman, 2012; Qin & Yan, 2013; Zietsman, & Vanderschuren, 2014). Yang and Regan (2013) used AHP for determining optimum transportation system operations strategies. Kaya et al. (2012), as well as Qin and Yan (2013) used AHP to rank a transportation system's project risk under uncertainty of the technical, operating, and financial environment. These researchers concluded that the AHP was helpful for ranking multiple transportation and project feasibility criteria. AHP provided a practical solution to a relative complex problem.

The AHP application in maintenance. Maintenance practitioners use the AHP to prioritize maintenance systems (Abu Dabous & Alkass, 2008; Fouladgar, Yazdani-Chamzini, Lashgari, Zavadskas, & Turskis, 2012; Shafiq, 2010). Van Horenbeek and Pintelon (2013) used the analytical hierarchy network for prioritizing the maintenance performance indicators, a significant assistance to maintenance managers responsible for setting priorities. Abu Dabous and Alkass (2008) used the AHP as a MCDM process in bridge maintenance management. AHP is facilitative in (a) enabling engineers to use their experience in the pairwise judgment, (b) allowing for refinement and additions of constraints, (c) providing for the measurement of consistency in judgments, and (d) it is not a black box decision support tool. Abu Dabous and Alkass applied the AHP for maintenance, safety, and integrity management. Shafiq (2010) successfully used AHP and inputs from SMEs to identify the highest risks of pipeline maintenance.

Future AHP development. The AHP is still developing, and decision makers use it for diverse types of applications. Saaty (2006) identified 15 areas of development. The four areas of interest to this study are (a) investigating the size of the hierarchy, (b) applying continuous judgments, (c) developing group participation guidelines, (d) and defining an explicit theory of using scenarios in risk analysis.

Theory of AHP

Like any other theories, AHP stems from several axioms (Forman & Gass, 2001). The first axiom is the reciprocal axiom, meaning that if criterion A is four times larger than criterion B, then criterion B is equal to a quarter of criterion A. The second axiom is the homogeneity axiom, meaning that the criteria or subcriteria compared should be less than one order apart to avoid large errors in judgments. The last axiom is the concept of hierarchy composition, indicating that the criteria or subcriteria do not depend on the lower level criteria. This axiom promotes a bottom-up approach for determining weights through pairwise comparisons.

The AHP might give incorrect answers if the decision maker did not adhere to the two overriding criteria of the AHP: (a) definition of the hierarchical structure and (b) definition of the priorities in the structure (Saaty, 2006). To prove a scientific theory, demonstrating that the theory would give the correct answers to a known problem with a known answer should be possible. Saaty (2006) examined the compatibility index to measure the closeness of priority vectors to demonstrate the validity of the AHP. However, Garuti and Salomon (2011) stated that with MCDM, getting different priority vectors that may be close is possible. How close is measurable with Saaty's compatibility index S. The different priority vectors result from participants in the AHP providing different judgments (Bana e Costa & Vansnick, 2008; Garuti & Salomon, 2011). These differences in judgments are measurable with a second index, the consistency index, CI (Saaty, 2006). To avoid these potential issues, the decision maker has to monitor these two indexes to ensure a valid solution to the problem.

Prioritization method. The AHP has its analytical foundation in the mathematical structure of consistent matrices and the determination of weights using the matrices associated right eigenvector (Lipovetsky, 2010; Saaty, 2010). The eigenvector (relative weight) of the matrix indicates the priority order, and the eigenvalue is an indication of the consistency of decisions by decision makers (Lipovetsky, 2010; Saaty, 2010). Alternatives to the eigenvector method Saaty used are the logarithmic least square method, the geometric mean method, the weighted least square (WLS) method, and the logarithmic goal programming method (Zakaria, Dahlan, & Hussin, 2012).

Wang and Chin (2011) also addressed some of the concerns with the eigenvector by defining an alternative approach called the linear programming approximation. Lipovetsky (2011) showed that a solution for the eigenvector is possible using the least squares method. Barfod and Leleur (2011) proposed the replacement of the eigenvector with the geometric mean method to avoid potential rank reversal. Researchers used all these derivatives in their quest to get better optimization. Mattioli and Lamonica (2011) reviewed multiple prioritizing methods, including eigenvalue method, modified dominant eigenvalue method, direct least squares method, weighted least squares method, and logarithmic least squares method. Mattioli and Lamonica (2011) found close concordance among these methods using real data in their comparisons. For this study, I followed the Saaty eigenvector approach with caution and awareness of possible inconsistencies as Kazibudzki (2013) highlighted in the study.

Consistency. The AHP is a process to obtain information from SMEs or decision makers in a structured manner (Saaty & Vargas, 2013a). The process may include precise measurements or measurements according to perceptions. The judgments made using a ratio scale provide a judgment matrix that is consistent (Saaty, 2008). According to Stoklasa et al. (2013), achieving consistency is not possible for a large number of decision-making criteria. Decision makers can minimize these criteria with the use of a hierarchy, which allows a two- or three-step judgment process. Wang, Luo, and Xu (2013) avoided inconsistency with the use of a cross-weight technique.

The AHP is also useful for the testing of consistency of the judgment matrix. With consistency, the inconsistency in the response of the SMEs is measurable. Decision makers can calculate the consistency ratio (CR) as the ratio of the consistency index (CI) to the random index (Chen, Chen, & Chen, 2010). A consistency ratio of less than 0.1 is acceptable according to Saaty (2006). If the CR is greater than 0.1, decision makers need a refinement of the judgment metric (pairwise metric; see section on research methodology). The CR is only acceptable with aggregated weights of criteria to determine the final priorities of the alternative strategies or solutions to the goal.

The AHP pairwise scale. The AHP has three stages: decomposition, measurement of preferences, and synthesis or fusion. It is a form of structured complexity. To keep it uncomplicated, decision makers need to break the problem into a hierarchal structure with levels of homogeneous criteria. The highest level of the hierarchy defines the goal or the problem (e.g., in choosing the best house to buy). Each of the following level shows a definition of a cluster or unique criterion of the higher level. The natural, lowest level is the level of explicit measurement (the attributes). The attributes may be the third or fourth level used to rank the alternative options (alternative houses available to buy); a pairwise comparison with the scale of 1 to 9 is the scale Saaty (2006) preferred to use. Saaty provided the rationale for using a discrete scale of 1 to 9 based on the work of psychologist George Miller in the 1950s. Miller determined that individuals could not simultaneously distinguish between too many alternatives, about seven alternatives, to maintain consistency (Saaty, 2006). Most AHP practitioners use the fundamental scale Saaty proposed, where 1 represents equal importance and 9 represents an extreme level of importance (see Table 2).

Table 2

AHP Pairwise Scale

Intensity	Definition	Explanation
1	Equal importance of criteria	Two criteria contribute equally to the property
2	Weak	
3	Moderate importance of one criterion over another	Experience and judgment slightly favor one criterion over another
4	Moderate plus	
5	Essential or strong importance of one criterion over another	Experience and judgment strongly favor one criterion over another
6	Strong plus	
7	Very strong or demonstrated importance of one criterion over another	A criterion is very strongly favored, and its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme importance of one criterion over another	The evidence favoring one criterion over another is of the highest possible order of affirmation
Reciprocals	If activity *A* has one of the preceding numbers assigned to it when compared with activity *B*, then *B* has the reciprocal value when compared with *A*	

Note. Adopted from "Fundamentals of decision-making and priority theory with the analytical hierarchy process" by T. L. Saaty, 2006, *Vol. VI of the AHP Series*, p. 73. Pittsburgh, PA: RWS Publications. Reprinted with permission from the author.

AHP summary. AHP, as a decision-making methodology, is gaining popularity ever since Saaty introduced it as a decision-making process. Sipahi and Timor (2011) did a literature review of the AHP application in the period 2005 to 2009. Sipahi and Timor reviewed and included more than 232 application articles from academic journals in the study. Most applications were in manufacturing, followed by environmental management, agriculture industry, power and energy industry, transportation industry, construction industry, and healthcare. In the manufacturing industry, the selection of machine tools may be a complex decision-making problem with the increasing number of alternatives available.

In summary, the AHP is facilitative of defining a complex problem in terms of criteria and subcriteria, using a top-down analysis for a bottom-up generation of the relative importance using a pairwise comparison. Zakaria, Dahlan, & Hussin (2010) reviewed the possible inconsistency in results using AHP as one of the primary critiques against AHP. Others have expressed concerns with non-evolutionary computing approach and the prioritization method (Mattioli & Lamonica, 2011). However, researchers found they could address these inconsistency problems with the definition of an inconsistency index. Dong and Saaty calculated the inconsistency index to confirm the reliability of comparisons (Dong et al., 2010; Saaty, 2006).

The outcome of the AHP is a measurement model that decision makers can use for the evaluation of possible solutions or alternatives. Forman and Gass (2001) summarized the AHP and defined three basic functions: (a) structuring complexity, (b) measuring on a ratio scale, and (c) synthesizing to allow the identification of a preferred solution. Tsyganok (2011) identified the need for future development in the definition of measurement stability, with a focus on ranking stability and estimating stability.

Transition and Summary

In Section 1, I identified the need for risk management of environmental regulatory compliance of oil sands projects in Alberta and defined the research problem. In this quantitative, descriptive study, I proposed to do an archival database search and literature research to identify potential environmental compliance risks and mitigation strategies. I used two instruments to obtain input from SMEs.

In this study, I used the AHP to analyze the pairwise comparison data from the specialized survey and determine the ranking of risks and mitigation strategies. The literature review provided background on the oil sands in Alberta and identified the continuous regulatory change and the possible adverse impact of oil sands developments to the environment. The literature review provided an overview of the history, theory, and application of AHP in the research.

The primary objective for this study in risk management was the ranking of the key environmental regulatory compliance criteria and the ranking of mitigation strategies. The hierarchy of environmental compliance risks and the ranking of mitigation strategies would help engineers and oil company executives to ensure future environmental regulatory compliance of oil sands projects.

Section 2: The Project

This section presents the research design and the role of the researcher. I also discuss the analytical hierararchy process (AHP) decision model used for ranking the environmental regulatory compliance risks and mitigation strategies of *in situ* oil sands projects in Alberta. This section includes the process for validating the assumptions required for the AHP. It also contains the initial survey instrument and data collection process, as well as the mathematical analysis of the data using the AHP software.

My project was conducted in several steps. I used a group of five SMEs in a pilot survey to assess the risk ranking and mitigation strategy ranking as part of instrument validation. I administered the final survey instrument to the larger sample of 15 SMEs. The results of the study would be helpful to project engineers and executives to have a better understanding of the ranking of each risk and mitigation strategy. The risk and mitigation ranking would enable project managers to improve the management of the regulatory compliance of oil sands projects in Alberta. I chose oil company executives who managed the key environmental regulatory risks of their businesses because they contribute to compliance and sustainability of oil sands projects (Ayyub et al., 2010). More informed managers and engineers of sustainable oil sands projects help to protect the environment and communities living in the oil sands region.

Purpose Statement

The purpose of this quantitative, descriptive study was to identify the environmental compliance risks and associated mitigation strategies for oil sands projects in Alberta, Canada. I also assessed the contributions these risks and mitigation strategies make to regulatory compliance of *in situ* oil sands projects in Alberta. In 2005, the Alberta government identified the key regulatory compliance criteria that contribute to environmental compliance. These criteria include technical, economic, financial, environmental, and regulatory criteria (Alberta Government, 2010). I grouped the lists of risks and mitigations in a three-level hierarchy using the key compliance criteria as the major groups. This research process is diagrammed in Figure 1.

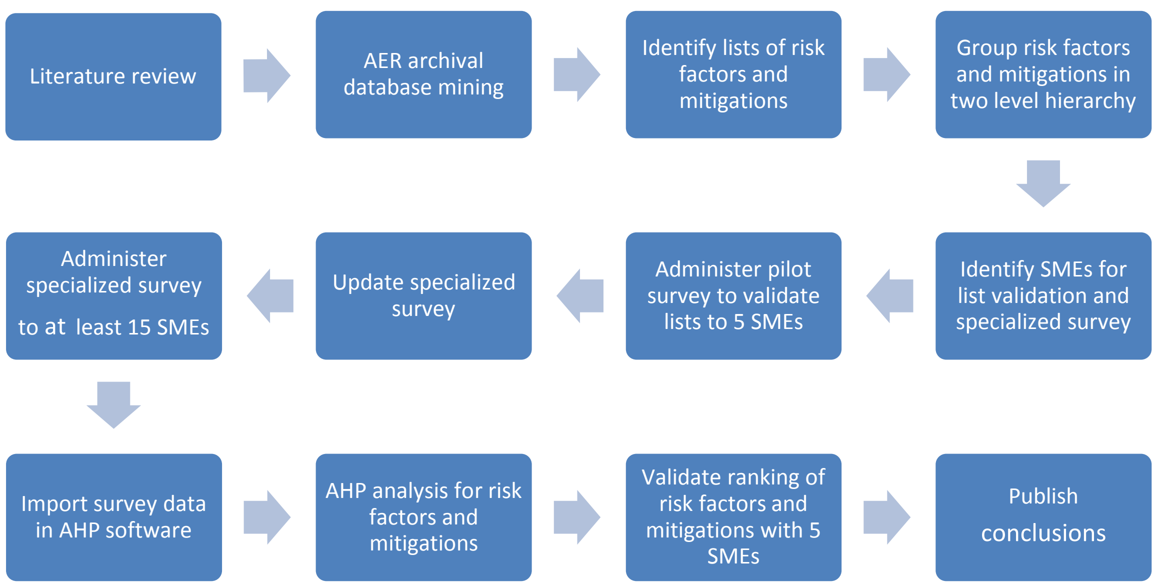


Figure 1. Schematic of the research process.

I used two survey instruments to collect data from industry business leaders. The first instrument was a pilot survey administered to five SMEs to validate the lists of risks and mitigation strategies grouped with the five key compliance criteria the Alberta government identified. Next, I updated the lists of risks and mitigation strategies to create a pairwise comparison-specialized survey divided into three parts. Part 1 collected participants' demographic information. Part 2 consisted of a pairwise comparison of risks and mitigation strategies based on the adjusted list of risks. Part 3 consisted of a pairwise comparison of risks and mitigation strategies created using the pilot survey. I administered the pairwise comparison-specialized survey to at least 15 senior executives and project engineers of *in situ* oil sands companies active in Alberta, Canada. I then imported the pairwise comparison matrices for Parts 2 and 3 into the AHP software.

The research design methodology selected for this study follows some of the principles Cooper and Schindler (2013) identified in business research. I used a commercial AHP software package, SuperDecisions, that was suitable for applying the AHP method (Saaty, 2003). I used SuperDecisions to determine the ranking of risks and mitigations. Finally, I reviewed the outcome of ranking risks and mitigation strategies with a small group of oil executives and project engineers, who indicated their acceptance of the final rankings.

The principles I considered for this study are as follows: (a) method of data collection, (b) the purpose of the research, (c) the scope of research, and (d) the researcher's perception of the research problem (Cooper & Schindler, 2013). The application of these principles resulted in the research process (see Figure 1). My desire was to identify those environmental compliance criteria and mitigation strategies that could contribute to the success of Alberta *in situ* oil sands projects without detrimental effects on the environment. I was not directly involved with or responsible for the environmental compliance of an *in situ* oil sands company and did stand to benefit directly from the findings; however, this study could have significant influence on the future risk strategy of oil sands projects in Alberta, Canada.

Role of the Researcher

As the researcher in this study, I first identified risks and mitigation strategies usingAlberta Energy Regulator (AER) archival data and literature. I personally administered both the pilot and the specialized survey and analyzed the data following the AHP, and identified and invited SMEs from oil companies in Alberta to participate. I also verified the validation and reliability of the survey and the interpretation of the outcome of the AHP. I had a particular interest in decision-making theory and environmental risk management, but was not employed by an oil sands company. However, my research was informed by my working as an engineering consultant in the oil and gas industry in Alberta since 2003.

Participants

For the AHP list validation phase, I invited five Alberta SMEs from either the Oil Sands Developers Group (OSDG) or the Canadian Oil Producers Association (CAPP) to validate the list of risks and mitigation strategies identified in the AER database mining. In the subsequent pairwise comparison-specialized survey, I used a purposive sample method and invited 52 Alberta SMEs from the OSDG and CAPP to participate in the pairwise comparison survey. I also invited a second group of five Alberta SMEs from the frame to participate in the triangulation of the ranks for risks and mitigations.

These participants were all drawn from locally registered oil sands companies. Alberta has about 40 registered oil sands companies. I invited at least one representative (an SME) from each oil sands company to participate in the pairwise comparison-specialized survey. I also invited SMEs that I had access to through personal and professional relationships. Only executives and senior project engineers working for oil companies with in situ oil sands projects in Alberta participated in the study. Inviting participants working on international projects would have had no benefit because these projects outside Canada were not subject to the Alberta environmental and regulatory requirements.

I deliberately invited executives, managers, and engineers with an influence on their respective oil company's environmental policies, compliance strategy, and risk management to participate in the study. Compliance with regulatory requirements in Canada is the responsibility of a company's board of directors, executives, senior managers, project engineers, and environmental officers. Under Canadian Federal law, company executives are personally accountable and liable in case of an environmental disaster (Torys, 2009). I ensured the confidentiality of participants as follows; I did not link individual names, company names, and email addresses to the survey and data.

Research Method and Design

I used an analytic MCDM decision model that employs the AHP technique to conduct this quantitative descriptive study. I first identified the environmental compliance risks and mitigation strategies documented in the literature and the AER archival database. The AER keeps a database of all reports filed for regulatory compliance of oil sands projects (ERCB, 2008). The reports were self-disclosure; project engineers and project managers identified all regulatory compliance issues and reported to the AER. The database also included regulatory compliance reports (from the AER) of investigations of compliance problems the AER inspectors identified on in situ oil sands projects (ERCB, 2010). Figure Error***! No text of specified style in document.****2* shows the research design.

I used five SMEs for the pilot survey selected from members of CAPP or OSDG, at least 15 SMEs in the specialized survey, and a second group of five SMEs for triangulation of the final rankings. I collected one specialized survey per oil sands company, with the exception of two companies from which two SMEs participated to check for inter rater reliability. The purposive sample of project engineers and company executives provided the best possible data since these engineers and executives were directly responsible for the risk management process during project planning and implementation.

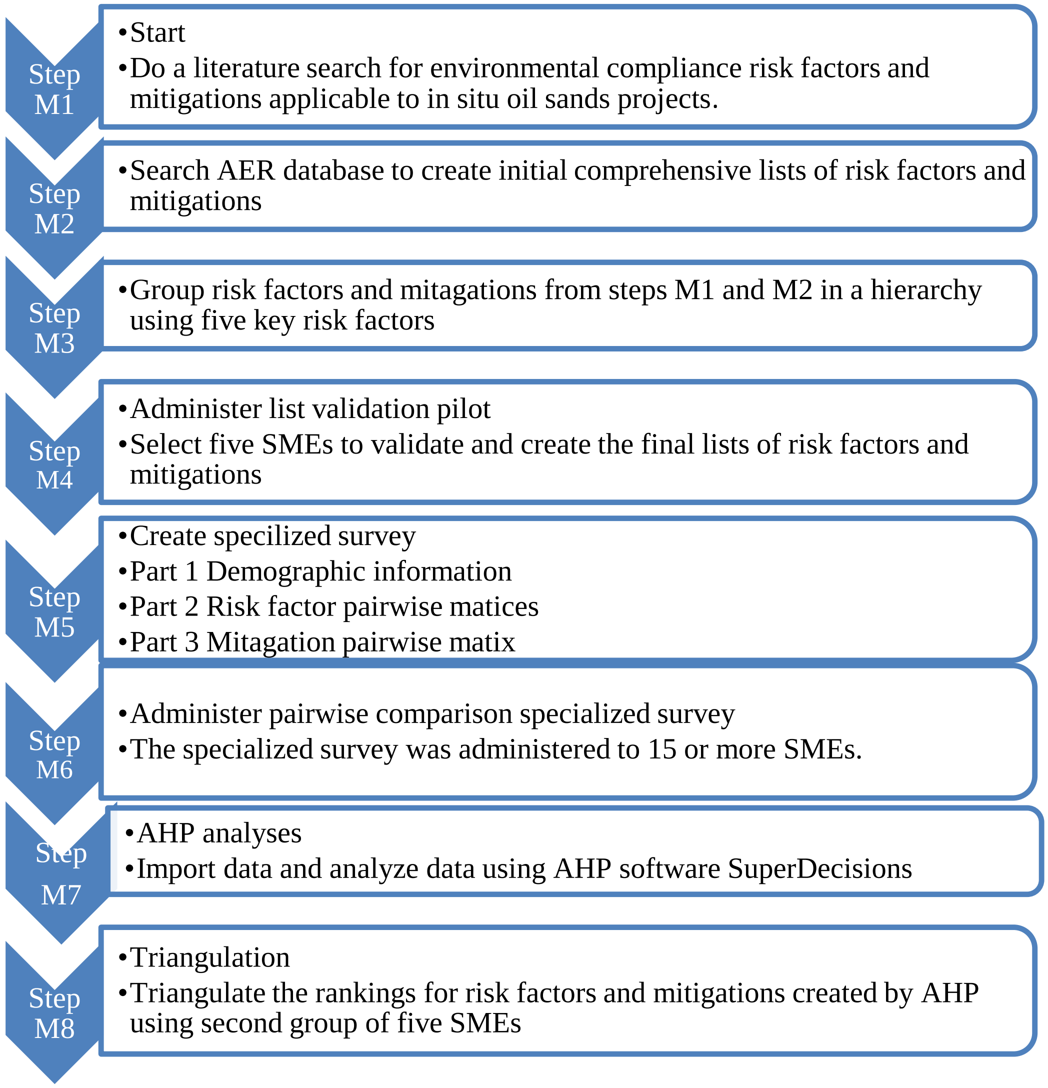


Figure ***Error! No text of specified style in document.****2*. Flow chart for the research design.

Method

Once the pairwise comparison data became available, I prioritized risks and mitigation strategies related to environmental regulatory compliance of in situ oil sands projects. I used the AHP, in accordance with the technical details Saaty (2006) defined, and implemented in the software SuperDecisions. The use of a quantitative method such as the Delphi technique may also be helpful to the researcher to identify and provide a spectrum of the key risks and mitigation strategies. However, the Delphi technique is tedious. If I identified multiple risks, then the Delphi technique would require multiple surveys (Yeung et al., 2012). Multiple surveys could be too time-consuming and could have discouraged executives to participate. Contrary to the effects of the Delphi technique, the AHP indicates the avoidance of injecting researcher subjectivity that may skew the outcome and final rankings of environmental compliance risks and mitigation strategies. The use of exploratory factor analysis (EFA) as a qualitative research method was also possible. However, this method required a large number of participants to prepare for a statistical valid analysis of a set of observed variables, and this study had a relative small sample of SMEs available.

The AHP was an appropriate method, as its practitioners could implement a systems approach to the problem and for a quantitative ranking of qualitative information. The AHP was a framework that was helpful for explaining the problem or goal as a system with a hierarchy (Saaty, 2006). The AHP was also facilitative of a systematic organization of the problem into smaller parts, to the point of pairwise comparison at the level of basic reasoning. The AHP practitioner could explicitly define the problem while working with smaller parts of a bigger problem. With the AHP, the practitioner could control the smaller parts of the problem better and be more thorough in the definition of the problem. The decision maker could use pairwise comparisons in the

AHP to define ratio scales at each level of the hierarchy. The pairwise comparisons could allow for comparisons based on intuition. Pairwise comparison could also provide a methodology to convert qualitative and quantitative data to comparable mathematic values (Saaty, 2006).

With my decision to use a pairwise comparison, specialized survey to obtain data for an analytical MCDM process (e.g., AHP), I was able to analyze and rank the environmental compliance risks and mitigation strategies. I derived a conclusion on the ranking of risks and mitigation strategies using a quantitative process. The AHP technique depends on inputs from a group of SMEs. Group decision-making supported Cooper and Schindler’s principle of reliable data and the involvement of participants in the research activity (Cooper & Schindler, 2013). With the involvement of SMEs in the process, reviewing the interrater reliability was possible by recruiting more than one SME from two oil sands companies.

Relative measurement. Saaty (2006) demonstrated in his work the potential of the AHP, which is useful to practitioners to quantify emotional criteria in a decision-making problem. Saaty (2006) used a ratio scale (RC) to measure the criteria that comprise the hierarchy. Scale of attributes may be measurable in physical dimensions or relative scales based on the importance of one objective to another (Saaty, 2011). With a normalized scale, practitioners could convert qualitative information to quantitative values. Saaty (2006) and Saaty and Vargas (2013b) proposed a 9-point scale. Yetim (2013) stated the 9-point scale works best if the number of criteria is less than seven. The

AHP includes the use of various scales (Kusherbaeva, Sushkov, & Tamazian, 2011b), and the most acceptable are the Saaty scale. The transformation process from verbal to the numerical scale still depends on the subjectivity of the individual decision maker (Ishizaka, Balkenborg, & Kaplan, 2011a; 2011b.)—another reason why a group of SME decision makers will stabilize this possibility. The transformation process is helpful for transforming a qualitative criterion into a quantitative criterion comparable to other quantitative criteria. I used the proposed 9-point scale in this study.

AHP is easy to use. The AHP originated in mathematical axioms (Forman & Gass, 2001), but a relatively easy methodology to use (Saaty, 2006). Cooper and Schindler (2013) identified the AHP as a research design concept. Academia, strategists, scientists, engineers, governments, health service professionals, and corporate decision makers, without the necessity of lengthy training, use the AHP (Saaty, 2006). Decision makers find it easy to use. The defined measurement scales are relative to the problem and are suitable for addressing and providing a solution to the problem (Saaty, 2006).

AHP and uncertainty. The literature indicated a debate regarding the difficulty of handling uncertainty in the decision process and the ability of the AHP to manage uncertainty (Tseng, 2010). Tseng stated that the scale of 1 to 9 Saaty proposed is an ineffective way of defining or capturing uncertainty. Practitioners revert to fuzzy-AHP to compensate for uncertainty in criteria associated with the decision-making process (Cozannet, Garcin, Bulteau, Mirgon, Yates, Méndez, ... & Oliveros, 2013; Toth, Wolfslehner, & Vacik, 2014; Wang, Chan, Yee, & Diaz-Rainey, 2012; Wang, Wu, & Lin, 2012)

Uncertainty is a function of the data used, and in this study, I retrieved the data from the AER database and used a survey to acquire inputs from SMEs. The risk with the highest possible uncertainty in this study is the possible change in environmental regulations during the project life cycle that decision makers did not anticipate. Those environmental risks that relate to qualitative data may cause an uncertainty as some researchers reported (Cozannet, et al. 2013). With the pairwise comparison for subjective and qualitative criteria, the decision maker finds it difficult to determine the exact value (Cozannet, et al. 2013). Researchers and decision makers can overcome this uncertainty with inputs from a large group of SMEs and review the consistency of the decision. One of the advantages of the AHP is the possibility to change qualitative data to quantitative values on a scale of 1 to 9. If a practitioner needs to prioritize a large group of criteria or criteria using pairwise comparison, the task may become complex along with a cognitive problem for the decision maker that creates consistency problems (Saaty, 2006). For this reason, reviewing the criteria and identifying subcriteria or an intermediate level supporting the criteria, and the goal are essential. As recommended by Yetim (2013), defining subcriteria would also ensure the level has not more than seven criteria.

Rationality in AHP. Saaty (2006) described the decision-making process as a method within the context of a system with interacting elements (also called *factors* or *criteria*). Each element has causes and effects influential to the system’s behavior, which is difficult for the decision maker to comprehend. Saaty defined five principles for a decision-making process:

- simple in design,
- suitable for individual or group decision-making,
- natural to the decision makers' intuition and conventional thinking,
- able to promote consensus and compromise, and
- easy to learn and understand.

Meeting the criteria is possible for an MCDM process or framework that Saaty (2006) envisaged if the decision maker defines a problem or goal in a systematic way. A hierarchy is complete if the decision maker evaluates elements at one level in terms of all the elements at the next higher level. In a hierarchy, developing some elements or criteria to the next lower level is possible in the process to provide more attention or gain a level with measurable attributes (Saaty, 2006). The AHP is facilitative of defining a complex problem in terms of criteria and subcriteria. The decision maker follows a top-down analysis when all the alternatives are unknown and a bottom-up process when the alternatives are identifiable. The objective is to choose the best alternative.

Hierarchies and hierarchy synthesis. A fundamental problem will have at least three levels: the problem or goal (level 0), the objectives or criteria (Level 1), and the alternatives (alt.). Decision makers may add subfactors or subcriteria (Level 2; Saaty, 2006), as shown in Figure 3. With these levels, the problem will have alternative solutions at the bottom of the hierarchy. The relationships among criteria of the same order and magnitude are essential in creating a hierarchy and in defining the levels. Saaty (2006) stated that an attribute in a lower level must have an association with one or more attributes of the next higher level.

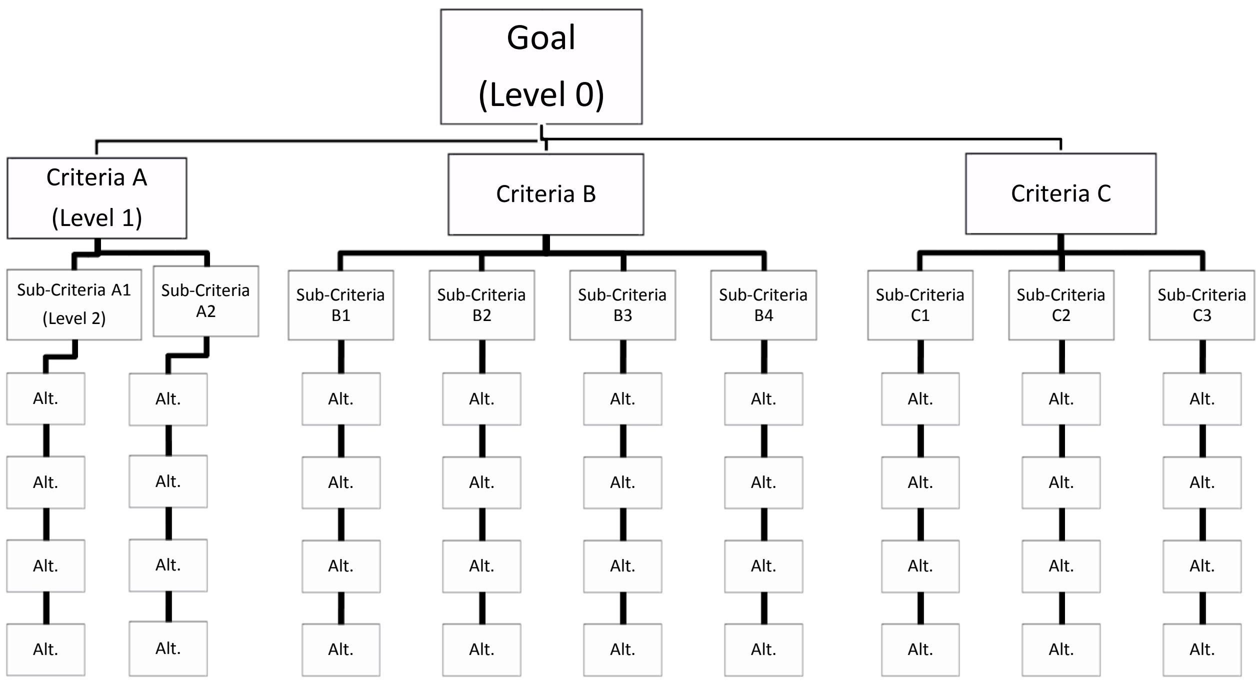


Figure 3. The AHP hierarchy.

Hierarchy description and types of hierarchies. The two types of hierarchies are structural and functional. *Structural hierarchies* apply to the system in terms of criteria of structural or physical properties, such as material, form, size, color, weight, or shape. *Functional hierarchies* refer to the system in terms of its functions rather than physical properties. The functional relationships of a complex system or problem are helpful for steering the system to a common goal or solution to the problem (Saaty, 2006). Functional hierarchies are the backbone of the AHP.

The AHP has two modes: the *distributive mode* and the *ideal mode* (Dolan, 2010). The distributive mode has a focus on determining the ranking of a set of options. The ideal mode has a focus on identifying the best set of opinions. For this study, I used the distributive mode to determine the ranking of risks and mitigation strategies.

The AHP synthesis. The final step in the AHP is *fusion* or *synthesis,* which is a way to calculate the final composite weight for each alternative or to integrate the multiple criteria of a problem to reach a conclusion or decision.

Rank preservation and reversal. The relationships between criteria A, B, and C have consistent transitivity when A is preferred to B, and B is preferred to C. Then A is preferred to C. The AHP allows for inconsistent transitivity relationships. For example, if A is preferred to B, and B is preferred to C, then A may be preferred to C or C may be preferred to A. Researchers have reported inconsistent transitivity relationships (Kusherbaeva, Sushkov, & Tamazian, 2011a; Pecchia, Bath, Pendleton, & Bracale, 2011; Zhang, Zhu, Wu, & Wang, 2010). Ishizaka (2012) stated that the Saaty scale is a non-transitivity scale; therefore, the need to test for transitivity to show the pairwise matrix is consistent.

Research Design

For the study, I did an archival database search and then used two instruments to obtain information from SMEs: a pilot survey and a pairwise comparison survey. The ranking risks and mitigations required input from SMEs. Using a specialized survey and the AHP allowed the SMEs to provide inputs anonymously and a methodology to access the working hypotheses described in Section 1. Hence, I used a *decision analytic design* as applied to MAUT (Estévez et al., 2013; Posavac & Carey, 2007). For a decision analytic design, Posavac and Carey (2007) identified five elements:

1. Identify the decision maker.
2. Identify the issue or issues the decision maker has to address; identify the choices or options the decision maker has to evaluate; identify the relevant dimensions of value, and rank the dimensions in order of importance.
3. Identify the choices or options the decision maker has to evaluate.
4. Identify the relevant dimensions of value.
5. Rank the dimensions in order of importance.

The decision makers play a pivotal role in the decision analytic design; they use their training or experience and guidelines from their organization to make decisions. In this study, the decision makers are the SMEs. The issues they addressed in this research were environmental regulatory compliance of in situ oil sands projects in Alberta. The options I evaluated were the compliance criteria defined in the environmental regulations and the dimensions of value that would minimize the environmental impact of in situ oil sands exploration. The third option was to comply with the minimum values for the specified environmental criteria.

Therefore, the first step in this AHP research design was to identify risks and mitigation strategies reported to the AER and captured in the AER oil sands database. I provided a hierarchy of risks for pairwise comparisons by the SMEs. The first level of the hierarchy consisted of key compliance criteria identified in the Alberta Government Environmental Strategy: (a) technological risks, (b) social risks, (c) financial risks, (d) economic risks, and (e) regulatory compliance risks (Government of Alberta, 2009).

Regulatory compliance consisted of two subgroups: human environmental risks and natural environmental risks (e.g., land use, water quality, water usage, and air quality). I listed the mitigation strategies in the second list for pairwise comparisons by SMEs.

Population and Sampling

In this study, I focused on the application of AHP on a sample of responses obtained from a population of risk management SMEs involved in Alberta in situ oil sands projects. I elected to do this study on the oil sands in Alberta because of the high concentration of in situ oil sands projects in the province. More than 87 oil sands projects in different the stages of execution are in Alberta (Government of Alberta, 2010).

The second reason for selecting Alberta was that I could form the sample frame via direct business contacts. I solicited executives and engineers from the sample frame; they were members of either CAPP or the OSDG. I also examined the purposeful sample frame to ensure the participants (a) took an active involvement in the decision-making and (b) were involved in risk management or environment, health, and safety (EH&S) management. Eligibility depended on the participant’s organizational function and subject knowledge. The knowledge of individual group members in the AHP decision group was the primary concern (Saaty, 2006). Additionally, individual decision makers with subject expertise and experience could provide valid inputs and be representative of the subject matter (Goepel 2011). Therefore, the expert knowledge and experience of the SMEs recruited determined the success of the survey.

I used the purposeful sample frame from Alberta oil sands projects for the two data collection phases. In the pilot phase, I purposefully selected five SMEs to validate the list of risks and mitigation strategies. I worked iteratively with the five prequalified SMEs to validate the lists for the survey (see Table 3).

Table 3

List of SMEs for the Pilot

Title	Name
VP Exploration	Withheld
VP Operations 1	Withheld
VP Operations 2	Withheld
VP Production	Withheld
Director In situ Projects	Withheld

I used the same frame for the second phase (the execution of the pairwise comparison-specialized survey) to select a purposeful sample of at least 15 SMEs. I selected one SME per oil sands organization except for one organization that had two participants. The recommended number of SMEs in a decision-making panel is 15 (Firestone, 2006). Goepel (2011) focused on group decision-making using AHP and suggested using a group of at least five SMEs for AHP. Goepel (2011) and Saaty (2006) concluded the background and experience of the SMEs are more valuable to the success of AHP than the number of SMEs in the decision-making panel.

In this study, I followed the guidelines from Firestone and Goepel. My objective was to recruit a purposeful sample of 15 or more SMEs from the frame. I planned to send an invitation via email to at least 40 participants with a copy of the survey. The pairwise comparison-specialized survey included two sections. The first section gave a brief description of the purpose of the research and an explanation of the research problem. The second section was an Excel spreadsheet, which contained the lists of environmental compliance risks and mitigation strategies and two pairwise matrixes the participant had to complete.

Ethical Research

An objective for my research was to adhere to the highest ethical standards set by Walden University. Therefore, the voluntary participants (SMEs) provided data in accordance with the National Institutes of Health (NIH) Office of Extramural Research and Walden University's Institutional Review Board (IRB) guidelines. Appendices A and B contain the consent form and a letter of cooperation, respectively. After receiving permission from the SMEs, participation in the study was voluntary, and all SMEs had the choice to withdraw at any time without any consequences. Participating in this study had no risk. I asked five SMEs to participate also in a pilot survey and to validate the specialized survey. The benefit to SMEs participation in the study was that of helping to rank environmental compliance risks and mitigation strategies for oil sands projects. Participating in the study entailed no compensation. I will provide an executive summary of the results to all participants after approval of my dissertation and after I have formally graduated.

I collected the data anonymously from the voluntary participants and companies and will keep the data secured by storing them on a CD disk for five years in my home office, as Walden University requires. Subsequently, I shall destroy the data in compliance with Walden University IRB guidelines. I did not collect or analyzed data until I received the formal IRB approval.

Data Collection

Instruments

For the study, I used two instruments. The first instrument was two lists of project risks and mitigation strategies compiled from the literature and AER oil sands database. I validated this list in the pilot phase with five SMEs. I used the validated list to update the specialized survey. The second instrument was a pairwise comparison-specialized survey to obtain data from the SMEs. The specialized survey consisted of three parts.

- Part 1 was about general/demographic information for each participant to fill.
- Part 2 was the pairwise comparison of risks based on the validated list of risks.
- Part 3 was the pairwise comparison of mitigations based on the validated list of mitigations.

Appendix C has the preliminary pairwise comparison-specialized survey. I captured the pairwise comparison for risks and mitigation strategies in pairwise matrices, using an Excel spreadsheet. The participants completed the matrices, which I used to import the data to the AHP software, SuperDecisions. W. J. Adams of Embry Riddle Aeronautic University, Florida and Rozann W. Saaty of Creative Decisions Foundation, Pittsburgh, Pennsylvania developed the SuperDecisions software for the AHP (Saaty, 2003). Alternative software available includes Criterion DecisionPlus, Decision Lens, Expert Choice, JavaAHP, Make-it-Rational, and Select Pro (Kusherbaeva, Sushkov, & Tamazyan, 2011c). Developing an Excel model is also possible for analyzing data. However, I did not consider the Excel option, as the time to develop and validate the Excel model would have been too long. I executed the specialized survey in five steps (see Figure 4).

I received the pairwise comparison survey’s results and conducted the AHP analysis using SuperDecisions. After sending the specialized survey, I sent two follow-up emails. I sent the first email one week after the specialized survey. To those who have not responded, I did send a second email at the end of the second week. The follow-up emails contained the same information as the original invitation. I hoped the personal connection obtained before sending the survey would have helped to increase the response rate from 20–50%. Fifteen or more participants would provide sufficient data to perform the AHP for risk and mitigation strategy rankings (Firestone, 2006; Goepel, 2011).

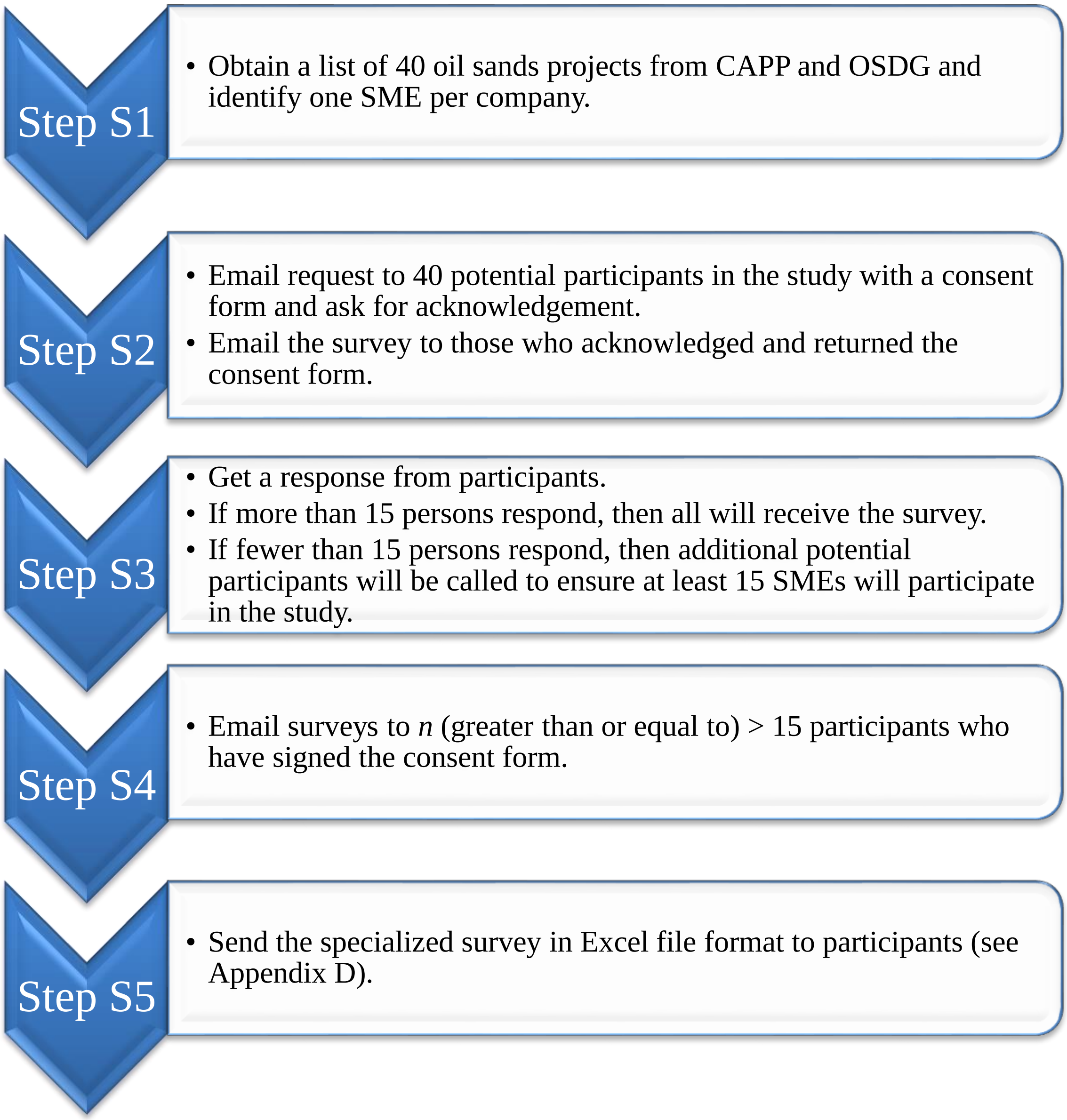


Figure 4. Execution steps for specialized survey.

Data Collection Technique

The data collection consisted of three phases. In Phase 1, I conducted a literature review and data mining to identify the list of risks and mitigation strategies (see Appendix C for a preliminary list). In Phase 2, a pilot phase, I administered the list to a group of five SMEs for validation and calibration. Phase 3 involved establishing the pairwise decision specialized survey that I administered to 15 SMEs (see following for details).

The first phase of my data collection included a literature review and data mining using the AER environmental compliance database. This database contained in situ oil sands environmental compliance reports the oil companies submitted to the AER since 2000. I used this data along with information from the literature review to define a list of environmental compliance risks and a list of mitigation strategies. I used lists of risks and mitigation strategies to define two risk management hierarchies. The pairwise comparison-specialized survey in Appendix C includes risks and mitigation strategies.

In Phase 2, I administered the lists to a group of five SMEs. The objective of this pilot survey was to review the lists of risks and mitigation strategies to ensure their validity and clarity. The pilot survey included a comment field for each risk and the definition of mitigation strategy in the lists. The participants used the comment field to provide recommendations and rewording of risks and mitigation definitions. I analyzed the responses from the validation group and used the updated lists to improve the pairwise decision specialized survey.

In Phase 3, the specialized survey, I administered the use of an Excel spreadsheet to more than 15 SMEs. I followed up to ensure they responded as early as possible. I imported the data received to the AHP software (SuperDecisions) and performed the analysis (see data analysis section for details). The second group of five SMEs validated the rankings of risks and mitigations obtained from the AHP analysis. I used the responses from the five SMEs as input to determine the conclusions of the rankings.

Data Organization Techniques

I maintained a comprehensive research log defining every step of the research, data collection, and schedule of interviews (telephonic recruitment of SMEs). Carcary (2009) recommended a research log, which is facilitative of making a research trail transparent and of improving the data organization. I saved the data from the survey and analysis on a CD-ROM for reference. I will store it for five years and then destroy it afterwards as Walden University IRB guidelines recommended.

Data Analysis Technique

I analyzed the data from the pilot survey and pairwise decision survey using the SuperDecisions AHP software mentioned previously. In the study, I used the AHP for risk management. The following example shows the application of the AHP in defining the rankings of risks for oil sands compliance. The application of AHP consisted of eight steps (see Figure 5). Following is a detailed explanation of each step.

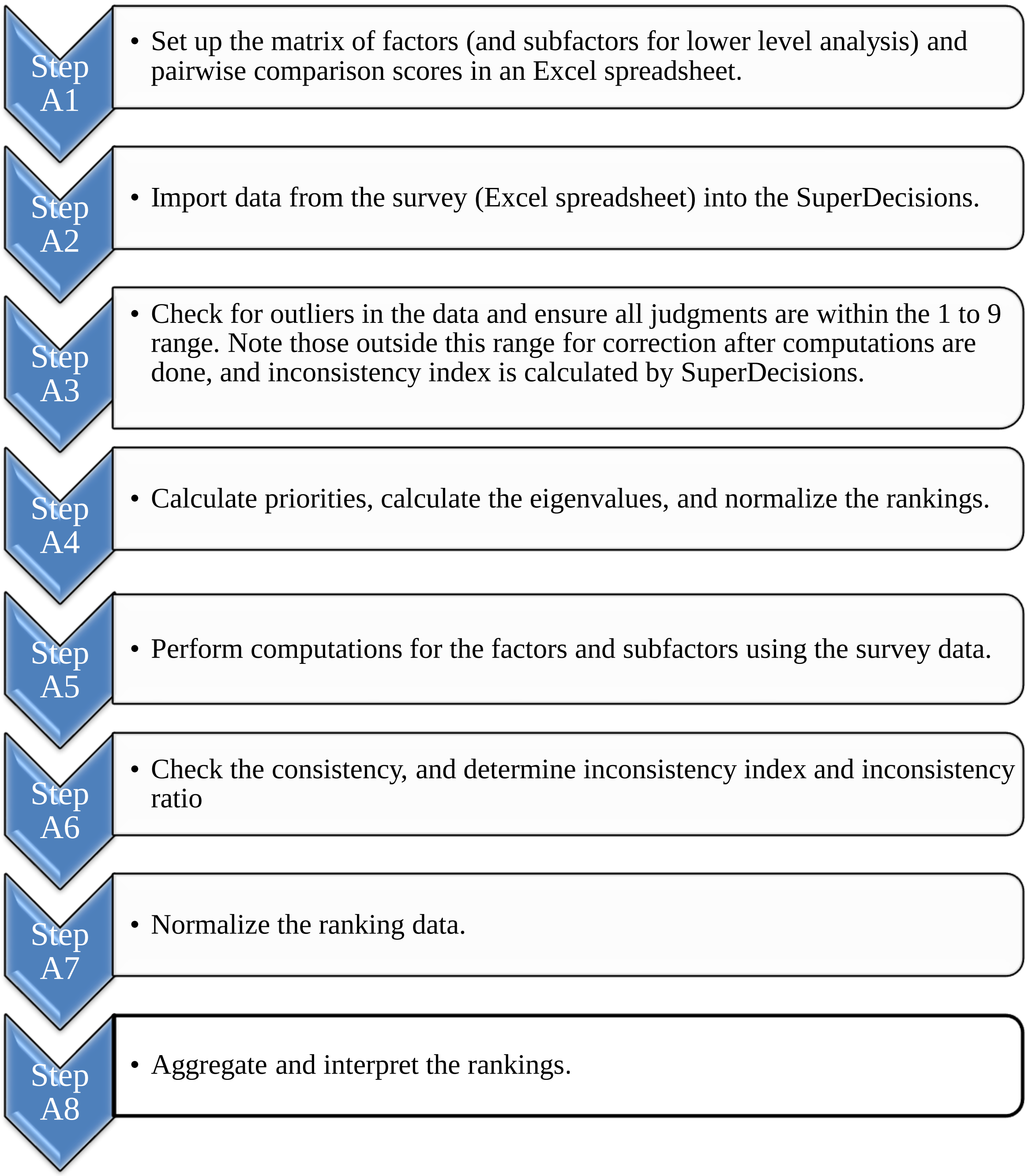


Figure 5. AHP execution steps.

Step A1: Setup the matrix of criteria. The hierarchical structure used by AHP permits users to better focus on specific criteria when doing a pairwise comparison

(Ishizaka & Ashraf Labib, 2009). In this example, I used a hierarchy with dummy data to describe the process and how I applied the software, SuperDecisions, which also defines the hierarchy (see Figure 6).

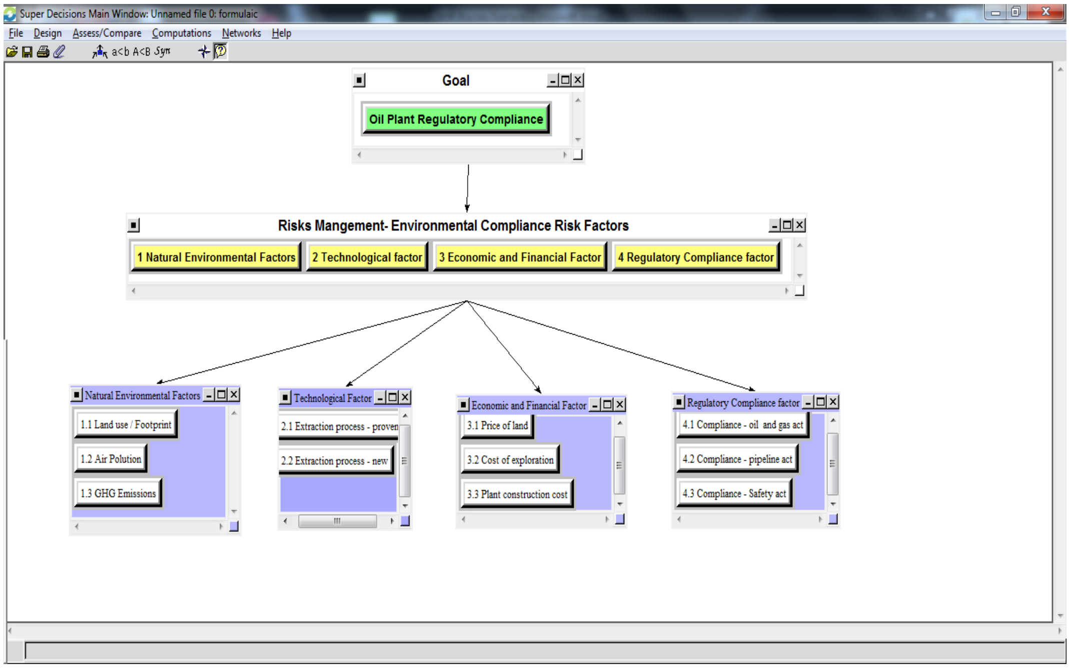


Figure 6. Risk management hierarchy as shown in SuperDecisions.

For this example, I defined the goal and criteria (see Table 4). I obtained the actual data from the survey and imported them to SuperDecisions. The hierarchy includes three levels: goal (Level 0), risk criteria supporting the goal (Level 1), and subcriteria (Level 2) defining or supporting the risk criteria as entered in SuperDecisions. Each level contains one or more criteria.

Table 4

Definition of Dummy Risk Management

Hierarchy	Definition	Definition of criteria
Level 0 Goal	Oil sands regulatory compliance	Identify risks important to managing the regulatory compliance and rank their importance to compliance
Level 1 Risk criteria	Identify risk management compliance risks	1. Economic and financial risk 2. Natural Environmental risk 3. Regulatory compliance risk 4. Technological risk
Level 2 Subcriteria	1. Economic and financial risk	1.1 Cost of exploration 1.2 Plant construction cost 1.3 Price of land
	2. Natural Environmental factor	2.1 Air Pollution 2.2 GHG Emissions 2.3 Land use/Footprint 2.4 Water use
	3. Regulatory compliance risk	3.1 Compliance with pipeline act 3.2 Compliance with oil sand act 3.3 Compliance with Safety Codes Act
	4. Technological risk	4.1 Ongoing Research 4.2 Process, new 4.3 Process, proven

Step A2: Import data from the survey into the software. I imported data from the survey via an Excel spreadsheet in SuperDecisions using the screen (see Figure 7). The SMEs did the pairwise comparisons specialized survey using the Saaty scale to compare the importance of criteria A to criteria B with respect to the goal. The survey used the same judgment scale used in SuperDecisions. This software uses a 9-point rating system or judgment scale (see Table 5). The software also translates the nine levels to a verbal judgment scale using the words equal, moderate, strong, very strong, and extreme (see Table 5). Extreme indicates the highest degree of importance (9 on a scale of 1 to 9), and equal suggests equal degree of importance (1 on a scale of 1 to 9). The pairwise comparisons data came from the survey for the criteria with regard to the goal, as done by the decision maker or SME. Figure 7 shows the input screen for the pairwise comparison imported from the survey.

Table 5

The Fundamental Scale for Making Judgments

Scale	Judgment Description	Judgment
1	Equal importance of criteria	Equal
2	Weak	Low moderate
3	Moderate importance of one criterion over another	Moderate
4	Moderate plus	Moderate plus
5	Essential or strong importance of one criterion over another	Strong
6	Strong plus	Strong plus
7	Very strong or demonstrated importance of one criterion over another	Very strong
8	Very, very strong	Very very strong
9	Extreme importance of one criterion over another	Extreme

Note. Adapted from “Fundamentals of decision-making and priority theory with the analytical hierarchy process” by T. L. Saaty, 2006, *Vol. VI of the AHP Series*, p. 73. Pittsburgh, PA: RWS Publications. Reprint with permission from the author.

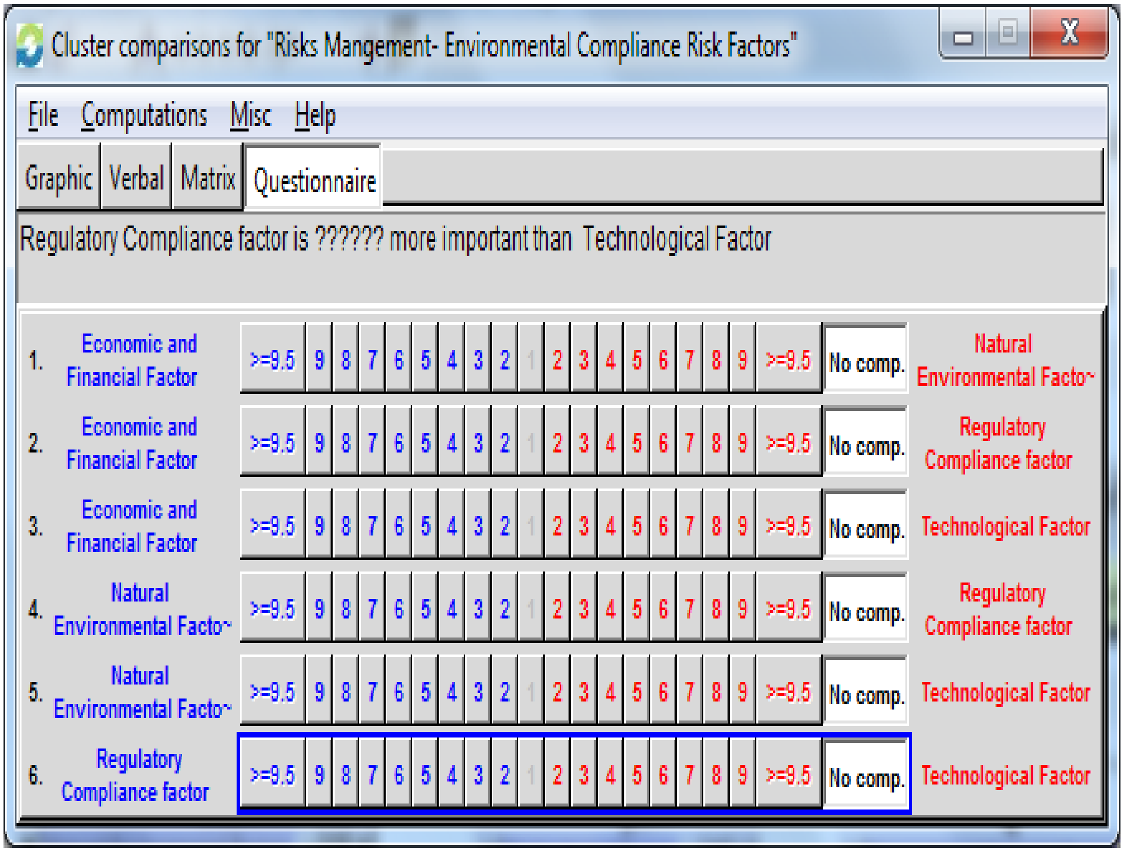


Figure 7. Level 1 pairwise comparisons input by the SME.

Step A3: Check for outliers in the data and consistency. I checked the data from the survey by reviewing the pairwise comparison screens in SuperDecisions for each level (see a typical screen in Figure 8 and Figure 9). Figure 10 shows the pairwise comparison for risks with respect to the goal, and Figure 11 shows the pairwise comparison for the subcriteria with respect to one of the Level 1 risks.

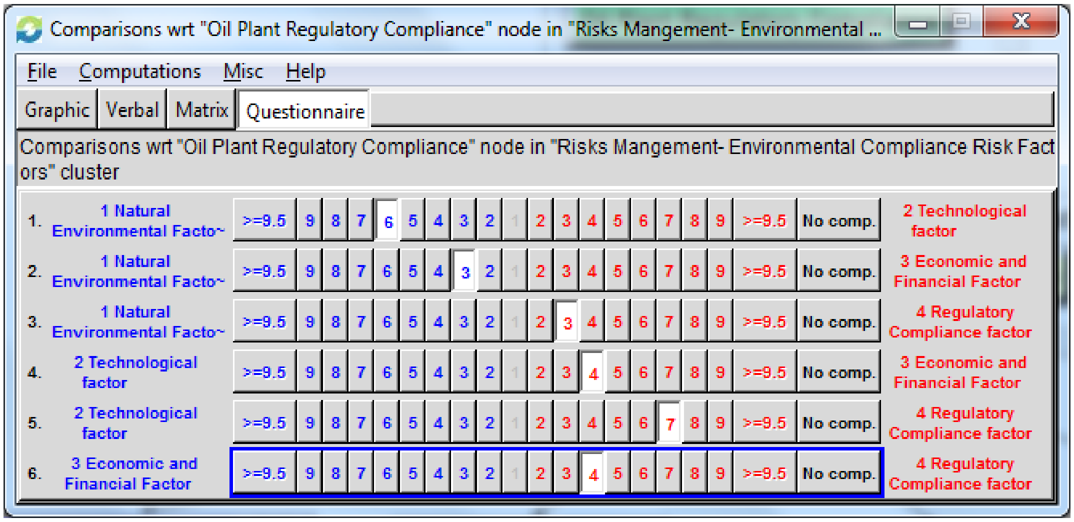


Figure 8. Pairwise comparisons for Level 1, risk management.

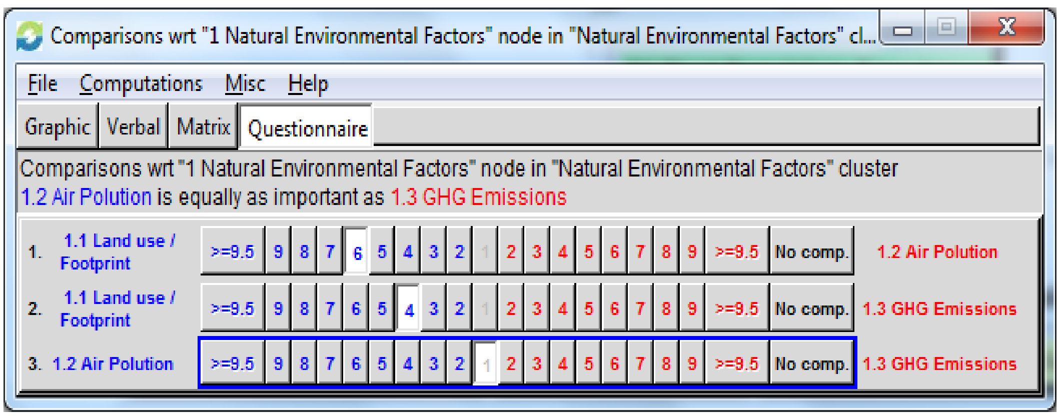


Figure 9. Subcriteria comparisons for Level 2, natural environmental risks.

At each level of the hierarchy, I used a matrix to define the pairwise comparisons of the decision maker (SME), which is an alternative way to look at the comparison in Figure 8 and Figure 9. Figure 10 shows the Level 1 risk matrix and Figure 11 shows the Level 2 subcriteria matrix.

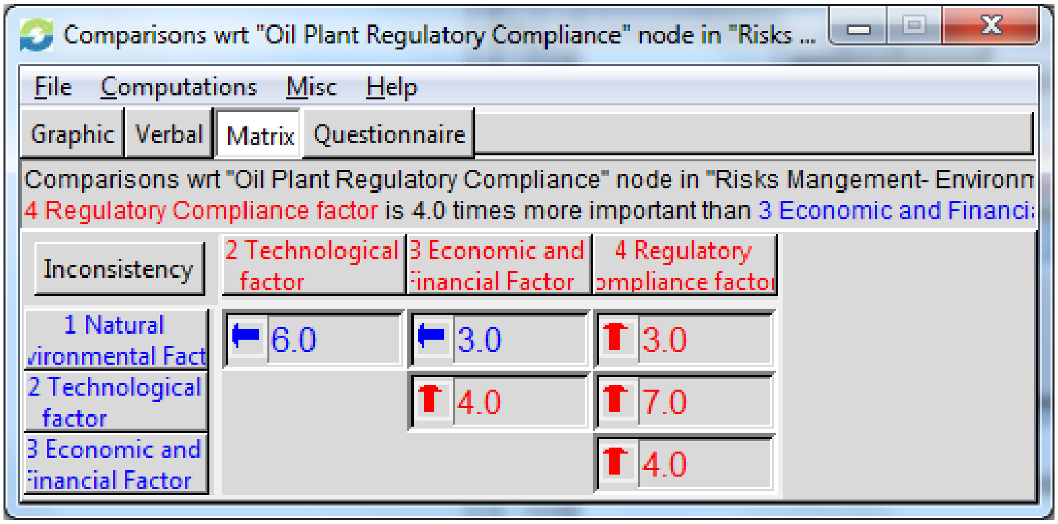


Figure 10. Matrix of Level 1 criteria with respect to the goal.

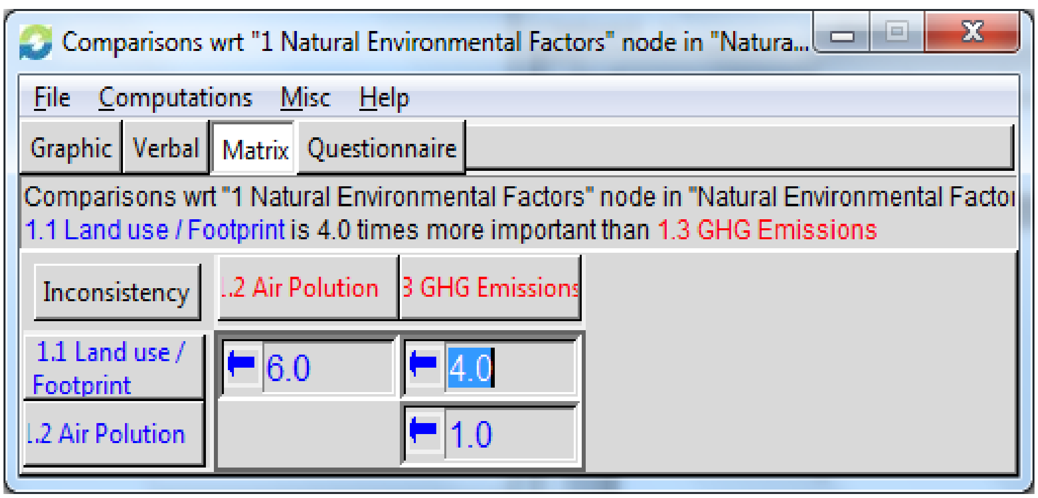
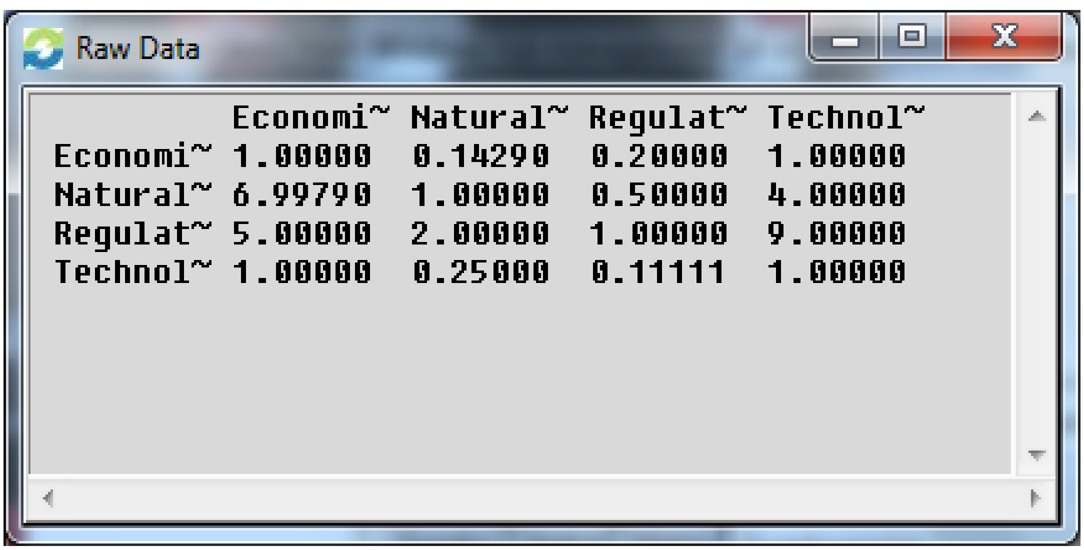


Figure 11. Matrix of Level 2 subcriteria with respect to the Level 1 criteria.

Step A4: Calculate priorities, calculate the eigenvalue and normalize the rankings. With the filled comparisons matrices it is possible to calculate priorities. The traditional AHP uses of the eigenvalue method; it is used in the SuperDecisions software. The AHP suggests an emphasis on a critical equation, A p = n p, where p represents the vector of priorities, n is the dimension of the A matrix, and A is the comparison matrix (Saaty 2006). This equation is the formulation of an eigenvector problem. The calculated priorities are exact for a consistent matrix. If there are known minor inconsistencies, priorities should differ only somewhat, according to the perturbation theory (Saaty 2006). The decision maker used the pairwise data to complete the eigenvector matrix in Figure 12, computed using the software from the input survey data. The matrix shows the four risks. We interpret the values in the matrix as follows. For example, natural environmental risks are between moderate and strong, more important than technological risks. According to the scale in Table 3 this converts to a value of 4. That means the inverse is true; technological risks relative to natural environmental risks is a value of 1/4 = 0.25, the reciprocal of 4.


Raw Data

	Economi~	Natural~	Regulat~	Technol~
Economi~	1.00000	0.14290	0.20000	1.00000
Natural~	6.99790	1.00000	0.50000	4.00000
Regulat~	5.00000	2.00000	1.00000	9.00000
Technol~	1.00000	0.25000	0.11111	1.00000

Figure 12. Eigenvector matrix for the criteria (risk).

Step A5: Perform computations for the criteria and subcriteria using the survey data. The software performs the computations and calculates the consistency ratio (CR; SuperDecisions has the term consistency index) every time it runs AHP. The software runs AHP for each hierarchy level: first for each criterion (SuperDecisions – node) on the subcriteria level (see Figure 13) and then for the Level 1 criteria. Figure 14 shows the result of the Level 1 criteria pairwise comparison. The results indicate that regulatory compliance has the highest risk ranking, and technological risk has the lowest risk ranking.

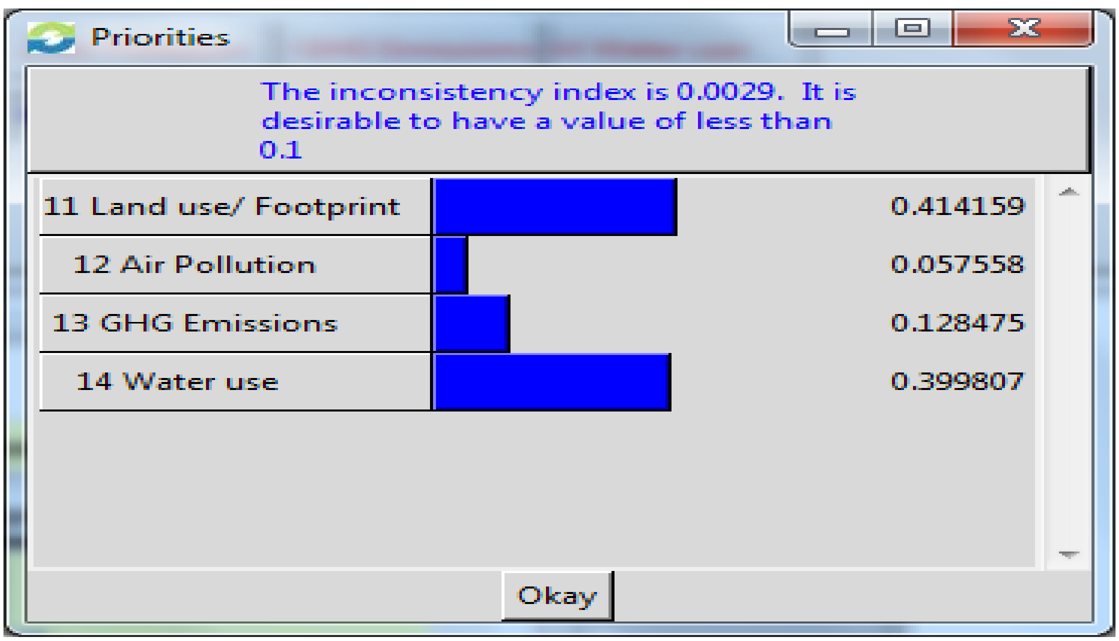


Figure 13. Results subcriteria ranking and inconsistency ratio.

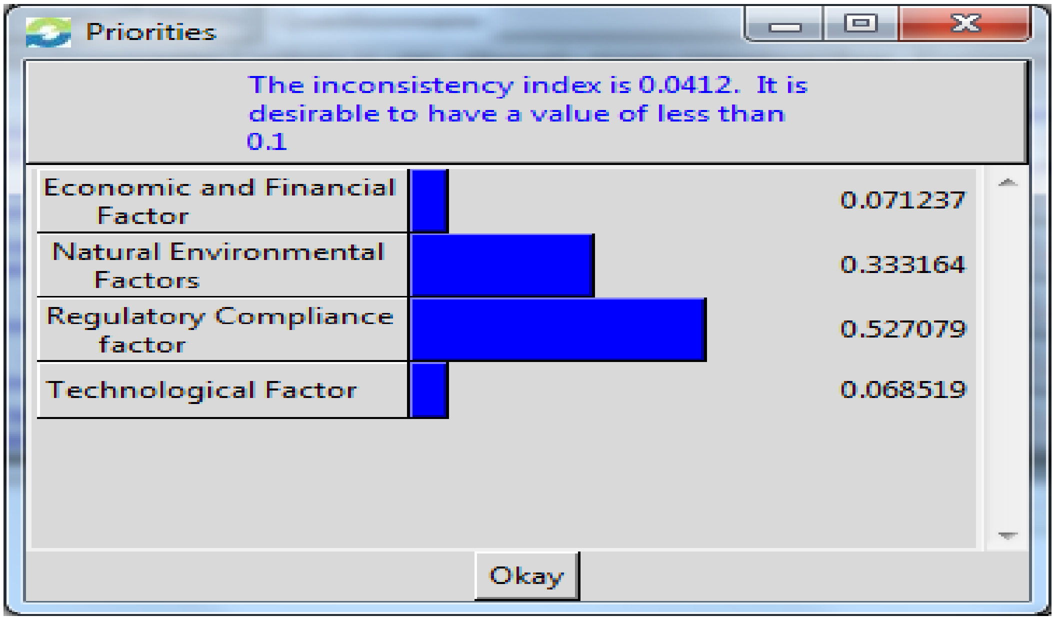


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Figure 14. The results of risk ranking and inconsistency ratio.

Step A6: Check the consistency and determine inconsistency index and inconsistency ratio. The pairwise decisions of SMEs make sense only if we obtain the resulting rankings from consistent or near consistent matrices. A researcher must apply a consistency check as Saaty (2006) proposed. Saaty introduced a consistency index (CI) and a random index (RI) for n x n matrices (see

Table 6). The inconsistency index of more than 500 randomly generated pairwise comparison matrices Saaty calculated is the basis of the RI. CR = CI/RI gives the consistency ratio (CR), the ratio of CI and RI.

Table 6

Random Index (RI)

N	2	3	4	5	6	7	8

RI	0.00	0.58	0.90	1.12	1.24	1.34	1.41

Saaty (2006) made some improvements on his inconsistency ratio in 1990 and later introduced a threshold of 5% for *3* x *3*, and 8% for *4* x *4* matrices. Ergu, Kou, Peng, and Shi (2011) proposed AHP practitioners should keep the original comparison information as far as possible when increasing the consistency ratio of metrics. I followed the same approach in this study. Figure *13* and Figure *14* show the priorities (ranking) derived from the pairwise matrix for criteria and subcriteria with acceptable CRs of 0.29% and 4.12%, respectively. SuperDecisions indicates that the CR should be less than 10% = 0.01. The software, SuperDecisions, shows an inconsistency report for the hierarchy, as well as changes to improve the consistency of the matrix (see Figure 15 and Figure 16). The changes should transpire in the pairwise comparison (see Figure 8 and Figure 9 for the applicable criteria).

Inconsistency Report

Rank	Row	Col	Current Val	Best Val	Old Inconsist.	New Inconsist.	% Improvement
1.	Economic and Financia	Regulatory Compliance	5.000000	11.016970	0.041178	0.010031	75.64 %
2.	Economic and Financia	Natural Environmental I	6.997900	3.097784	0.041178	0.011109	73.02 %
3.	Natural Environmental I	Regulatory Compliance	2.000000	1.270002	0.041178	0.031045	24.61 %
4.	Regulatory Compliance	Technological Factor	9.000000	6.623608	0.041178	0.035424	13.97 %
5.	Natural Environmental I	Technological Factor	4.000000	5.865249	0.041178	0.035897	12.82 %
6.	Economic and Financia	Technological Factor	1.000000	1.076779	0.041178	0.041333	-0.38 %

Figure 15. Inconsistency report for the criteria, with suggested improvements.

Inconsistency Report

Rank	Row	Col	Current Val	Best Val	Old Inconsist.	New Inconsist.	% Improvement
1.	1.1 Land use / Foc	1.3 GHG Emissions	4.000000	5.997918	0.010358	0.000156	98.49 %
2.	1.1 Land use / Foc	1.2 Air Polution	6.000000	3.998196	0.010358	0.000163	98.43 %
3.	1.2 Air Polution	1.3 GHG Emissions	1.000000	1.493707	0.010358	0.000178	98.28 %

Figure 16. Inconsistency report for the subcriteria, with consistency improvements.

Step A7: Normalize the ranking data. Finding all data complies with the CR, the rankings normalized. Figure 17 and Figure 18 show the normalized ranking for the criteria and subcriteria.

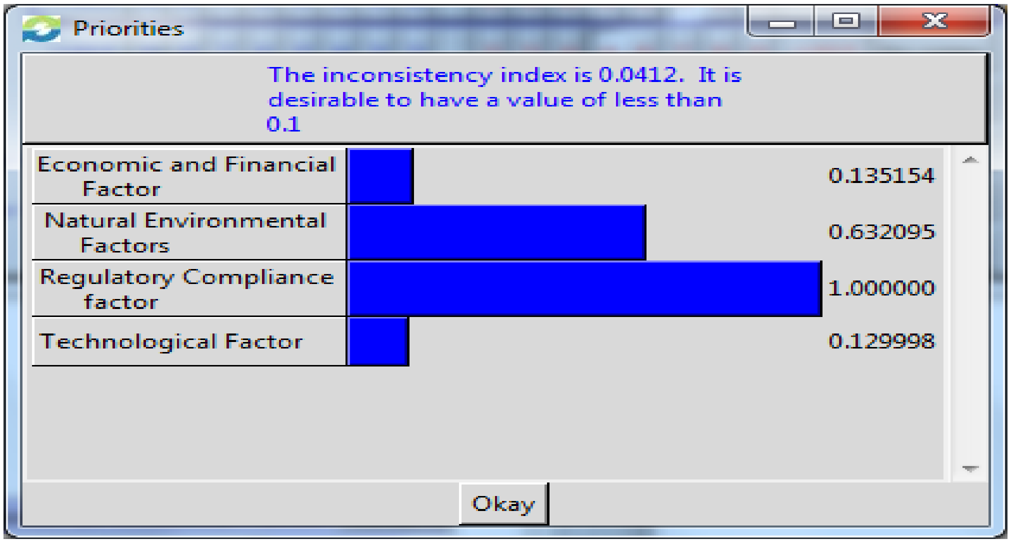


Figure 17. Inconsistency ratio for risk criteria showing normalized ranking.

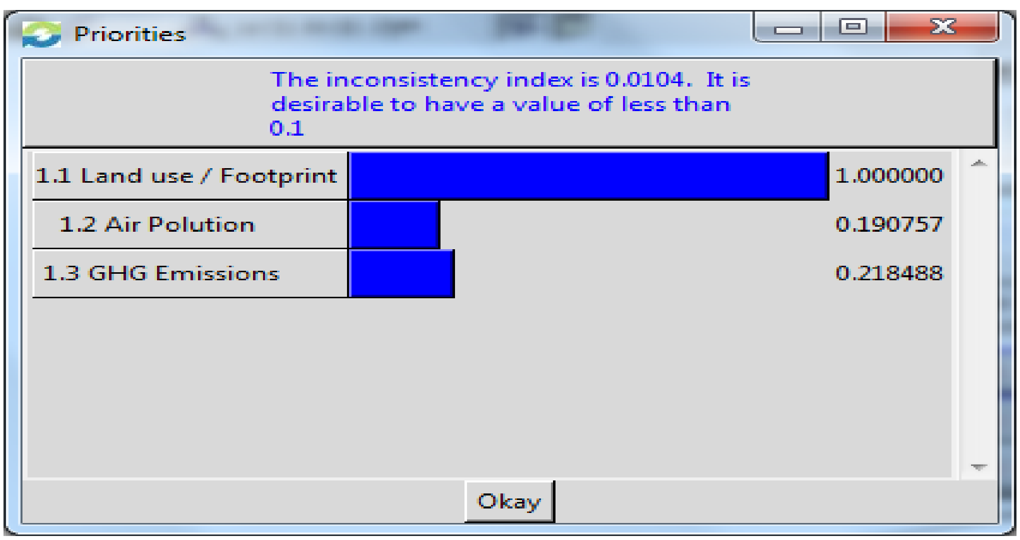
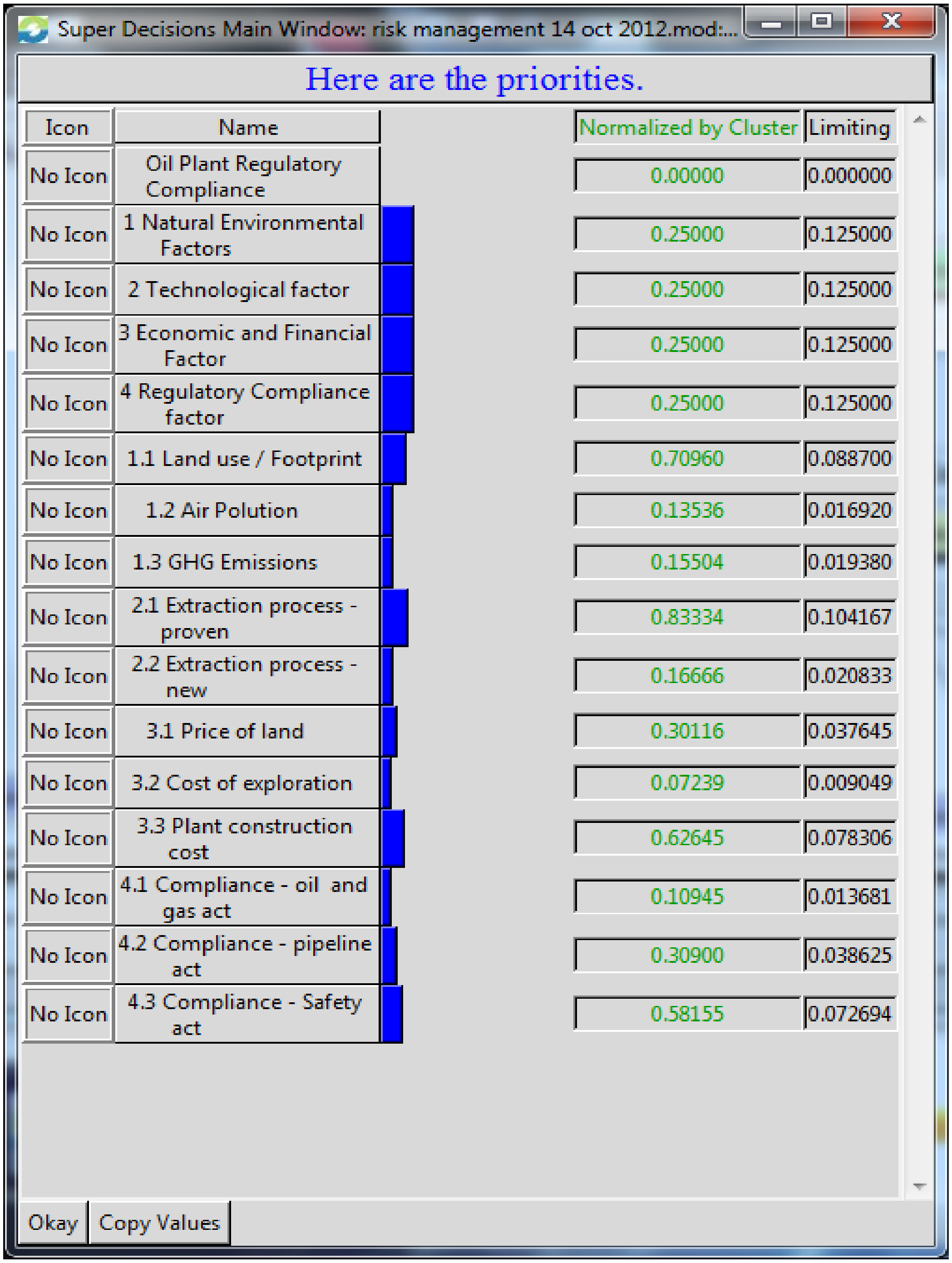


Figure 18. Inconsistency ratio for subcriteria showing normalized ranking.

Step A8: Aggregate. The next step in the AHP is to combine all the weights across all criteria to determine the final ranking of criteria and subcriteria. SuperDecisions calculates the ranking using the classic AHP approach or distributive mode, it accepts an additive aggregation with normalization of the sum of the priorities to unity (see Figure 19). Figure 19 shows example results, with Extraction Process Proven (0.8333) as the highest priorities in achieving Technical compliance and overall ranking shown in the Limiting column.



Icon	Name	Normalized by Cluster	Limiting
No Icon	Oil Plant Regulatory Compliance	0.00000	0.000000
No Icon	1 Natural Environmental Factors	0.25000	0.125000
No Icon	2 Technological factor	0.25000	0.125000
No Icon	3 Economic and Financial Factor	0.25000	0.125000
No Icon	4 Regulatory Compliance factor	0.25000	0.125000
No Icon	1.1 Land use / Footprint	0.70960	0.088700
No Icon	1.2 Air Polution	0.13536	0.016920
No Icon	1.3 GHG Emissions	0.15504	0.019380
No Icon	2.1 Extraction process - proven	0.83334	0.104167
No Icon	2.2 Extraction process - new	0.16666	0.020833
No Icon	3.1 Price of land	0.30116	0.037645
No Icon	3.2 Cost of exploration	0.07239	0.009049
No Icon	3.3 Plant construction cost	0.62645	0.078306
No Icon	4.1 Compliance - oil and gas act	0.10945	0.013681
No Icon	4.2 Compliance - pipeline act	0.30900	0.038625
No Icon	4.3 Compliance - Safety act	0.58155	0.072694

Figure 19. Aggregation of all the criteria in the hierarchy.

Reliability and Validity

Reliability

The repeatability of the measurements of an instrument (e.g., a survey) determines its reliability. Frankfort-Nachmias and Nachmias (2008) referred to the reliability of the instrument as the function of the consistent variable errors produced by an instrument every time it measures a variable. Decision makers can use three well-applied methods to check for reliability of the instrument (survey) and responses: the test-retest method, the parallel forms technique, and the split-half method. In the test-retest method, the decision maker administers the survey twice to the same people. Senior executives (SMEs) have limited time to participate in research studies or surveys. Therefore, creating a test-retest method was not feasible in this research due to time constraints. The parallel forms method develops and applies to different instruments, but with the same intent; the decision maker can administer the instruments to the same group. Again, this was not feasible because of the time it would have taken and the fact that I used only one instrument. The split-half method produces one survey but splits the questions in two parts (even and odd numbered questions).

For the split-half method, I could have correlated the results of the two questionnaires to determine the reliability of the overall instrument. Although the split-half method could have applied to my research, it was unnecessary. AHP computes the eigenvector for each SME (Saaty, 2010), and from this eigenvector, the decision maker can calculate a consistency factor across the SMEs (Kusherbaeva et al., 2011b). In this study, I checked the eigenvector for each data set for consistency of the pairwise comparisons with the calculation of the consistency ratio (Chen et al., 2010). If the consistency ratio (CR) is less than 0.1 then, the consistency is acceptable (Saaty, 2006) and the instrument (survey) reliable. However, if the CR is more than 0.1 then the consistency will improve by identifying the most inconsistent judgment and changing its value (see Step A6 and Figure 15), thus changing the eigenvector to improve the consistency (Saaty, 2006).

Validity

Demonstrating that the research method chosen for the study of the problem statement is the most appropriate inquiry strategy helps ensure the validity of the research. Reliability of quantitative data and qualitative data has the same prerequisites: accuracy of data recording and consistent measurement and interpretation of data. Lincoln and Guba proposed their criteria for judging the validity of studies (Schwandt, et al., 2007). They suggested a trustworthiness criterion along with the scientific understanding of validity credibility (internal validity), transferability (external validity), dependability (or reliability), and conformability (or objectivity). Schwandt et al. (2007) discussed the validity as Lincoln and Guba described. Schwandt et al. further concluded the validity of quantitative research is complex—difficult to understand and difficult to solve.

Van Solms (2011) argued a different approach to prove the validity of the AHP was necessary. Van Solms also stated that for decision makers the focus should not be on the *prediction of outcomes* but rather on the ability of the research method (i.e., AHP) to support valid decisions. However, success depends on trustworthiness and authenticity (Schwandt et al., 2007). I needed to identify potential internal and external threats to ensure the quality of data. The first step was the assurance of logical validity, which I performed during the first phase of identifying environmental compliance risk and mitigation strategies. Reviewing these factors and mitigation strategies to ensure they are technically feasible and able to conform to engineering logic. The next step was an analysis of the outcome of the risk identification and mitigation strategies in a pilot study to get confirmation from SMEs (Ellis & Levy, 2010). The final step was a review of the AHP ranking and if it answers the research questions and the working hypotheses. Van Solms (2011) emphasized that the decision maker could prove the validity if the AHP is providing decisions based on human interest.

I checked the transferability of data by comparing the rankings of the pilot survey with the final survey rankings. The rankings showed repeatability of results if measured at a different time. To ensure credibility, the final ranking of environmental compliance risks and mitigation strategies had to be acceptable from the viewpoint of the SMEs. The feedback provided by participants towards the end of the AHP was helpful for solidifying and validated the results of the AHP (Ellis & Levy, 2010). The application of triangulation indicated the validity of the AHP.

Internal threats to validity. The first internal threat is obtaining too small a sample of SMEs in the study; the mitigating strategy would be to meet the minimum sample size to obtain saturation of data. The second internal threat was the time to do the data mining, the survey, AHP evaluation, and possible follow-up interviews. A high percentage of project engineers worked on contract and moved to the next project. If the time between the initial survey and possible follow-up communication became too long, the contact with the project engineers might be lost. A third threat to internal validity was not identifying the actual risks and mitigation strategies to environmental compliance.

External threats to validity. An external threat would be erroneous inferences drawn from data gathered from a small sample relative to the population. Moreover, the project engineers might not have sufficient experience to provide consistent pairwise comparison of risks and mitigation strategies. The external validity might be possible if I could extend the environmental risk ranking and mitigation strategy ranking to the oil industry outside of Alberta. I reviewed the outcome of the AHP for risks and mitigation strategies with five or more SMEs to get confirmation of the logic of the ranking defined by the AHP.

Transition and Summary

The quantitative study in risk management of regulatory compliance of oil sands projects is an AHP study. The purpose of the quantitative study was to identify and rank environmental compliance risks and mitigation strategies for in situ oil sands projects (SAGD projects) in Alberta, Canada. In Section 2, I defined the purpose, research design, methodology, sampling plan, and the role of the researcher from which I presented the results of implementing the research plan in Section 3.

Section 3: Application to Professional Practice and Implications for Change

Any project has a defined timeline and project managers work to achieve a defined objective by a predetermined end date (Bower & Walker, 2007). Oil executives' objectives for oil sands projects are to execute a successful *in situ* project because that will contribute not only to the long-term financial sustainability of the company but also to the long-term environmental sustainability. I sought to identify and rank the key environmental compliance risks and mitigation strategies of *in situ oil* sands projects. If company executives comprehend the ranking of environmental compliance risks and mitigations, then they will improve environmental and regulatory compliance, as well as the long-term financial and environmental sustainability of their companies.

Overview of Study

This quantitative research study focused on risk management regarding *in situ* oil sands projects and the ranking of environmental compliance risks and mitigations by project engineers and executives in the oil sands industry. I conducted this study using a pilot survey, a pairwise comparison-specialized survey, and the application of analytical hierarchy process (AHP), a multicriteria decision-making (MCDM) method for the final ranking of the risks and mitigation strategies. By applying a well-defined risk management process to the set of ranked criteria derived from this study, I created a list that enables oil sands project engineers to improve their consistency in decision-making. The study conclusions are useful to oil sands risk managers and serve to inform them of environmental requirements related to their work.

For this study, I defined one principal, four secondary RQs and five working hypotheses for test examination and testing against the outcome of the risk and mitigation strategy rankings. I collected the data via a pilot survey and a pairwise specialized comparison survey; all participants were subject matter experts (SME) involved in Alberta in situ oil sands projects. A detailed presentation of the data and findings follows.

Presentation of the Findings

In this quantitative study, I identified and ranked the environmental compliance risks and mitigation strategies using two instruments: a pilot study and a pairwise comparison-specialized survey of oil company executives and project engineers. I used the pilot survey to validate the lists of risks and mitigation strategies compiled from the literature and Alberta Energy Regulator (AER) oil sands database. I used the pairwise comparison-specialized survey to obtain data from the SMEs. The participants completed the survey matrices, which I import into the AHP software used to analyze the data, SuperDecisions.

I analyzed the pairwise comparison data using AHP. In the findings, I confirmed the one principal, four secondary RQs and five working hypotheses about risk management to ensure environmental regulatory compliance under the uncertainty of future regulatory requirements. The secondary research questions about project risks and mitigation strategies were as follows:

Research Question 1: How do the natural environmental compliance risks rank against human environmental risks in the assessment of future environmental regulatory compliance?

Research Question 2: Which mitigation strategy emerged as the best to ensure future environmental regulatory compliance?

Research Question 3: Which of the natural environmental compliance risks (land use, water quality, and water usage or air quality) is most beneficial for addressing future environmental regulatory compliance?

Research Question 4: Is R&D technology beneficial to the mitigation of environmental regulatory compliance risks?

Pilot Survey

I used a pilot survey to validate the lists of environmental compliance risks and mitigation strategies identified in the literature survey and AER database mining. I distributed the lists of risks and mitigation strategies to six SMEs I knew. After two weeks, I contacted the SMEs to remind them and check if they may have questions. I received five responses after four weeks, with one SME declining participation. Table 7 shows the demographics of the SMEs invited to participate in the pilot survey.

Table 7

Demographics of Participants

Participant (Survey No.)	Senior Project Engineer	Oil Company Executive	Pilot Survey Participant	Declined Participation in Pilot Survey
B1		X	X	
C1	X		X	
C3	X		X	
S2		X		X
T1	X		X	
T2		X	X	
Total	3	3	5	1

Based on the comments and completion of the pilot survey by the SMEs, I made changes to the initial lists of risks and mitigation strategies. I refined the hierarchies and questionnaires for the specialized pairwise comparison survey. The SMEs also recommended changes in the pilot survey related to the layout of the pairwise questions in the Excel spreadsheet. The subsequent changes also led to changes in the risk hierarchy and mitigation hierarchy.

The most significant change in response to the pilot survey results was a change in the first level of the risk hierarchy. I added a new criterion on Level 1, Environmental Compliance risk with two subcriteria, Natural Environmental Compliance risk and Human Environmental Compliance risk. The second change because of the pilot survey was the addition of two subcriteria to level 2 subcriteria for Level 1 criterion Regulatory Compliance. The subcriteria added were: (a) Implement a Pressure Equipment Integrity Program and (b) Implement a Pipeline Integrity Program. Figure 20 shows the initial hierarchy of risks and Figure 21 shows the validated hierarchy. Figure 22 and Figure 23 respectively shows the hierarchies for the mitigation strategies before and after the pilot survey.

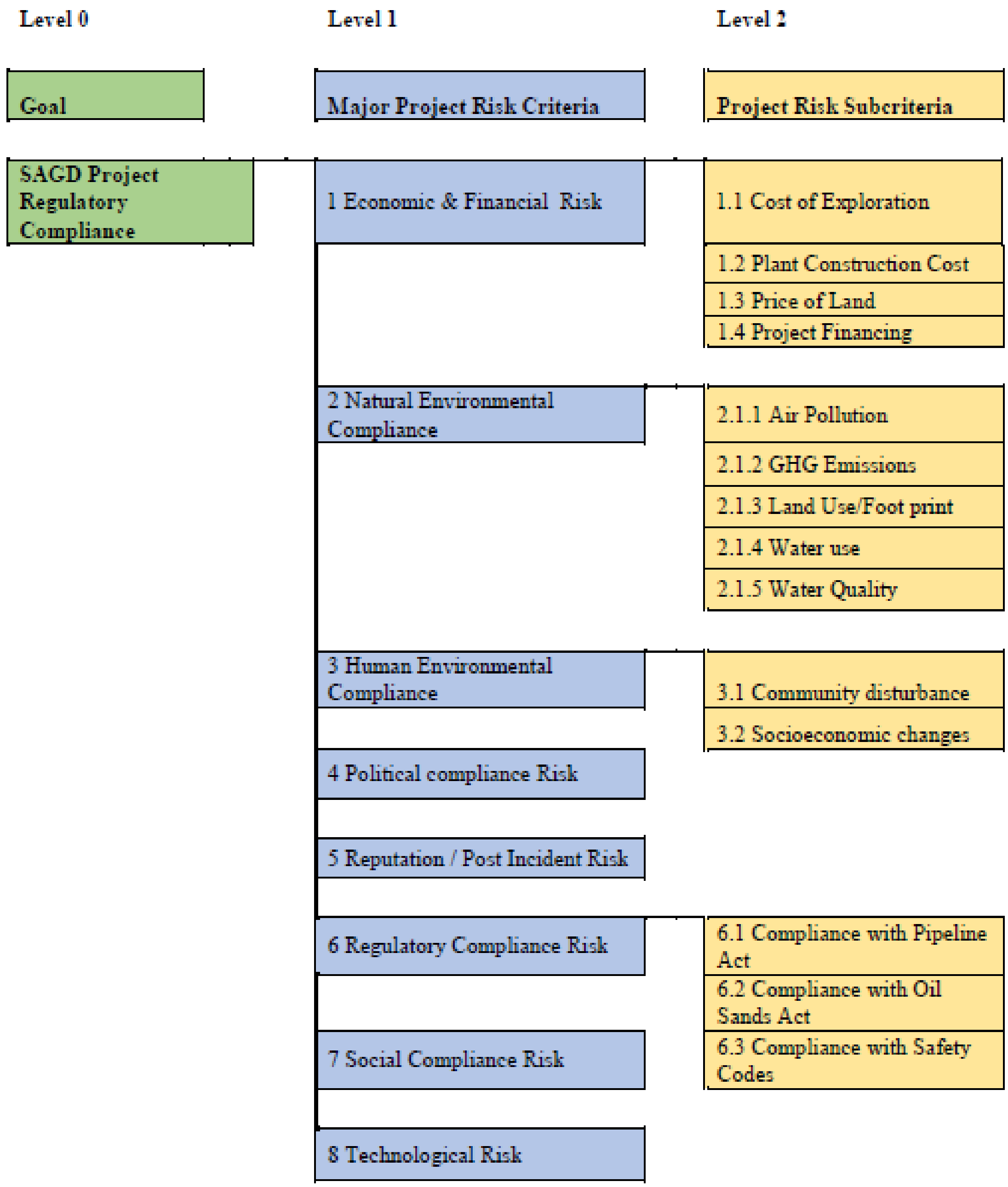


Figure 20. Risk hierarchy prior to the pilot survey.

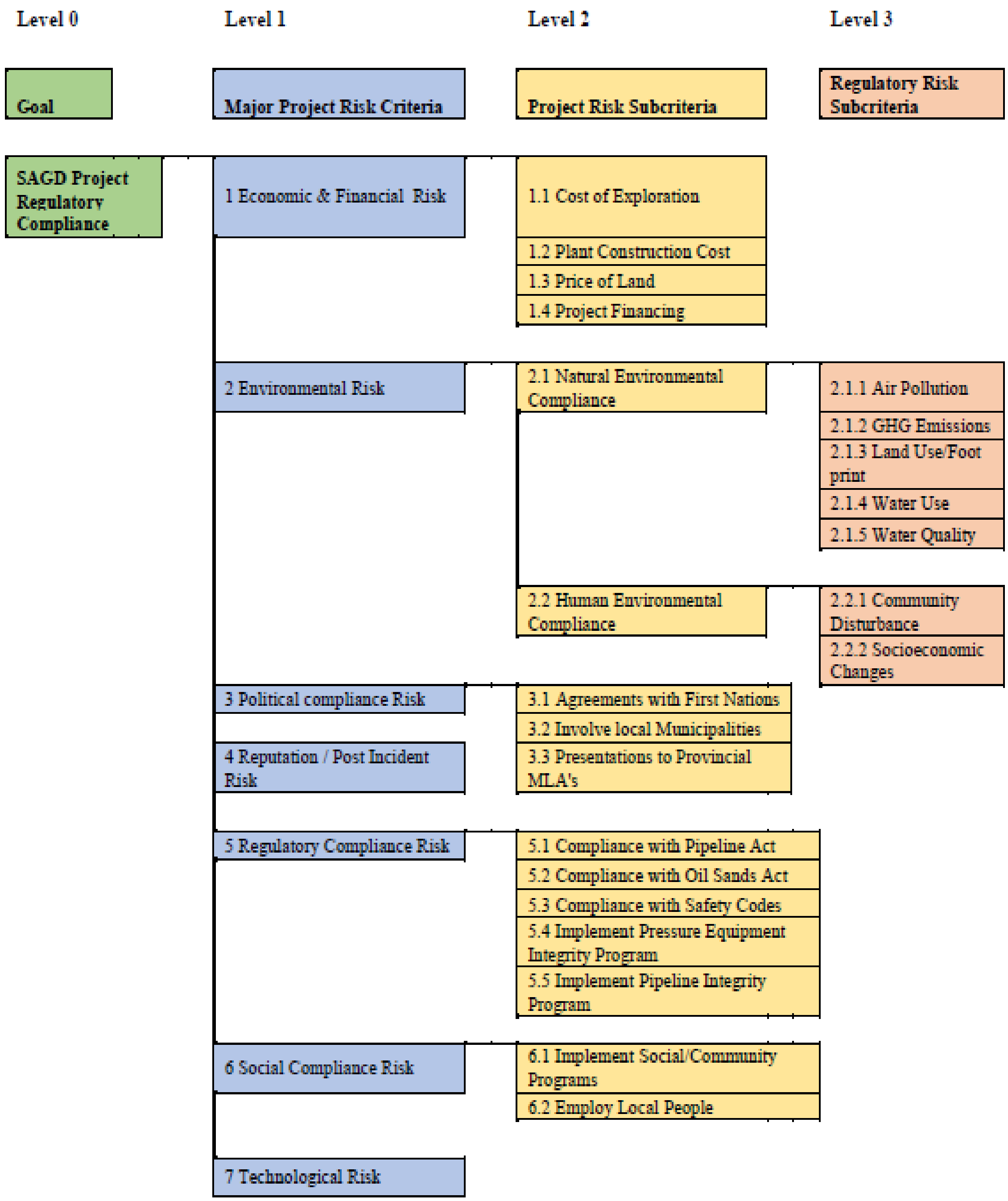


Figure 21. Risk hierarchy validated in the pilot survey

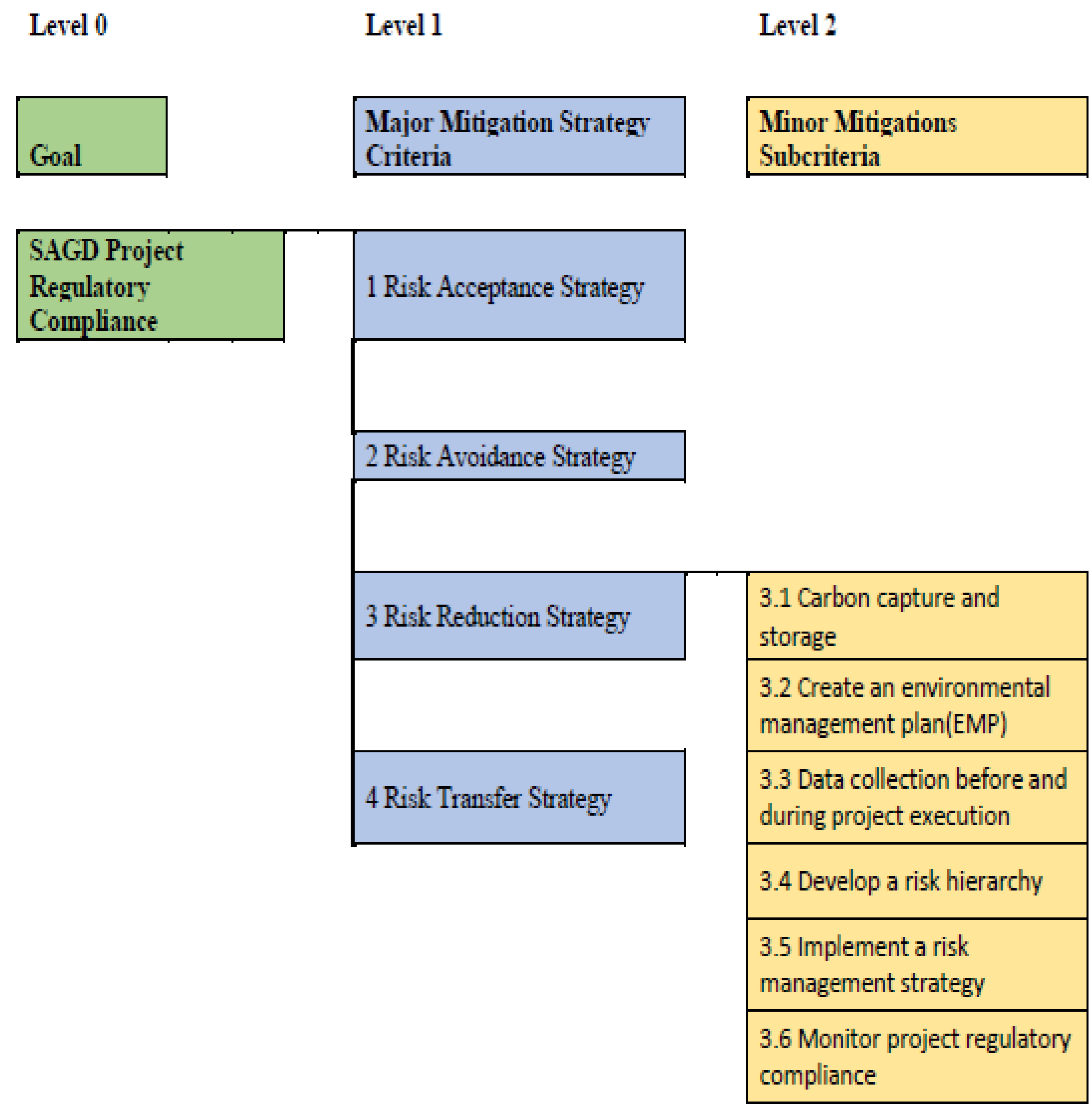


Figure 22. Mitigation Strategies hierarchy prior to the pilot survey

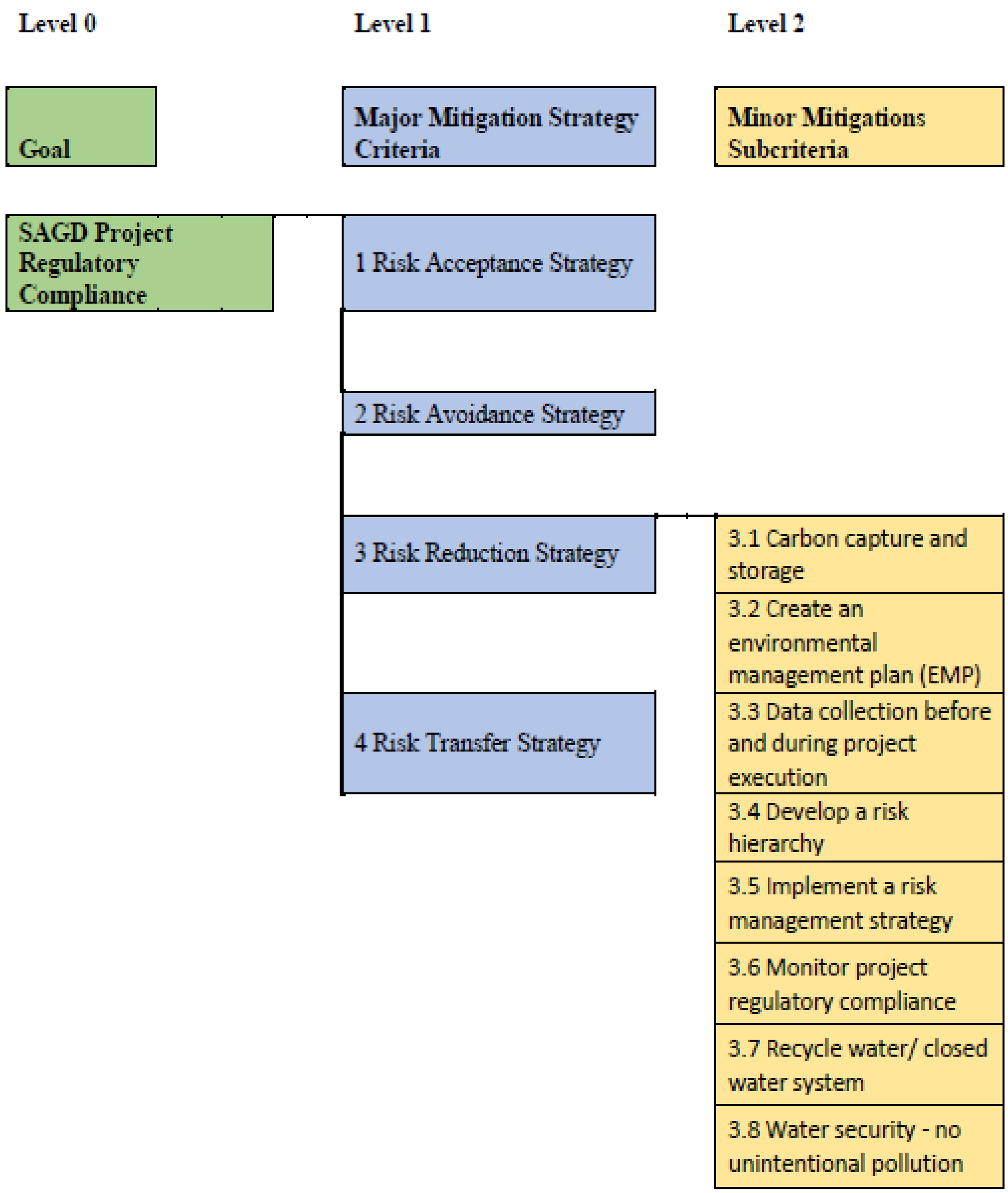


Figure 23. Mitigation Strategies validated in the pilot survey

I used the risk hierarchy shown in Figure 20, the mitigation hierarchy shown in Figure 22, and a questionnaire (Appendix C) in the pilot survey. I administered the pilot survey following the pilot flowchart (Figure 24). Appendix D shows the final risks and mitigation strategies hierarchies, while Appendix E has the final pairwise comparison-specialized survey (extract from the Excel spreadsheet used).

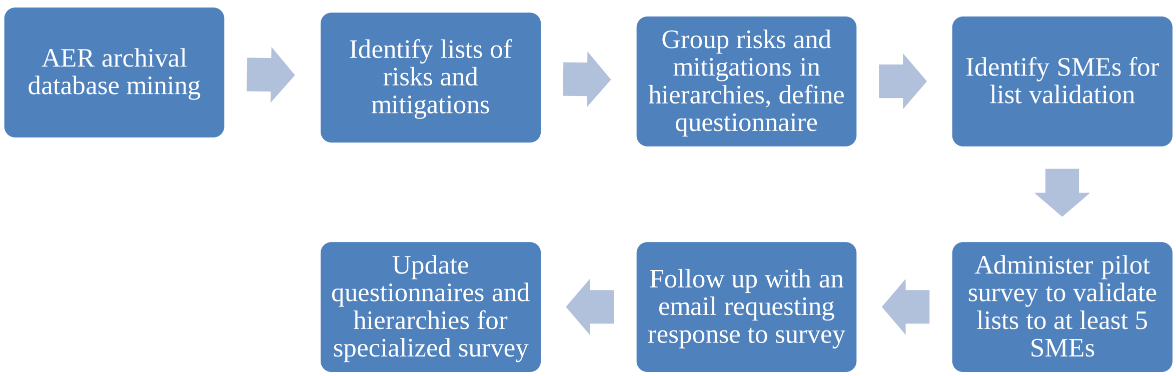


Figure 24. Pilot survey flowchart showing the process followed

The Pairwise Comparison Specialized Survey

The main study participants were recruited using a purposive sample of 52 oil sands company executives and project engineers/managers from the CAPP and OSDG list of companies with active oil sands projects in Alberta. These 52 SMEs represented 31 companies. I initially sent an email to each potential participant with a consent form indicating my request and acknowledgement of his or her intent to participate. I followed up with emails every two weeks trying to recruit as many participants as possible. Three potential particapants replied with a negative response, indicating that it was against their company's policy to participate in the survey. In general, executives and engineers representing international oil companies declined participation. The final list of participants included 16 SMEs, not including the five SMEs that participated in the pilot study. Seventeen SMEs responded but one's response was incomplete and disqualified. The sample represented *N* > 15 surveys received from 52 SMEs with a response rate of 34%. Table 8 displays the demographics of the participants with no personal or company information. I sent the pairwise comparison-specialized survey to 18 senior project engineers, 26 oil company executives and 8 regulatory managers. The final 16 respondents included six project engineers, seven company executives and four regulatory managers. All participants were members of SAGD projects in Alberta, either as a company executive or as a senior project manager, project engineer or regulatory manager.

Table 8

Demographics of Pairwise Comparison Specialized Survey Participants

Participant (Survey No.)	Senior Project Engineer	Oil Company Executive	Regulatory Manager	Pairwise Comparison Specialized Survey
A1			X	X
C2	X			X
C3		X		X
E1			X	X
H1	X			X
L1			X	X
L2	X			X
O1		X		X
O2	X			X
O3		X		X
O4		X		X
P1		X		X
P2		X		X
P3	X			X
P4	X			X
R1			X	X
S1		X		X
Total	6	7	4	16

I received from the participants the pairwise comparison surveys in Excel or PDF format files. I entered each survey into the AHP software, SuperDecisions, to calculate the ranking of risks and mitigation strategies following the AHP application steps shown in Figure 5. I followed these steps for each survey received to obtain N=16 data sets similar to that shown in Figure 19. Each data set included two lists of rankings, one for the risks and one for the mitigation strategies.

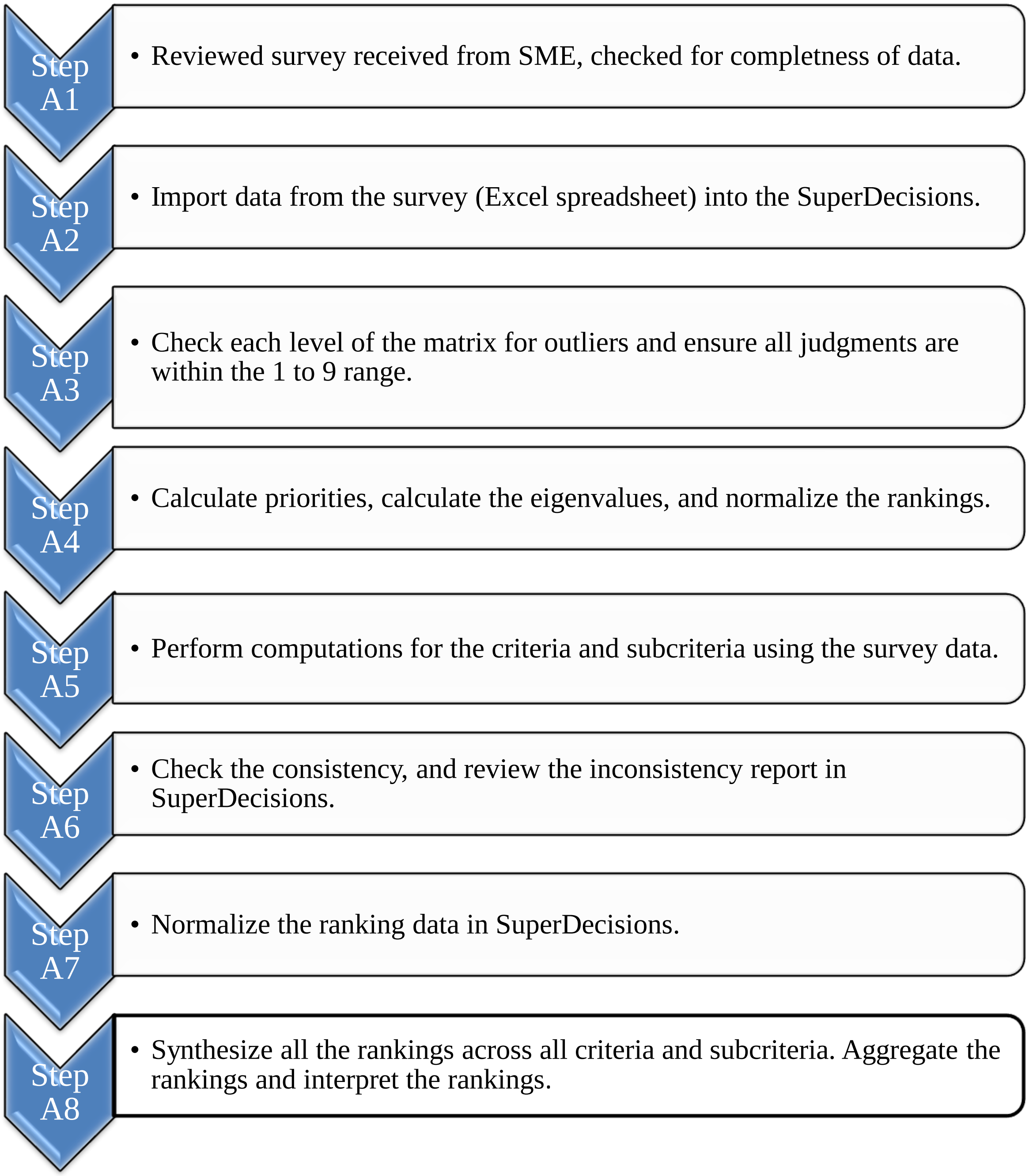


Figure 25. AHP application steps followed for each survey received.

Following the AHP analysis, I aggregated the rankings for *N*=16 surveys to obtain the final rankings for risks and mitigation strategies. For the aggregation of AHP rankings, the AHP practitioner may use either the arithmetic mean or the geometric mean. Saaty (2006) proposed the geometric mean rather than the arithmetic mean as the proper way to aggregate judgments by more than one judge. Aczel and Saaty (as cited by Saaty, 2006) proved Saaty's theorem using the geometric mean if all participants have equal importance in the aggregated result. For my study, all SMEs had equal importance. Other researchers (Dong, Zhang, Hong, & Xu, 2010; Ishizaka & Labib, 2011b) also supported using the geometric mean. Xu (as sited by Groselj, & Stirn, 2012) stated that if the individual SME pairwise comparison matrices were of acceptable consistency then the aggregated resultant matrix would have an acceptable consistency. In my study, I checked the different matrices for consistency and compliance to the CR < 0.1 rule as described in step A6 (see Figure 25). See Appendix F and G for the consistency of each survey used in the analysis. I aggregated the rankings obtained from the individual pairwise comparison matrices using the geometric mean method. The improvement in consistency of the final aggregated ranking satisfied the Pareto principle of social choice theory (Dong, et al., 2010).

Risk Ranking

Table 9 shows the ranking of all risks based on the surveys of 16 SMEs and aggregated using the geometric mean. Table 10 shows the overall ranking of all risks.

Table 9

Aggregated Risk Ranking per Level Using Geometric Mean

Ranking	Criteria / subcriteria	Geometric Mean Weight (%)	Weight Normalized (%)
1	5 Regulatory compliance	19.28	22.78
2	4 Reputation/Post incident	15.15	17.90
3	2 Environmental Compliance	14.35	16.95
4	1 Economics and financial	13.01	15.37
5	7 Technological	11.92	14.08
6	6 Social compliance	6.66	7.87
7	3 Political	4.27	5.04
	Level 1 Project Risks Total	84.64	100.00
1	12 Plant construction cost	28.07	36.10
2	14 Project financing	24.47	31.47
3	11 Cost of exploration	16.76	21.56
4	13 Price of land	8.45	10.87
	Level 2 Economics & Financial total	77.75	100.00
1	22 Human Environmental Compliance	48.11	55.64
2	21 Natural Environmental Compliance	38.35	44.36
	Level 2 Environmental Compliance Total	86.46	100.00
1	31Agreements with First Nations	55.87	57.75
2	33 Involve local municipality	26.84	27.74
3	32 Presentations to provincial MLAs	14.04	14.51
	Level 2 Political Total	96.75	100.00
1	53 Comply with the Safety Codes Act	23.07	26.71
2	54 Implement a Pressure Equipment Integrity Program	20.63	23.89
3	52 Comply with the Oil Sands Act	15.93	18.44
4	55 Implement a Pipeline Integrity Management Program	13.40	15.51
5	51 Comply with the Pipeline Act	13.34	15.45
	Level 2 Regulatory Compliance Total	86.37	100.00
1	62 Employ local people	71.71	74.43

Ranking	Criteria / subcriteria	Geometric Mean Weight (%)	Weight Normalized (%)
2	61 Implement social/community programs	24.64	25.57
	Level 2 Social Compliance Total	96.35	100.00
1	215 Water quality	27.85	32.37
2	214 Water use	23.51	27.32
3	211 Air pollution	15.02	17.46
4	212 GHG emissions	10.16	11.81
5	213 Land use/Footprint	9.50	11.04
	Level 3 Natural Environmental Compliance Total	86.04	100.00
1	221 Community disturbance	59.05	65.34
2	222 Socioeconomic changes	31.33	34.66
	Level 3 Human Environmental Compliance Total	90.38	100.00

Table 10

Overall Ranking of Risks, Highest to Lowest

Ranking	Criteria/Subcriteria	Geometric Mean Weight (%)	Weight Normalized (%)
1	5 Regulatory compliance	9.17	12.37
2	2 Environmental risks	7.78	10.50
3	1 Economics & financial	7.25	9.78
4	4 Reputation/Post incident	6.84	9.23
5	7 Technological	5.52	7.45
6	22 Human environmental compliance	3.45	4.66
7	21 Natural environmental compliance	3.23	4.36
8	6 Social compliance	3.11	4.20
9	3 Political	2.51	3.39
10	53 Comply to the Safety Codes Act	2.46	3.32
11	62 Employ local people	2.28	3.08
12	12 Plant construction cost	2.08	2.81
13	14 Project financing	1.86	2.51
14	54 Implement a Pressure Equipment Integrity Program	1.81	2.44

Ranking	Criteria/Subcriteria	Geometric Mean Weight (%)	Weight Normalized (%)
15	221 Community disturbance	1.59	2.15
16	31Agreements with First Nations	1.43	1.93
17	52 Comply to the Oil Sands Act	1.38	1.86
18	222 Socioeconomic changes	1.38	1.86
19	51 Comply to the Pipeline Act	1.35	1.82
20	11 Cost of exploration	1.32	1.78
21	55 Implement a Pipeline Integrity Management Program	1.16	1.57
22	215 Water quality	1.00	1.35
23	61 Implement social/community programs	0.74	1.00
24	33 Involve local municipality	0.63	0.86
25	214 Water use	0.60	0.81
26	13 Price of land	0.58	0.79
27	211 Air pollution	0.49	0.67
28	212 GHG emissions	0.38	0.52
29	32 Presentations to provincial MLA's	0.36	0.49
30	213 Land use/Footprint	0.32	0.44
		74.14	100.00

Findings Related to Secondary Research Questions

For the first research question, I analyzed the relationship of the Natural Environmental Compliance risks and the Human Environmental Compliance risks in the assessment of future environmental regulatory compliance. The results from the risks specialized survey and the following AHP analysis indicated that Human Environmental Compliance is more important than Natural Environmental Compliance by a small margin, 55.4% compared to 44.6% (see Table 11). In the overall risk ranking, the Human Environmental Compliance risk was sixth in ranking while the Natural Environmental Compliance risk was seventh, with weights of 3.4% and 3.2%, respectively. The ranking of these risk criteria showed the answer for the research question. The Human Environmental Compliance risk was marginally more important than the Natural Environmental Compliance. In the overall ranking, Human Environmental Compliance and Natural Environmental Compliance ranked in the top 10 of the overall risk criteria ranking. In practice, SMEs would consider these two environmental compliance risks of equal importance.

Table 11

Environmental Compliance Risk Ranking

Environmental Compliance Risk	Geometric Mean Weight (%)	Normalized Weight (%)
22 Human environmental compliance	48.11	55.6
21 Natural environmental compliance	38.35	44.4

The Second Research Question

I investigated to see if there is a best mitigation strategy to implement to ensure future environmental regulatory compliance. The four highest ranked mitigation strategies have a weight range between 10% and 27% and the highest environmental regulatory compliance strategy (i.e. recycle water/closed water system), has a weight of 5% (see Table 12). The four top environmental regulatory compliance strategies have a weight of 15.8%, higher than any of the alternative risk mitigation strategies such as risk avoidance, risk transfer, and risk acceptance (see Table 13).

Table 12

Aggregated Ranking of Top Five Mitigation Strategies

Alternative Mitigation Strategy	Ranking	Aggregated Weight (%)
3 Risk reduction	1	27.08
2 Risk avoidance	2	12.75
4 Risk transfer	3	10.55
1 Risk acceptance	4	10.14
3.7 Recycle water/closed water system	5	4.947

Table 13

Aggregated Weight of Top 4 Environmental Regulatory Compliance Strategies

Environmental Regulatory Compliance Strategies	Ranking	Aggregated Weight (%)
3.7 Recycle water/closed water system	5	4.94
3.8 Water security	6	4.34
3.6 Monitor project regulatory compliance	7	3.97
3.2 Create an EMP	8	2.60
Total		15.84

The different mitigation strategies for environmental compliance have an even weight spread, and I divided them into three groups, see normalized weights in Table 14. The average weight of the top three mitigation strategies of Group 1 is 16.3% ($\sigma = 1.8\%$) with a standard deviation of 1.8%. Group 2 has an average weight of 8.9% ($\sigma = 0.6\%$)

and Group 3 has an average weight of 4.2% (σ = 0.9%). Therefore, I can conclude that project engineers and executives should not implement a single mitigation strategy for environmental regulatory compliance but rather a multicriteria strategy, as Groups 1 and 2 show, for environmental regulatory compliance (see Table 14).

Table 14

Level 2 Normalized Weights for Level 1 Criteria, Environmental Regulatory Compliance Strategies

Environmental Regulatory Compliance Strategies	Normalized Weight (%)	Ranking	Average Weight (%)	*σ*.
Group 1			16.3	1.8
3.7 Recycle water/closed water system	18.23	1		
3.8 Water security	16.00	2		
3.6 Monitor project regulatory compliance	14.64	3		
Group 2			8.9	0.6
3.2 Create an EMP	9.61	4		
3.5 Implement risk management strategy	8.62	5		
3.3 Data collection	8.55	6		
Group 3			4.2	0.9
3.4 Develop a risk hierarchy	4.89	7		
3.1 Carbon capture and storage	3.56	8		

In summary, the eight environmental regulatory compliance strategies (risk reduction strategies) have a uniform distribution of normalized weights, with the highest ranked strategy, recycle water/closed water system (18.23%) and the lowest ranked strategy, carbon capture and storage (3.56%). A clear preferred mitigation strategy is not apparent; the narrow weighing of the alternative risk reduction strategies is indicative of a preferred multicriteria approach to regulatory compliance risk management rather than a single significant risk mitigation strategy.

The Third Research Question

This research question is about the Natural Environmental Compliance risk criteria (land use, water quality, and water usage or air quality), which are among the most beneficial for addressing future environmental regulatory compliance. In Table 8, I listed the two highest ranked Natural Environmental Compliance risks such as water quality and water use. These risks correspond with the research trend observed in the industry (Research and Innovation, 2014). Table 15 shows the ranking of Level 2 criterion Natural Environmental Compliance Risk. The ranking divides the Natural Environmental Compliance Risks in two distinct groups: one group with a weight more than 29% and a second group with a weight less than 19%. The two highest ranked level 3 environmental risks—Water Quality and Water Use—have a combined ranking of 58.4%. Water is therefore the highest Natural Environmental Compliance risk, much higher than Air Quality (Air Pollution and GHG Emissions with combined weight = 30.60%) and Land Use (Forest Clearing, with a weight of less than 11%).

Researchers in Alberta emphasized the use of water in SAGD facilities and focused on methods to optimize the SOR (Research and Innovation, 2014). The improvement of SOR has a direct influence on water quality and water quantity. In January 2013, the oil sands industry formed the Oil Sands Water Management Initiative with the objective of providing water quality and water usage optimization to the industry. This effort led to the first in situ oil sands SOR reduction initiative in October 2013 and the second In Situ Oil Sands SOR Reduction conference is in October 2014 in Calgary (In situ oil sands SOR reduction initiative, 2013).

Table 15

Ranking of Level 3 Subcriteria for Level 2 Criterion Natural Environmental Compliance Risks, Normalized Weights

Risks	Ranking	Geometric Mean Aggregated Weight (%)	Normalized Aggregated Weight (%)
215 Water quality	1	28.13	32.75
214 Water use	2	22.03	25.64
211 Air pollution	3	15.69	18.26
212 GHG emissions	4	10.60	12.33
213 Land use/Footprint	5	9.46	11.01
	Total	85.90	100.00

The Fourth Research Question

This research question was about the contribution of technology to the reduction of risk and support to the mitigation of environmental regulatory compliance risks. As I have discussed in Research Question 3, the highest ranked Level 3 subcriteria for the Level 2 subcriterion, Natural Environmental Compliance, were the subcriteria Water

Quality and Air Quality (see Table 15). To reduce these environmental risks, the Alberta Government required oil companies' leaders to develop new technologies to reduce the environmental impact of new oil sands projects (Government of Alberta, 2009). The two top ranked Regulatory Compliance mitigation strategies were the Level 2 subcriteria (a) Recycle Water/Closed Water system and (b) Water Security (see Table 13).

The SAGD process plant mitigations strategies with the highest water utilization impact were (a) the quantity of water required per barrel of oil (SOR) and (b) the design of a closed water system. These two plant futures were functions of the water management design of the SAGD facility. Current research has an emphasis on water management and the improvement of SOR (In situ oil sands SOR reduction initiative, 2013). Technology as a risk has the fifth highest ranking out of 30 risks (see Table 10); therefore, mitigating potential technology risks requires large investments in R&D. The Alberta government, as well as oil companies' scientists/researchers involved in the oil sands, addressed R&D. According to Research and Innovation (2014), local universities received more than $250 million government grants for research related to environmental issues. Research and Innovation further noted that the in situ oil producers in Alberta formed the Canadian Oil Sands Innovation Alliance (COSIA) to accelerate the pace of environmental research in Canada's oil sands.

Findings on Hypotheses

Working Hypothesis 1. In Section 2 I defined five working hypotheses for review. Following are the definitions of WH1:

- Null Working Hypothesis 1 (WH1o): In this study, I identified the key risks. The SMEs might consider all risks equally important in the management of environmental risks.
- Alternative Working Hypothesis 1 (WH1a): In this study, I identified the key risks. The SMEs might consider certain risks distinctly more relevant than other risks in the management of environmental compliance might.

Table 16 shows the five highest ranked risks from a list of 30. The highest ranked risk, Regulatory Compliance, was 20% higher than the second highest ranked risk, Reputation/Post Incident. The fifth highest ranked risk, Technology, was nearly 1.7 times (5.82% vs. 3.39%) as high as the sixth highest ranked risk, Human Environmental Compliance risk. Therefore, the null Working Hypothesis 1 (WH1o) was unacceptable. The results from the survey and AHP (see Table 16) supported the alternative Working Hypothesis 1 (WH1a), indicating the top five risks were distinctly more relevant than the other 25 risks in the risk management of in situ oil sands projects.

Table 16

Highest Ranked Risks

Risk Criteria	Ranking	Aggregated Weight (%)
5 Regulatory compliance	1	9.36
4 Reputation/Post incident	2	7.81
2 Environmental risks	3	7.35
1 Economics & financial	4	6.49
7 Technological	5	5.82
	Total	36.83

Working Hypothesis 2. I defined Working Hypothesis 2 (WH2) as follows:

- Null Working Hypothesis 2 (WH2o): Using the AHP, SMEs would be able to identify that all mitigation strategies were equally important to future regulatory compliance of oil sands facilities.
- Alternative Working Hypothesis 2 (WH2a): Using the AHP, SMEs would be able to identify that some mitigation strategies were distinctly more relevant to future regulatory compliance of oil sands facilities.

The Level 1 criterion Risk Reduction was the preferred mitigation strategy (normalized weight = 44.75%), and the other three Level 1 criteria had weights between 16.75% and 21.06% (see Table 17). I rejected the null Working Hypothesis 2 (WH2o). The results from the survey and AHP (see Table 17) supported the alternative Working

Hypothesis 2 (WH2a). Compared with other mitigation strategies, one mitigation strategy (i.e., Risk Reduction) was distinctly more important to future regulatory compliance of oil sands facilities. In a Nigerian environmental risk management study, Nwite identified Risk Transfer as the preferred mitigation strategy (Nwite, 2014). Nwite's results is an indication of a different approach to risk management in Alberta and Nigeria.

Table 17

Ranking of Mitigation Strategies

Criteria	Ranking	Limiting Weight (%)	Normalized Weight (%)
Level 1 criteria - Alternative strategies			
1 Risk acceptance	4	14.07	16.75
2 Risk avoidance	2	17.69	21.06
3 Risk reduction	1	37.58	44.75
4 Risk transfer	3	14.64	17.43
	Total	83.98	100.00
Level 2 subcriteria - Mitigation strategies			
3.1 Carbon capture and storage	8	3.56	4.23
3.2 Create an EMP	4	9.61	11.43
3.3 Data collection	6	8.55	10.17
3.4 Develop a risk hierarchy	7	4.89	5.81
3.5 Implement risk management strategy	5	8.62	10.25
3.6 Monitor project regulatory compliance	3	14.64	17.41
3.7 Recycle water/closed water system	1	18.23	21.67
3.8 Water security	2	16.01	19.03
	Total	84.11	100

Working Hypothesis 3. I defined Working Hypothesis 3 (WH3) as follows:

- Null Working Hypothesis 3 (WH3o): All the Regulatory Compliance subcriteria for oil sands projects were equally important.

- Alternative Working Hypothesis 3 (WH3a): Some of the Regulatory Compliance subcriteria for oil sands projects were more important than other subcriteria.

Table 18 shows the ranking of the Level 2 subcriteria for the Level 1 criterion Regulatory Compliance. The most important Level 2 subcriterion was Comply with the Safety Codes Act. The second highest subcriterion, Implement a Pressure Equipment Integrity Program, was a requirement specified in the Safety Codes Act. The highest ranking of Comply with the Safety Codes Act was understandable because for in situ facilities the focus would be on the process plant rather than pipelines.

Table 18

Ranking of Level 2 Subcriteria for Level 1 Regulatory Compliance Criterion

Level 2 Subcriteria	Ranking	Geometric Mean Weight (%)	Normalized Weight (%)
53 Comply with the Safety Codes Act	1	22.87	26.27
54 Implement a Pressure Equipment Integrity Program	2	20.59	23.65
52 Comply with the Oil Sands Act	3	16.16	18.57
51 Comply with the Pipeline Act	4	13.74	15.78
55 Implement a Pipeline Integrity Management Program	5	13.68	15.72
	Total	87.04	100.00

The Oil Sands Act is important during the SAGD project application process but not prominent during the project execution phase, which is the focus of this risk management study. In the pilot survey, four of the five SMEs ranked these three regulatory compliance acts as equally important if these acts were the only Level 2 subcriteria for Level 1 criterion Regulatory Compliance, thus excluding the two subcriteria related to integrity management programs (i.e., Implement a Pressure Equipment Integrity Program and Implement a Pipeline Integrity Management Program). This result does not support the null Working Hypothesis 4 (WH4o) and therefore the null working hypothesis is probably not true. However, the results support the alternative Working Hypothesis 3 (WH3a) that Compliance with the Safety Codes Act is more important than other regulatory compliance criteria.

Working Hypothesis 4. I defined Working Hypothesis 4 (WH4) as follows:

- Null Working Hypothesis 4 (WH4o): Implementing an integrity management program at the start of an oil sands project would be less important than the financial savings for not implementing an integrity management program.
- Alternative Working Hypothesis 4 (WH4a): Implementing an integrity management program at the start of an oil sands project would be more important than the financial savings for not implementing an integrity management program.

In my research, I did not identify the Cost of Integrity Management Programs as a risk nor the possible savings for not implementing integrity management programs for pressure equipment and pipelines. Four risk criteria were supporting the null Working Hypothesis 4 (WH4; see Table 19). The Level 2 subcriteria Plant Construction Cost, Project Financing, and Implement a Pressure Equipment Integrity Program were grouped together in the overall ranking with aggregated weights between 1.16% and 2.08% (see Table 19), and overall rankings of 12, 13, and 14 respectively. I therefore concluded that the implementation of an integrity management program is equally as important as the cost of construction and the project financing. This result does not support the null nor the alternative Working Hypothesis 4 and therefore the neither the null (WH4o) nor the alternative (WH4a) working hypothesis is probably not true. Working Hypothesis 4 is a potential area for future research.

Table 19

Level 2 Subcriteria Related to Cost and Integrity Management

Level 2 Subcriteria	Ranking	Aggregated Weight (%)
12 Plant construction cost	12	2.08
14 Project financing	13	1.86
54 Implement a Pressure Equipment Integrity Program	14	1.81
55 Implement a Pipeline Integrity Management Program	21	1.16

Working Hypothesis 5. I defined Working Hypothesis 5 (WH5) as follows:

- Null Working Hypothesis 5 (WH5o): A multicriteria risk management approach for an oil sands project used multiple mitigation strategies to ensure future environmental regulatory compliance.
- Alternative Working Hypothesis 5 (WH5a): A multicriteria risk management

approach for an oil sands project used the most significant mitigation strategy to ensure future environmental regulatory compliance.

The Level 1 criterion Risk Reduction was the mitigation strategy with the highest ranking. Risk Reduction had a normalized weight of 44.05%, which was double any of the other Level 1 mitigation criteria (see Table 20). The eight Level 2 subcriteria supporting the Level 1 criterion Risk Reduction had a σ^2 = 0.24% and σ = 4.94% of normalized weights, with the highest ranked Level 2 subcriterion, Recycle Water/Closed Water system (18%), and the lowest ranked subcriterion, Carbon Capture & Storage (3.5%). The low ranking of the Level 2 mitigation strategy Carbon Capture & Storage was significant, as the Alberta Government had committed $2 billion in carbon capture and storage initiatives (Bedair, 2013). Current technology made carbon capture programs more suitable to large processing facilities and refineries (Englander et al., 2013) than smaller SAGD facilities. SAGD Project engineers could consider carbon capture technology a high risk and therefore the low ranking as a mitigation strategy.

Table 20

Ranking of Level 1 Alternative Mitigation Strategies Criteria

Level 1 Criteria	Ranking	Aggregated Geometric Weight (%)	Normalized Weight (%)
1 Risk acceptance	4	14.07	16.85
2 Risk avoidance	2	17.69	21.19
3 Risk reduction	1	36.78	44.05
4 Risk transfer	3	14.96	17.91
	Total	83.49	100.00

No clear preference was evident for particular Level 2 subcriteria for the Level 1 criterion Risk Reduction (see Table 21). The close weighing of the Level 2 subcriteria (alternative risk reduction strategies) in Table 21 was indicative of a preferred multicriteria approach to regulatory compliance risk management rather than a single significant risk mitigation strategy. I therefore concluded that the null Working Hypothesis 5 (WH5o) was true.

Table 21

Alternative Risk Reduction Strategies

Alternative Mitigation Strategy	Ranking	Aggregated Geometric Weight (%)	Normalized Weight (%)
3.1 Carbon capture and storage	8	3.56	4.24
3.2 Create an EMP	4	9.61	11.42
3.3 Data collection	6	8.55	10.16
3.4 Develop a risk hierarchy	7	4.89	5.81
3.5 Implement risk management strategy	5	8.62	10.25
3.6 Monitor project regulatory compliance	3	14.64	17.41
3.7 Recycle water/closed water system	1	18.23	21.68
3.8 Water security	2	16.00	19.03
	Total	84.10	100.00

In summary, I identified 30 risk criteria in a four-level hierarchy and 12 mitigation strategy criteria in a three-level hierarchy. The 16 SMEs that completed the surveys identified the three highest risk criteria for in situ oil sands projects to be (a) Regulatory Compliance, (b) Reputation/Post Incident and (c) Environmental Compliance, with (d) Economics and Financial, and (e) Technological criteria a close second. I analyzed the 16 SME's mitigation strategies surveys using the AHP and I identified Risk Reduction as the preferred mitigation strategy. I recommended a multicriteria mitigation strategy for environmental regulatory compliance based on the mitigation strategy rankings. In this study, I reviewed five working hypotheses, found two null working hypotheses to be true, and rejected both WH4o and WH4a. I recommended WH4 for future research (see Table 21).

Table 22

Summary Outcome of Working Hypotheses

Working Hypothesis	True	False	Comment
WH1o		Yes	
WH1a	Yes		
WH2o		Yes	
WH2a	Yes		
WH3o	Yes		
WH3a		Yes	
WH4o		Yes	Need further
WH4a		Yes	research
WH5o	Yes		
WH5a		Yes	

Applications to Professional Practice

The quality of decision-making is a major part of the success of executives, engineers, and corporations' leaders. Findings from this study can broaden the awareness for a consistent approach to risk management decision-making in oil sands projects. The ranking of risks and mitigation strategies might help junior and inexperienced leaders to follow a consistent framework for decision-making during the execution of an in situ oil sands project. The potential to improve sustainability with the use of a consistent risk management approach should support the business process of oil sands companies' leaders. A consistent risk management approach could also lead to higher profit margins and long-term sustainable business. Leaders in other industries like mining and forestry could apply the AHP risks and mitigations ranking process to the risk management of projects that interface with the environment and need to comply with new regulatory requirements and legislation.

Implications for Social Change

This study in environmental compliance risk management could help the oil sands industry's leaders to attain greater compliance with the latest environmental and regulatory requirements from start to phase-out of their in situ oil sands projects. I did meet the objective of demonstrating the feasibility of the AHP process for identifying key compliance risks and mitigation strategies for oil sands projects. Company executives and project engineers implementing these risk management strategies may be consistent in their decision-making related to environmental issues and able to identify potential issues for new projects. Being proactive with environmental management may help companies' leaders to create a better impression with the public and local communities of their commitment to the environment and compliance with regulations. Successful risk management may improve the economic sustainability in other industries where public involvement is important to holistic sustainability (Boggia & Cortina, 2010). Further research may help with the development of a predictability model for future environmental regulatory compliance requirements. Such a model may support company executives and project engineers with managing the risk and developing mitigation strategies to ensure environmental regulatory compliance during the life cycle of in situ oil sands projects. Managers and engineers who understand the ranking of regulatory and environmental compliance risks and mitigation strategies would be better prepared to ensure future sustainability of their projects within the local community and natural environment.

Recommendations for Action

Oil sands company executives and project engineers should implement a risk management plan early in their in situ oil sands project to mitigate all risks related to environmental regulatory compliance. Moreover, following this recommendation would help ensure a sustainable project, while being compliant with provincial jurisdictions and observing responsible social strategy with the local community. I am a member of the Canadian Heavy Oil Association and my objective will be to publish or present the results of the study at the next annual conference to create better awareness of the outcome of the study. The research methodology, AHP, is an appropriate method for new projects with participation of project members, for ranking the risks and assuring identifying and catalyzing the implementation of mitigation strategies of specific projects. The pairwise comparison-specialized survey is applicable to in situ oil sands projects in Alberta and, with caution, outside Alberta. Project managers should implement the specialized survey early in their project to establish each project's specific ranking of risks, identifying and deploying counterbalancing mitigation strategies.

Recommendations for Further Study

Findings from this study might be one of the first discourses on the risk management of oil sands projects with a focus on identifying potential risks and preferred mitigation strategies, to ensure future regulatory and environmental compliance. The results indicated that the highest risks for in situ oil sands projects may be regulatory compliance and risks related to the environment. Future researchers might address the need for prediction of future trends in regulations and environmental requirements. Having the capacity to predict these trends would be helpful to project executives and engineers to implement mitigation strategies to ensure compliance at the end of the construction phase and start of the production phase. Researchers might address the change in the importance of risks with the life cycle change of the in situ facility.

The SMEs ranked the Level 2 subcriterion Implementation of Pressure Equipment Integrity Programs second for the Regulatory Compliance subcriteria. However, there remains a need to know if project managers might not implement these programs as a cost saving exercise. In that case, the production managers would have to implement the integrity program during the SAGD production phase and they could discover non-compliance issues. Researchers should consider further study of working hypothesis WH4 to determine if WH4o is true. Researchers could redefine WH4 to investigate the total benefit of implementing an early integrity management program rather than focus on cost benefit only.

In my study, I only addressed in situ oil sands projects in Alberta. Future researchers might expand the study coverage to other oil and gas projects. Future study coverage could include other projects interacting with the natural environment and the need to comply with local regulations and requirements such as forestry, paper and pulp, utility plants and mining. Further generalizations should include Canada-wide applicability and potential applications of the identified risks and mitigation strategies.

To improve the research methodology researchers could combine the AHP with other group decision-making techniques such as social choice theory (SCT) or the Delphi technique to allow for multiple iterations and agreement of the SMEs. The application of SCT with the AHP could help with group consensus in the final verification phase (Srdjevic, Pipan, Srdjevic, Blagojevic, & Zoranovic, 2013). Vidal, Marle and Bocquet (2011) proposed to use the Delphi technique to determine the complexity of the problem before using the AHP technique while Poompipatpong and Kengpol (2013) proposed to first use the AHP with SMEs followed with the Delphi method to improve consensus. The Delphi technique might be useful to determine the essential parameters of a complex management problem and then decision makers could use AHP to make the final decision (Etebarian, Shirvani, Soltani & Moradi, 2014).

An alternative research methodology would be to do the pairwise comparison-specialized survey in a group session with five to ten SMEs. An interactive focus group and AHP analysis with participants would allow immediate feedback to the group on inconsistency and aggregated results, an iterative process to improve consensus similar to the Delphi technique. The group of SMEs could review and discuss to obtain group consensus and possibly a better ranking of risks and mitigation actions. This approach could allow for addressing working hypothesis WH4 and further investigation.

I used the AHP technique to identify and rank complex criteria related to risk management in this study. I used the geometric mean aggregation method proposed by Saaty. I recommended for future research the use of Fuzzy AHP to study risk rankings with uncertainty being a factor and to avoid subjectivity. Ishizaka and Nguyen (2013) and Kharola (2014) recommended fuzzy analysis to limit subjectivity and for intuitive decisions. Radu and Stefanie (2013) supported the use of fuzzy theory to improve risk ranking of complex systems. Kubler, Voisin, Derigent, Rondeau, and Thomas (2012) proposed a fuzzy aggregate model as an improvement on the geometric mean aggregate model proposed by Saaty. Further research related to AHP could focus on inconsistency matrix correction. Programs such as SuperDecisions provide the AHP analysis with suggested corrections to the pairwise comparison matrix to improve the consistency. Making changes to the matrix to improve consistency could alter the SMEs original judgments (Wanderer, Karanik & Carpintero, 2013). Researchers could develop an algorithm to improve the consistency or to define a protocol for matrix correction without altering the intent of the SME’s judgment.

In this study, I addressed the ranking of risks and mitigation strategies. Further researchers could for example link the five highest ranked risk criteria to the alternative mitigation strategies. Linking risks and mitigation strategies would provide a comprehensive risk management plan to project managers; providing a much-needed improvement in oil sands project risk management (Bloomer, Jagoda, & Landry, 2010; Chanmeka, Thomas, Caldas, & Mulva, 2012).

Reflections

As an engineering manager involved in oil sands projects and as a responsible citizen, this study was of great interest to me. The Canadian engineering oath reminds all engineers of their responsibility not only towards their employers or clients, but also equally important, their responsibility to the public and the environment. Engineers' actions should contribute to a sustainable long-term society and environment. Conducting this study helped me to identify those risks and mitigation strategies that could help other engineers and senior company executives to act responsibly towards the public and the environment while executing in situ oil sands projects within the Alberta regulatory framework. The implementation of a risk management program would ensure the project is sustainable and compliant with regulations even if start-up happens 3 to 5 years after conceptual approval. My biggest disappointment during the execution of this study was the inability to reach senior executives of international companies and solicit their participation as SMEs in the survey. Executives of oil corporations changed company policies, after the BP Horizon oil spill, regarding the release of risk management, environmental policy, and jurisdictional compliance information. SMEs from these international companies declined to participate in the specialized survey.

Summary and Study Conclusions

The ranking of risk criteria applicable to in situ oil sands projects was, in order, (a) Regulatory Compliance, (b) Company Reputations/Post Incident, (c) Environmental Compliance, and (e) Economics and Financials. There was a clear indication of a long-term sustainable approach to in situ oil sands projects with an understanding of the relationship among regulatory compliance, environment, economics, and the public (company reputation/post incident). The mitigation strategies of in situ company executives and project engineers should focus on a Risk Reduction strategy rather than Risk Transfer, Risk Acceptance or Risk Avoidance mitigation strategies. Furthermore, executives should follow a multicriteria mitigation strategy for environmental and regulatory compliance. The identified environmental compliance risks and mitigation strategies in the oil sands industry in Alberta could be applicable to other provinces in Canada. However, applying the environmental compliance risk and mitigation strategy rankings to other provinces might need further research that review unique provincial regulatory requirements and include the participation of SMEs from these provinces.

A summary of my conclusions of this study is as follows:

- Risk management of environmental regulatory compliance of oil sands projects should be a primary strategy.
- AHP was an ideal MCDM method applied to the ranking of risks in the oil sands

industry.

- Understanding and ranking risks and mitigation strategies should improve environmental compliance.
- Regulatory compliance would lead to improved socioeconomic environment.
- A sustainable environment in the oil sands should increase public confidence.
- Environmental compliance of oil sands projects should be a global business requirement.

With future research based on the outcome of this study, my hope is for project engineers and executives to manage their oil sands projects successfully. To be truly successful, oil sands projects should not only be economically successful but should also be successful in the management of environmental compliance risks. Project engineers should implement mitigation strategies that would inspire public confidence in the sustainable future of oil sands extraction.

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Appendix A: Consent Form

You are invited to take part in a research study about environmental compliance risk management of oil sands in situ projects. You were chosen to participate in the study as a senior management member or senior project manager of an oil sands in situ project in Alberta. You are perceived to have the knowledge and experience with major projects, project risk management, and the regulatory compliance of in situ projects in Alberta. This form is part of a process called "informed consent" to allow you to understand this study before deciding whether to take part.

This study is being conducted by a researcher named Izak J. Roux P. Eng., who is a doctoral student at Walden University.

Background Information:

The purpose of this study is to identify and weigh the key environmental compliance risks and rank the most appropriate mitigation strategies. Experienced managers and engineers from Alberta oil sands companies will be surveyed. For large construction projects, including in situ oil sands projects, involving environmental changes a new primary risk may be added, that is compliance with environmental regulations. The environmental compliance risks will be identified as well as mitigation strategies to help management with the risk management of future in situ projects in Alberta.

Procedures:

If you agree to be in this study, you will be asked to:

- Participate in a survey to weigh environmental compliance risks and mitigation strategies (approximately 1 hour).
- Participate in a feedback review after the rankings of the risk and mitigations been determined (approximately 1hour)

Voluntary Nature of the Study:

This study is voluntary. Everyone will respect your decision of whether or not you choose to be in the study. If you decide to join the study now, you can still change your mind during or after the study. You may stop at any time.

Risks and Benefits of Being in the Study:

There is no risk associated with participating in this study. The benefit of participating in the study is that of helping to rank environmental compliance risks and mitigation strategies. This risk management knowledge may be applied to your current or future in situ projects.

Compensation:

There is no compensation for participating in the study. The researcher will provide an executive summary of the results to all participants and the researcher offer to make a presentation of the outcome of the study to your company executives. The presentation will be offered after the dissertation has been approved, and the researcher has formally graduated.

Privacy:

Any information you provide will be kept anonymous. The researcher will not use your personal information or the company name for any purposes outside of this research project. In addition, the researcher will not include your name or anything else that could identify you or your company in the study reports; however, the researcher may seek to publish the results of this study in scholarly journals. I shall keep the data secure by storing it on a CD disk in my home office for a period of at least 5 years as required by the university.

Contacts and Questions:

You may ask any questions you have now. Alternatively, if you have questions later, you may contact the researcher via telephone (780) 885-9883 or email izak.roux@waldenu.edu. If you want to talk privately about your rights as a participant, you can call Dr. Leilani Endicott. She is the Walden University representative who can discuss this with you. Her phone number is 1-800-925-3368, extension 1210. Walden University's approval number for this study is 04-16-14-0164187 and it expires on April 15, 2015.

The researcher will give you a copy of this form to keep.

Statement of Consent:

I have read the above information, and I feel I understand the study well enough to make a decision about my involvement. By returning a completed survey, I understand that I agree to the terms described above, and I confirm that my organization is supportive of my participation.

Printed Name of Participant ______________________

Date of consent ______________________

Participant's Written or Electronic Signature ______________________

Researcher's Written or Electronic Signature ______________________

Appendix B: Invitation Email and Letter of Cooperation

Sample Invitation Email

Dear Sir/Miss/Madame

With reference to our telephonic discussion, you are invited to participate in this survey. This will be an anonymous and voluntary survey, and all participants may quit at any time. The survey is in support of my doctoral study with the Technology and Management Faculty, Walden University, Minnesota, USA. The title of my dissertation is “Applying the Analytic Hierarchy Process to Oil sands Environmental Compliance Risk Management”.

The objective of this survey will be the determination of the ranking of environmental compliance risks and mitigation strategies. Your opinion as a senior executive (or senior project engineer) involved in SAGD projects will be required. Each participant’s inputs will be used along with other participants’ inputs to weigh the importance of environmental compliance risks and mitigation strategies. These inputs will determine the overall ranking of environmental compliance risks and mitigation strategies. The results of this study will be summarized in an executive summary and made available to all participants.

I thank you for participating in this survey and contributing to my research. Please complete a consent form and send it with your acknowledgement to the email address indicated. If you wish to receive a summary of the research results, please indicate so in an email to izak.roux@waldenu.edu

Thank you

Izak J. Roux, P, Eng.

Doctoral Student

Sample Letter of Cooperation from a Community Research Partner

Community Research Partner Name

Calgary

Alberta, Canada

Date

Dear Izak Roux,

Based on my review of your research proposal, I give permission for you to conduct the study entitled Applying the Analytic Hierarchy Process to Oil sands Environmental Compliance Risk Management within the Insert Name of Community Partner. As part of this study, I authorize you to recruit oil sands project experts who may participate in the specialized survey. Individuals' participation will be voluntary and at their discretion.

We understand that our organization's responsibilities include the following: Identify subject matter experts, introduce them to you and that no site intervention will be required. We reserve the right to withdraw from the study at any time if our circumstances change.

I confirm that I am authorized to approve research in this setting.

I understand that the data collected will remain entirely confidential and may not be provided to anyone outside of the research team without permission from the Walden University IRB.

Sincerely,

Authorization Official

Contact Information

Appendix C: Pairwise Decision Specialized Survey

Oil Sand *In Situ* Projects Environmental Compliance Risk and Mitigation Strategy Survey

The survey is divided into two parts. The first part focuses on risks contributing to environmental regulatory compliance. The second part of the survey focuses on the ranking of the mitigation strategies. The survey will be completed using the Excel spreadsheet attached to the email.

In the survey, you will be requested to compare two factors or two mitigation strategies at a time. It is important not to consider any other risk or mitigation strategy when doing the pairwise comparison. To compare two criteria A and B; they are either equal important, or A is more important than B or B is more important than A. The difference in importance is defined on a scale of 1 to 9.

Definition of Pairwise Comparison Scale

1	Equal
2	Low moderate
3	Moderate
4	Moderate plus
5	Strong
6	Strong plus
7	Very strong
8	Very very strong
9	Extreme

For example, the natural environmental risk has four subcriteria that need to be weighed using pairwise comparison. The subcriteria are

a. Air Pollution;

b. GHG Emissions;

c. Land use;

d. Water use.

Say you prefer *air pollution* moderately to *water use.* You think *land use* is very strong more important than *air pollution.* You may also consider *GHG emissions* to be *strong more important* than *water use.* If so, you will need to enter the pairwise comparison weights as follows:

Air Pollution	9	7	5	**X** **3**	1	3	5	7	9	Water Use
Land Use	9	**X** **7**	5	3	1	3	5	7	9	Air Pollution
Water Use	9	7	5	3	1	3	X 5	7	9	GHG Emissions

Note: The survey is designed to allow only one comparison of two criteria, for example, if you give an answer to “X vs. Y” once and you will not have to answer the question of “Y vs. X”.

Background Information

During the evaluation, design, and execution phases, project engineers and executives of in situ oil sands projects have to make decisions that affect the plant design. Their decisions will affect the plant's potential to comply with the future environmental legislation and regulations. It is important to develop a consistent risk management system for the project. At the beginning of a project, minimal environmental and process data may be available, and there is uncertainty about future environmental and regulatory requirements. The success of the project and the future sustainability depends on the environmental risk management strategy followed by decision makers and working with all stakeholders (Álvarez et al., 2013). The outcome of this study will provide a ranking of compliance issues relative to other characteristics of the in situ oil sands facility. The final ranking will help executives and project engineers to better management the risk under the uncertainty of future environmental compliance requirements. Better risk management should improve business sustainability and corporate environmental responsibility. Engineers and project managers who understand the potential regulatory compliance risk may have a better chance to complete the project successfully

Environmental risk imposes a threat to the natural environment and a social and economic threat to the communities in the province of Alberta. A better understanding of the criteria influencing future regulatory compliance might reduce project compliance risks. The identification and ranking of the environmental compliance risks and mitigation strategies will allow project managers to focus on the relevant risks and strategies early in the project life cycle.

Example:

Natural Environmental risks are *equally important* to Human environmental risks.

Natural Environmental risks are *strongly more important* than Political risks

Economic risks are *absolute more important* than Natural Environmental risks.

Natural Environmental risks	9	7	5	3	**1** **X**	3	5	7	9	Human environmental risks
Natural Environmental risks	9	7	**5** **X**	3	1	3	5	7	9	Political
Natural Environmental risks	9	7	5	3	1	3	5	7	**X** **9**	Economic

Note: Do not be concerned if you create inconsistencies by accident, the technique will take care of that. An example of inconsistency is if A is more important than B, and B is more important than C then A will be more important than C.

Definition of risks

1. Economic compliance risk;
2. Financial compliance risk;
3. Human environmental risks;
4. Political compliance risk;

5. Post Failure risk;
6. Regulatory compliance risk;
7. Reputational compliance risk;
8. Social compliance risk;
9. Technological compliance risk.

Rank the following compliance factors, using pairwise comparison (This list could change following the pilot survey)

1Economic compliance risk	9	7	5	3	1	3	5	7	9	2Financial compliance risk
1Economic compliance risk	9	7	5	3	1	3	5	7	9	3Human environmental risks
1Economic compliance risk	9	7	5	3	1	3	5	7	9	4Political compliance risk
1Economic compliance risk	9	7	5	3	1	3	5	7	9	5Post Failure risk
1Economic compliance risk	9	7	5	3	1	3	5	7	9	6Regulatory compliance risk
1Economic compliance risk	9	7	5	3	1	3	5	7	9	7Reputational compliance risk
1Economic compliance risk	9	7	5	3	1	3	5	7	9	8Social compliance risk
1Economic compliance risk	9	7	5	3	1	3	5	7	9	9Technological compliance risk
2Financial compliance risk	9	7	5	3	1	3	5	7	9	3Human environmental risks

2Financial compliance risk	9	7	5	3	1	3	5	7	9	4Political compliance risk
2Financial compliance risk	9	7	5	3	1	3	5	7	9	5Post Failure risk
2Financial compliance risk	9	7	5	3	1	3	5	7	9	6Regulatory compliance risk
2Financial compliance risk	9	7	5	3	1	3	5	7	9	7Reputational compliance risk
2Financial compliance risk	9	7	5	3	1	3	5	7	9	8Social compliance risk
2Financial compliance risk	9	7	5	3	1	3	5	7	9	9Technological compliance risk
3Human environmental risks	9	7	5	3	1	3	5	7	9	4Political compliance risk
3Human environmental risks	9	7	5	3	1	3	5	7	9	5Post Failure risk
3Human environmental risks	9	7	5	3	1	3	5	7	9	6Regulatory compliance risk
3Human environmental risks	9	7	5	3	1	3	5	7	9	7Reputational compliance risk
3Human environmental	9	7	5	3	1	3	5	7	9	8Social compliance risk

risks										
3Human environmental risks	9	7	5	3	1	3	5	7	9	9Technological compliance risk
4Political compliance risk	9	7	5	3	1	3	5	7	9	5Post Failure risk
4Political compliance risk	9	7	5	3	1	3	5	7	9	6Regulatory compliance risk
4Political compliance risk	9	7	5	3	1	3	5	7	9	7Reputational compliance risk
4Political compliance risk	9	7	5	3	1	3	5	7	9	8Social compliance risk
4Political compliance risk	9	7	5	3	1	3	5	7	9	9Technological compliance risk
5Post Failure risk	9	7	5	3	1	3	5	7	9	6Regulatory compliance risk
5Post Failure risk	9	7	5	3	1	3	5	7	9	7Reputational compliance risk
5Post Failure risk	9	7	5	3	1	3	5	7	9	8Social compliance risk
5Post Failure risk	9	7	5	3	1	3	5	7	9	9Technological compliance risk
6Regulatory compliance risk	9	7	5	3	1	3	5	7	9	7Reputational compliance risk

6Regulatory compliance risk	9	7	5	3	1	3	5	7	9	8Social compliance risk
6Regulatory compliance risk	9	7	5	3	1	3	5	7	9	9Technological compliance risk
7Reputational compliance risk	9	7	5	3	1	3	5	7	9	8Social compliance risk
7Reputational compliance risk	9	7	5	3	1	3	5	7	9	9Technological compliance risk
8Social compliance risk	9	7	5	3	1	3	5	7	9	9Technological compliance risk

Rank the following environmental risks, using pairwise comparison

Air Pollution	9	7	5	3	1	3	5	7	9	GHG Emissions
Air Pollution	9	7	5	3	1	3	5	7	9	Land Use/Footprint
Air Pollution	9	7	5	3	1	3	5	7	9	Water use
Air Pollution	9	7	5	3	1	3	5	7	9	Water Quality
GHG Emissions	9	7	5	3	1	3	5	7	9	Land Use/Footprint
GHG Emissions	9	7	5	3	1	3	5	7	9	Water use
GHG Emissions	9	7	5	3	1	3	5	7	9	Water Quality
Land Use/Footprint	9	7	5	3	1	3	5	7	9	Water use
Land Use/Footprint	9	7	5	3	1	3	5	7	9	Water Quality
Water use	9	7	5	3	1	3	5	7	9	Water Quality

Rank the following mitigation strategies, using pairwise comparison

risk acceptance	9	7	5	3	1	3	5	7	9	risk avoidance
risk acceptance	9	7	5	3	1	3	5	7	9	risk reduction
risk acceptance	9	7	5	3	1	3	5	7	9	risk transfer
risk avoidance	9	7	5	3	1	3	5	7	9	risk reduction
risk avoidance	9	7	5	3	1	3	5	7	9	risk transfer
risk reduction	9	7	5	3	1	3	5	7	9	risk transfer

Rank the following mitigation strategies, using pairwise comparison (This list could change following the pilot survey)

carbon capture and storage	9	7	5	3	1	3	5	7	9	create an environmental management plan(EMP)
carbon capture and storage	9	7	5	3	1	3	5	7	9	data collection before and during project execution
carbon capture and storage	9	7	5	3	1	3	5	7	9	develop a risk hierarchy
carbon capture and storage	9	7	5	3	1	3	5	7	9	implement a risk management strategy
carbon capture and storage	9	7	5	3	1	3	5	7	9	intent of a policy statement from the executive
carbon capture and storage	9	7	5	3	1	3	5	7	9	monitor project regulatory

										compliance
carbon capture and storage	9	7	5	3	1	3	5	7	9	recycle water/ closed water system
carbon capture and storage	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution
create an environmental management plan(EMP)	9	7	5	3	1	3	5	7	9	data collection before and during project execution
create an environmental management plan(EMP)	9	7	5	3	1	3	5	7	9	develop a risk hierarchy
create an environmental management plan(EMP)	9	7	5	3	1	3	5	7	9	implement a risk management strategy

create an environmental management plan(EMP)	9	7	5	3	1	3	5	7	9	intent of a policy statement from the executive
create an environmental management plan(EMP)	9	7	5	3	1	3	5	7	9	monitor project regulatory compliance
create an environmental management plan(EMP)	9	7	5	3	1	3	5	7	9	recycle water/ closed water system
create an environmental management plan(EMP)	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution
Data collection before and during project execution	9	7	5	3	1	3	5	7	9	develop a risk hierarchy

Data collection before and during project execution	9	7	5	3	1	3	5	7	9	implement a risk management strategy
Data collection before and during project execution	9	7	5	3	1	3	5	7	9	intent of a policy statement from the executive
Data collection before and during project execution	9	7	5	3	1	3	5	7	9	monitor project regulatory compliance
Data collection before and during project execution	9	7	5	3	1	3	5	7	9	recycle water/ closed water system
Data collection before and during project execution	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution
develop a risk hierarchy	9	7	5	3	1	3	5	7	9	implement a risk management strategy

develop a risk hierarchy	9	7	5	3	1	3	5	7	9	intent of a policy statement from the executive
develop a risk hierarchy	9	7	5	3	1	3	5	7	9	monitor project regulatory compliance
develop a risk hierarchy	9	7	5	3	1	3	5	7	9	recycle water/ closed water system
develop a risk hierarchy	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution
implement a risk management strategy	9	7	5	3	1	3	5	7	9	intent of a policy statement from the executive
implement a risk management strategy	9	7	5	3	1	3	5	7	9	monitor project regulatory compliance
implement a risk	9	7	5	3	1	3	5	7	9	recycle water/ closed

management strategy										water system
implement a risk management strategy	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution
intent of a policy statement from the executive	9	7	5	3	1	3	5	7	9	monitor project regulatory compliance
intent of a policy statement from the executive	9	7	5	3	1	3	5	7	9	recycle water/ closed water system
intent of a policy statement from the executive	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution
monitor project regulatory compliance leading	9	7	5	3	1	3	5	7	9	recycle water/ closed water system

edge technology										
monitor project regulatory compliance leading edge technology	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution
recycle water/ closed water system	9	7	5	3	1	3	5	7	9	water security - no unintentional pollution

Appendix D: Mitigation Strategy Questionnaire

Ranking of mitigation strategies

Definition of pairwise comparison scale

1	Equal important
2	Between equal and moderate important
3	Moderate more important
4	Between moderate and strong more important
5	Strong more important
6	Between strong and very strong more important
7	Very strong more important
8	Between very strong and extreme more important
9	Extreme more important

Rank the following mitigation strategies, using pairwise comparison

1 RIsk acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	2 Risk avoidance
1 RIsk acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3 Risk reduction
1 RIsk acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	4 Risk transfer
2 Risk avoidance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3 Risk reduction
2 Risk avoidance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	4 Risk transfer
3 Risk reduction	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	4 Risk transfer

Figure D1. Mitigation strategies specialized survey questionnaire for Level 1 criteria.

Rank the following mitigation strategies, using pairwise comparison																		
3.1 Carbon capture and storage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.2 Create an environmental management plan(EMP)
3.1 Carbon capture and storage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.3 Data collection before and during project execution
3.1 Carbon capture and storage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.4 Develop a risk hierarchy
3.1 Carbon capture and storage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.5 Implement a risk management strategy
3.1 Carbon capture and storage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.6 Monitor project regulatory compliance
3.1 Carbon capture and storage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.7 Recycle water/ closed water system
3.1 Carbon capture and storage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.8 Water security - no unintentional pollution
3.2 Create an environmental management plan(EMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.3 Data collection before and during project execution
3.2 Create an environmental management plan(EMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.4 Develop a risk hierarchy
3.2 Create an environmental management plan(EMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.5 Implement a risk management strategy
3.2 Create an environmental management plan(EMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.6 Monitor project regulatory compliance
3.2 Create an environmental management plan(EMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.7 Recycle water/ closed water system
3.2 Create an environmental management plan(EMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.8 Water security - no unintentional pollution
3.3 Data collection before and during project execution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.4 Develop a risk hierarchy
3.3 Data collection before and during project execution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.5 Implement a risk management strategy
3.3 Data collection before and during project execution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.6 Monitor project regulatory compliance
3.3 Data collection before and during project execution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.7 Recycle water/ closed water system
3.3 Data collection before and during project execution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.8 Water security - no unintentional pollution

Figure D2. Mitigations specialized survey questionnaire for Level 2 criteria (Part 1).

3.4 Develop a risk hierarchy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.5 Implement a risk management strategy
3.4 Develop a risk hierarchy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.6 Monitor project regulatory compliance
3.4 Develop a risk hierarchy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.7 Recycle water/ closed water system
3.4 Develop a risk hierarchy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.8 Water security - no unintentional pollution
3.5 Implement a risk management strategy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.6 Monitor project regulatory compliance
3.5 Implement a risk management strategy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.7 Recycle water/ closed water system
3.5 Implement a risk management strategy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.8 Water security - no unintentional pollution
3.6 Monitor project regulatory compliance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.7 Recycle water/ closed water system
3.6 Monitor project regulatory compliance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.8 Water security - no unintentional pollution
3.7 Recycle water/ closed water system	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3.8 Water security - no unintentional pollution

Figure D3. Mitigations specialized survey questionnaire for Level 2 criteria (Part 2)

Appendix E: Risks Specialized Survey Results

Table E1

Specialized Survey Results for Risks Level 1 Criteria

SAGD Project Regulatory Compliance								
Survey No.	Consistency	1 Economics and Financial	2 Environmental Risks	3 Political	4 Reputation/Post Incident	5 Regulatory Compliance	6 Social Compliance	7 Technological
	%							
A1	9.87	5.48	13.40	2.45	13.08	19.42	30.34	15.82
C2	9.62	21.18	13.69	6.45	15.99	12.24	3.94	26.52
C3	7.49	10.72	16.41	3.53	7.93	25.06	17.76	18.60
E1	8.03	8.95	5.46	3.57	15.71	51.28	6.59	8.45
H1	8.89	23.14	21.52	4.68	10.08	22.20	5.22	13.16
L1	8.76	15.19	4.93	3.05	40.66	13.17	5.78	17.22
L2	9.98	3.24	16.91	8.67	19.13	43.01	5.12	3.92
O1	6.73	11.91	14.33	3.78	27.41	13.33	4.68	24.56
O2	6.95	22.61	12.24	7.49	6.27	6.27	5.40	39.71
O3	9.23	18.31	20.26	4.11	25.43	12.83	7.15	11.91
P1	8.69	12.99	30.80	5.37	6.23	35.32	6.99	2.29
P2	9.73	9.33	36.24	2.14	17.73	24.53	4.07	5.96
P3	8.40	53.15	13.88	5.68	8.16	9.96	6.19	2.98

SAGD Project Regulatory Compliance								
Survey No.	Consistency	1 Economics and Financial	2 Environmental Risks	3 Political	4 Reputation/Post Incident	5 Regulatory Compliance	6 Social Compliance	7 Technological
	%							
P4	8.33	22.37	5.08	11.80	16.77	10.28	6.16	27.54
R1	8.91	8.59	14.03	6.05	11.95	21.72	8.95	28.72
S1	7.51	22.36	20.53	4.38	14.37	23.44	8.37	6.56

Table E2

Level 2 Subcriteria for Level 1 Criterion Economics and Financial Risk

	Economics and Financial Risks				
Survey No.	Consistency (%)	11 Cost of Exploration (%)	12 Plant Construction Cost (%)	13 Price of Land (%)	14 Project Financing (%)
A1	7.55	7.79	25.58	5.54	61.09
C2	6.64	54.56	30.01	6.20	9.23
C3	8.02	9.77	42.16	3.60	44.47
E1	6.95	15.93	19.96	8.44	55.67
H1	7.42	14.31	28.76	6.45	50.48
L1	8.93	14.19	18.24	61.44	6.14
L2	0.00	12.50	62.50	12.50	12.50
O1	5.79	16.86	61.32	12.26	9.56
O2	6.48	3.66	31.51	15.30	49.53
O3	7.34	46.80	38.82	5.98	8.40
P1	7.72	7.57	30.16	3.98	58.29
P2	7.96	53.21	4.91	15.83	26.06
P3	4.75	42.57	46.13	3.94	7.36
P4	5.36	27.83	18.28	9.59	44.30
R1	3.86	21.43	45.64	10.74	22.19
S1	6.91	8.84	43.15	3.93	44.08

Table E3

Level 2 Subcriteria for Level 1 Criterion Environmental Risk

		Environmental Risks	
Survey No.	Consistency (%)	21 Natural Environmental Compliance (%)	22 Human Environmental Compliance (%)
A1	0.0	17	83
C2	0.0	80	20
C3	0.0	20	80
E1	0.0	20	80
H1	0.0	50	50
L1	0.0	80	20
L2	0.0	50	50
O1	0.0	50	50
O2	0.0	80	20
O3	0.0	75	25
P1	0.0	15	86
P2	0.0	20	80
P3	0.0	86	14
P4	0.0	33	67
R1	0.0	50	50
S1	0.0	25	75

Table E4

Level 3 Subcriteria for Level 2 Criterion Natural Environmental Risk

Survey No.	Natural Environmental Risks					
	Consistency (%)	211 Air Pollution (%)	212 GHG Emissions (%)	213 Land use/ Footprint (%)	214 Water Use (%)	215 Water Quality (%)
A1	7.8	16.3	43.1	5.1	27.5	7.9
C2	5.1	10.3	17.8	3.9	24.7	43.1
C3	6.8	12.7	5.6	11.1	29.6	40.8
E1	7.0	22.8	19.5	8.7	13.1	35.8
H1	3.5	13.1	9.8	11.5	32.7	32.7
L1	8.1	7.9	4.5	13.3	30.7	43.6
L2	0.0	35.9	3.8	19.2	25.0	15.9
O1	4.4	14.1	4.5	14.1	33.6	33.6
O2	9.6	19.5	33.3	5.4	17.6	24.1
O3	7.3	5.2	24.9	7.4	22.1	40.3
P1	8.9	17.2	2.9	4.0	17.7	58.0
P2	8.6	9.0	13.7	37.5	25.4	14.2
P3	5.5	6.0	40.9	4.6	8.5	39.8
P4	8.3	20.3	8.6	19.1	11.2	40.7
R1	4.3	51.1	20.0	6.3	7.3	15.2
S1	6.7	10.1	5.2	17.3	38.2	29.1

Table E5

Level 3 Subcriteria for Level 2 Criterion Human Environmental Risk

Survey No.	Consistency (%)	Human Environmental Risks 221 Community Disturbance (%)	222 Socioeconomic Changes (%)
A1	0.0	87.0	13.0
C2	0.0	80.0	20.0
C3	0.0	50.0	50.0
E1	0.0	33.0	67.0
H1	0.0	75.0	25.0
L1	0.0	80.0	20.0
L2	0.0	50.0	50.0
O1	0.0	50.0	50.0
O2	0.0	80.0	20.0
O3	0.0	25.0	76.0
P1	0.0	85.0	14.0
P2	0.0	33.0	67.0
P3	0.0	14.0	86.0
P4	0.0	25.0	75.0
R1	0.0	67.0	33.0
S1	0.0	67.0	33.0

Table E6

Level 2 Subcriteria for Level 1 Criterion Political Risk

		Political Risk		
Survey No.	Consistency (%)	31Agreements with First Nations (%)	32 Presentations to Provincial MLAs (%)	33 Involve Local Municipality (%)
A1	0.89	58.76	8.90	32.34
C2	2.37	56.96	9.74	33.31
C3	0.00	50.00	25.00	25.00
E1	5.16	52.78	13.96	33.25
H1	5.16	52.79	13.96	33.25
L1	3.70	63.70	10.47	25.83
L2	5.16	41.26	25.99	32.75
O1	2.37	68.33	19.98	11.69
O2	0.36	64.83	22.97	12.20
O3	1.76	55.84	12.20	31.96
P1	5.16	57.36	6.50	36.14
P2	1.76	62.50	13.65	23.85
P3	3.11	65.86	7.86	26.28
P4	0.89	53.96	29.70	16.34
R1	5.16	59.36	15.71	24.93
S1	3.11	65.86	7.86	26.28

Table E7

Level 2 Subcriteria for Level 1 Criterion Regulatory Compliance Risk

		Regulatory Compliance Risks				
Survey No.	Consistency (%)	51 Comply with the Pipeline Act (%)	52 Comply with the Oil Sands Act (%)	53 Comply with the Safety Codes Act (%)	54 Implement a Pressure Equipment Integrity Program (%)	55 Implement a Pipeline Integrity Management Program (%)
A1	8.2	5.0	9.3	16.2	34.9	34.7
C2	8.3	20.5	10.7	6.6	58.3	3.9
C3	1.7	17.1	17.1	26.4	19.7	19.7
E1	8.8	5.7	5.7	50.8	30.0	7.8
H1	0.0	27.3	27.3	27.3	9.1	9.1
L1	5.1	5.1	10.9	10.4	51.8	21.8
L2	6.3	27.4	4.5	22.3	26.9	18.9
O1	2.0	27.0	29.2	24.9	10.9	7.9
O2	7.8	33.8	24.1	13.2	9.9	19.0
O3	4.4	9.4	13.9	41.7	17.5	17.5
P1	2.8	7.3	12.5	48.0	16.1	16.1
P2	5.5	18.2	14.6	35.2	22.7	9.4
P3	4.5	6.2	5.4	28.9	36.8	22.7
P4	2.4	11.5	14.5	39.0	22.7	12.3
R1	3.4	23.4	19.4	23.4	23.4	10.3
S1	9.7	28.6	15.2	21.1	20.4	14.7

Table E8

Level 2 Subcriteria for Level 1 Criterion Social Compliance Risk

Social Compliance Risk			
Survey No.	Consistency (%)	61 Implement Social/ Community Programs (%)	62 Employ Local People (%)
A1	0.0	16.7	83.3
C2	0.0	25.0	75.0
C3	0.0	50.0	50.0
E1	0.0	16.7	83.3
H1	0.0	16.7	83.3
L1	0.0	16.7	83.3
L2	0.0	50.0	50.0
O1	0.0	50.0	50.0
O2	0.0	33.3	66.7
O3	0.0	16.7	83.3
P1	0.0	14.3	85.7
P2	0.0	25.0	75.0
P3	0.0	14.3	85.7
P4	0.0	25.0	75.0
R1	0.0	25.0	75.0
S1	0.0	25.0	75.0

Table E9

Aggregated Risk Ranking per Level and Criteria Using Geometric Mean

Ranking	Criteria / subcriteria	Geometric Mean Weight (%)	Weight Normalized (%)
1	5 Regulatory compliance	19.28	22.78
2	4 Reputation/Post incident	15.15	17.90
3	2 Environmental Compliance	14.35	16.95
4	1 Economics and financial	13.01	15.37
5	7 Technological	11.92	14.08
6	6 Social compliance	6.66	7.87
7	3 Political	4.27	5.04
	Level 1 Project Risks Total	84.64	100.00
1	12 Plant construction cost	28.07	36.10
2	14 Project financing	24.47	31.47
3	11 Cost of exploration	16.76	21.56
4	13 Price of land	8.45	10.87
	Level 2 Economics & Financial Total	77.75	100.00
1	22 Human Environmental Compliance	48.11	55.64
2	21 Natural Environmental Compliance	38.35	44.36
	Level 2 Environmental Compliance Total	86.46	100.00
1	31Agreements with First Nations	55.87	57.75
2	33 Involve local municipality	26.84	27.74
3	32 Presentations to provincial MLAs	14.04	14.51
	Level 2 Political Total	96.75	100.00
1	53 Comply with the Safety Codes Act	23.07	26.71
2	54 Implement a Pressure Equipment Integrity Program	20.63	23.89
3	52 Comply with the Oil Sands Act	15.93	18.44
4	55 Implement a Pipeline Integrity Management Program	13.40	15.51
5	51 Comply with the Pipeline Act	13.34	15.45
	Level 2 Regulatory Compliance Total	86.37	100.00

Ranking	Criteria / subcriteria	Geometric Mean Weight (%)	Weight Normalized (%)
1	62 Employ local people	71.71	74.43
2	61 Implement social/community programs	24.64	25.57
	Level 2 Social Compliance Total	96.35	100.00
1	215 Water quality	27.85	32.37
2	214 Water use	23.51	27.32
3	211 Air pollution	15.02	17.46
4	212 GHG emissions	10.16	11.81
5	213 Land use/Footprint	9.50	11.04
	Level 3 Natural Environmental Compliance Total	86.04	100.00
1	221 Community disturbance	59.05	65.34
2	222 Socioeconomic changes	31.33	34.66
	Level 3 Human Environmental Compliance Total	90.38	100.00

Table E10

Overall Ranking of Risks, Highest to Lowest

Ranking	Criteria / subcriteria	Geometric Mean Weight (%)	Weight Normalized (%)
1	5 Regulatory compliance	9.17	12.38
2	2 Environmental risks	7.78	10.50
3	1 Economics and financial	7.25	9.79
4	4 Reputation/Post incident	6.84	9.23
5	7 Technological	5.52	7.45
6	22 Human environmental compliance	3.45	4.66
7	21 Natural environmental compliance	3.23	4.36
8	6 Social compliance	3.11	4.20
9	3 Political	2.51	3.39
10	53 Comply to the Safety Codes Act	2.46	3.32
11	62 Employ local people	2.28	3.08
12	12 Plant construction cost	2.08	2.81
13	14 Project financing	1.86	2.51
14	54 Implement a Pressure Equipment Integrity Program	1.81	2.44
15	221 Community disturbance	1.59	2.15
16	31Agreements with First Nations	1.43	1.93
17	52 Comply to the Oil Sands Act	1.38	1.86
18	222 Socioeconomic changes	1.38	1.86
19	51 Comply to the Pipeline Act	1.35	1.82
20	11 Cost of Exploration	1.32	1.78
21	55 Implement a Pipeline Integrity Management Program	1.16	1.57
22	215 Water quality	1.00	1.35
23	61 Implement social/community programs	0.74	1.00
24	33 Involve local municipality	0.63	0.85
25	214 Water use	0.63	0.85
26	13 Price of land	0.58	0.78
27	211 Air pollution	0.49	0.66
28	212 GHG emissions	0.38	0.51
29	32 Presentations to provincial MLA's	0.36	0.49
30	213 Land use/Footprint	0.32	0.43
	Total	74.09	100.00

Appendix F: Risks Survey Results (Normalized)

Table F1

Normalized Risks per Surveys, Aggregated Ranking N=16 (Part 1)

Risk Criteria per Level	Geometric Mean for N = 16 Surveys	σ²	σ	Aggregated Ranking for N = 16	A1	C2	C3
	%					Survey No. %	
1 Economics and financial	14.62	1.28	11.71	3	5.48	21.18	10.72
2 Environmental risks	15. 70	0.66	8.38	2	13.40	13.69	16.41
3 Political	5.06	0.05	2.41	7	2.45	6.45	3.53
4 Reputation/Post incident	13.79	0.50	7.34	4	13.08	15.99	7.93
5 Regulatory compliance	18.507	1.56	12.93	1	19.42	12.24	25.06
6 Social compliance	6.27	0.11	3.37	6	30.34	3.94	17.76
7 Technological	11.14	1.24	11.52	5	15.82	26.52	18.60
11 Cost of exploration	18.22	2.76	17.20	3	7.79	54.56	9.77
12 Plant construction cost	28.63	2.68	16.94	1	25.58	30.01	42.16
13 Price of land	8.005	0.25	5.14	2	5.54	6.20	3.60
14 Project financing	25.70	3.59	19.62	4	61.09	9.23	44.47

Risk Criteria per Level	Geometric Mean for $N = 16$ Surveys	σ²	σ	Aggregated Ranking for $N = 16$	Survey No. A1	C2	C3
	%				%		
21 Natural environmental compliance	41.46	6.12	25.60	2	16.67	80.00	20.00
22 Human environmental compliance	44.26	6.12	25.60	1	83.33	20.00	80.00
31 Agreements with First Nations	57.09	0.47	7.06	1	52.78	56.96	50.00
32 Presentations to provincial MLA's	14.34	0.50	7.29	3	13.96	9.74	25.00
33 Involve local municipality	25.24	0.57	7.80	2	33.26	33.31	25.00
51 Comply to the Pipeline Act	14.71	0.83	9.41	3	4.95	20.51	16.45
52 Comply to the Oil Sands Act	15.06	0.46	7.03	4	9.29	10.68	22.08
53 Comply to the Safety Codes Act	26.81	1.41	12.305	1	16.17	6.59	32.91
54 Implement a Pressure Equipment Integrity Program	19.69	1.44	12.43	2	34.90	58.30	14.28
55 Implement a Pipeline Integrity Management Program	12.60	0.32	5.88	5	34.68	3.92	14.28
61 Implement social/community programs	23.92	1.17	11.17	2	16.67	25.00	50.00
62 Employ local people	73.29	1.17	11.17	1	83.33	75.00	50.00
211 Air pollution	15.05	1.29	11.77	3	16.31	10.31	12.75

Risk Criteria per Level	Geometric Mean for N = 16 Surveys	σ²	σ	Aggregated Ranking for N = 16	Survey No. A1	C2	C3
	%				%		
212 GHG emissions	11.66	1.20	11.34	4	43.15	17.88	5.69
213 Land use/Footprint	9.79	0.76	9.03	5	5.09	3.97	11.11
214 Water use	18.61	0.95	10.08	2	27.49	24.71	29.62
215 Water quality	31.11	1.28	11.71	1	7.96	43.13	40.83
221 Community disturbance	46.24	5.97	25.28	1	87.50	80.00	50.00
222 Socioeconomic changes	39.97	5.97	25.28	2	12.50	20.00	50.00

Table F2

Normalized Risks per Surveys, Aggregated Ranking N=16 (Part 2)

Risk Criteria per Level	Geometric Mean for N = 16 Surveys	Aggregated Ranking for N = 16	Survey No. E1	H1	L1	O1
	%		%			
1 Economics and financial	14.62	3	8.95	23.14	3.24	11.91
2 Environmental risks	15.70	2	5.46	21.52	16.91	14.33
3 Political	5.06	7	3.57	4.68	8.67	3.78
4 Reputation/Post incident	13.79	4	15.71	10.08	19.13	27.41
5 Regulatory compliance	18.507	1	51.28	22.20	43.01	13.33
6 Social compliance	6.27	6	6.59	5.22	5.12	4.68
7 Technological	11.14	5	8.45	13.16	3.92	24.56
11 Cost of exploration	18.22	3	15.93	14.31	12.50	16.86
12 Plant construction cost	28.63	1	19.96	28.76	62.50	61.32
13 Price of land	8.00	2	8.44	6.45	12.50	12.26
14 Project financing	25.70	4	55.67	50.48	12.50	9.56
21 Natural Environmental Compliance	41.46	2	20.00	50.00	50.00	50.00
22 Human Environmental Compliance	44.26	1	80.00	50.00	50.00	50.00
31 Agreements with First Nations	57.09	1	52.78	52.79	41.26	68.33
32 Presentations to provincial MLA's	14.34	3	13.96	13.96	25.99	19.98
33 Involve local Municipality	25.24	2	33.25	33.25	32.75	11.69
51 Comply to the Pipeline Act	14.71	3	5.71	27.27	5.67	27.05

Risk Criteria per Level	Geometric Mean for N = 16 Surveys	Aggregated Ranking for N = 16	Survey No. E1	H1	L1	O1
	%		%			
52 Comply to the Oil sands act	15.06	4	5.71	27.27	15.53	29.19
53 Comply to the Safety Codes Act	26.81	1	50.81	27.27	34.43	24.90
54 Implement a Pressure Equipment Integrity Program	19.69	2	29.97	9.09	20.74	10.91
55 Implement a Pipeline Integrity Management Program	12.60	5	7.82	9.09	23.63	7.94
61 Implement social/ community programs	23.92	2	16.67	16.67	25.00	50.00
62 Employ local people	73.29	1	83.33	83.33	75.00	50.00
211 Air pollution	15.05	3	22.84	13.15	27.41	14.12
212 GHG emissions	11.66	4	19.54	9.80	4.46	4.55
213 Land use/ Footprint	9.79	5	8.75	11.54	22.32	14.12
214 Water use	18.61	2	13.06	32.75	26.89	33.61
215 Water quality	31.114	1	35.80	32.75	18.92	33.61
221 Community disturbance	46.24	1	33.34	75.00	83.33	50.00
222 Socioeconomic changes	39.97	2	66.67	25.00	16.67	50.00

Table F3

Normalized Risks per Surveys, Aggregated Ranking N=16 (Part 3)

Risk Criteria per Level	Geometric Mean for *N* = 16 Surveys	Aggregated Ranking for *N* = 16	Survey No. O2	Survey No. O3	Survey No. O4	Survey No. P1
	%		%			
1 Economics & Financial	14.618	3	14.33	22.61	18.31	22.37
2 Environmental Risks	15.697	2	24.10	12.24	20.26	5.08
3 Political	5.056	7	4.59	7.49	4.11	11.80
4 Reputation/Post Incident	13.788	4	28.43	6.27	25.43	16.77
5 Regulatory Compliance	18.497	1	13.98	6.27	12.83	10.28
6 Social Compliance	6.272	6	5.05	5.40	7.15	6.16
7 Technological	11.137	5	9.53	39.71	11.91	27.54
11 Cost of exploration	18.219	3	20.38	3.66	46.80	27.83
12 Plant construction cost	28.632	1	8.52	31.51	38.82	18.28
13 Price of land	7.995	2	20.38	15.30	5.98	9.59
14 Project Financing	25.701	4	50.72	49.53	8.40	44.31
21 Natural Environmental Compliance	41.457	2	75.00	80.00	75.00	33.33
22 Human Environmental Compliance	44.259	1	25.00	20.00	25.00	66.67
31 Agreements with First Nations	57.087	1	58.16	64.83	55.84	53.96
32 Presentations to provincial MLA's	14.338	3	10.95	22.97	12.20	29.70
33 Involve local Municipality	25.242	2	30.90	12.20	31.96	16.34
51 Comply to the Pipeline Act	14.706	3	20.00	33.82	9.40	11.53
52 Comply to the Oil sands act	15.061	4	20.00	24.10	13.89	14.49
53 Comply to the Safety Codes Act	26.811	1	20.00	13.16	41.68	39.03
54 Implement a Pressure Equipment Integrity Program	19.694	2	20.00	9.92	17.51	22.68

Risk Criteria per Level	Geometric Mean for N = 16 Surveys	Aggregated Ranking for N = 16	Survey No. O2	O3	O4	P1
	%		%			
55 Implement a Pipeline Integrity Management Program	12.597	5	20.00	19.00	17.51	12.27
61 Implement social/community programs	23.922%	2	25.00	33.33	16.67	25.00
62 Employ local people	73.292%	1	75.00	66.67	83.33	75.00
211 Air Pollution	15.053%	3	30.10	19.50	5.18	20.35
212 GHG Emissions	11.655%	4	19.92	33.31	24.91	8.68
213 Land use/Footprint	9.792%	5	8.85	5.38	7.44	19.07
214 Water use	18.613%	2	8.32	17.66	22.16	11.20
215 Water quality	31.114%	1	32.81	24.15	40.31	40.70
221 Community Disturbance	46.240%	1	25.00	80.00	25.00	25.00
222 Socioeconomic changes	39.973%	2	75.00	20.00	75.00	75.00

Table F4

Normalized Risks per Surveys, Aggregated Ranking N=16 (Part 4)

Risk Criteria	Geometric Mean for *N* = 16 Surveys	Aggregated Ranking for *N* = 16	Survey No. P2	P3	P4	R1	S1
	%		%				
1 Economics & Financial	14.618	3	12.99	9.33	53.15	8.59	22.36
2 Environmental Risks	15.697	2	30.8	36.24	13.88	14.03	20.53
3 Political	5.056	7	5.37	2.14	5.68	6.05	4.38
4 Reputation/Post Incident	13.788	4	6.23	17.73	8.16	11.95	14.37
5 Regulatory Compliance	18.497	1	35.32	24.53	9.96	21.72	23.44
6 Social Compliance	6.272	6	6.99	4.07	6.19	8.95	8.37
7 Technological	11.137	5	2.29	5.96	2.98	28.72	6.56
11 Cost of exploration	18.219	3	7.57	53.21	42.57	21.43	8.84
12 Plant construction cost	28.632	1	30.16	4.91	46.14	45.64	43.15
13 Price of land	7.995	2	3.98	15.83	3.94	10.74	3.93
14 Project Financing	25.701	4	58.29	26.06	7.36	22.19	44.08
21 Natural Environmental Compliance	41.457	2	7.57	53.21	42.57	21.43	8.84
22 Human Environmental Compliance	44.259	1	30.16	4.91	46.14	45.64	43.15
31 Agreements with First Nations	57.087	1	3.98	15.83	3.94	10.74	3.93
32 Presentations to provincial MLA's	14.338	3	58.29	26.06	7.36	22.19	44.08
33 Involve local Municipality	25.242	2	36.14	24.93	26.28	24.93	26.28
51 Comply to the Pipeline Act	14.706	3	7.3	18.19	6.2	23.42	28.61
52 Comply to the Oil sands act	15.061	4	12.5	14.6	5.37	19.41	15.16

Risk Criteria	Geometric Mean for *N* = 16 Surveys	Aggregated Ranking for *N* = 16	Survey No. P2	P3	P4	R1	S1
	%		%				
53 Comply to the Safety Codes Act	26.811	1	47.96	35.16	28.93	23.42	21.11
54 Implement a Pressure Equipment Integrity Program	19.694	2	16.12	22.65	36.84	23.42	20.39
55 Implement a Pipeline Integrity Management Program	12.597	5	16.12	9.41	22.67	10.32	14.74
61 Implement social/communit y programs	23.922%	2	14.29	25	14.29	25	25
62 Employ local people	73.292%	1	85.72	75	85.71	75	75
211 Air Pollution	15.053%	3	17.19	9.1	6.04	51.12	10.1
212 GHG Emissions	11.655%	4	2.99	13.72	40.99	20.05	5.21
213 Land use/Footprint	9.792%	5	4.05	37.52	4.64	6.29	17.3
214 Water use	18.613%	2	17.75	25.47	8.51	7.35	38.25
215 Water quality	31.114%	1	58.02	14.19	39.83	15.19	29.14
221 Community Disturbance	46.240%	1	85.71	33.33	14.28	66.67	66.67
222 Socioeconomic changes	39.973%	2	14.29	66.67	85.72	33.33	33.33

Appendix G: Mitigation Strategies Survey Results

Table G1

Specialized Survey Results, Consistency Check for N = 16

Level 2 - Risk Reduction Mitigation Strategies, Normalized Weights					
Survey No.	A1	C2	C3	E1	H1
Consistency (%)	8.19	8.86	8.80	8.25	5.60
3 Risk Reduction Strategy	Normalized Weight (%)				
3.1 Carbon capture and storage	21.09	2.34	7.33	2.35	2.18
3.2 Create an EMP	34.22	21.75	3.52	21.83	13.95
3.3 Data collection	6.18	4.09	5.74	4.23	20.24
3.4 Develop a risk hierarchy	3.68	5.71	3.60	5.28	5.76
3.5 Implement risk management strategy	15.93	6.81	9.88	6.82	11.54
3.6 Monitor project regulatory compliance	6.07	31.83	13.40	31.92	17.27
3.7 Recycle water/closed water system	10.60	16.73	24.29	16.80	22.15
3.8 Water security	2.23	10.75	32.25	10.76	6.91
Survey No.	A1	C1	C2	E1	H1
3 Risk Reduction Strategy	Idealized Weight (%)				
3.1 Carbon capture and storage	61.63	7.34	22.74	7.37	9.82
3.2 Create an EMP	100.00	68.34	10.91	68.38	62.98
3.3 Data collection	18.06	12.85	17.79	13.26	91.35
3.4 Develop a risk hierarchy	10.77	17.94	11.15	16.55	26.00
3.5 Implement risk management strategy	46.54	21.39	30.63	21.37	52.08
3.6 Monitor project regulatory compliance	17.74	100.00	41.56	100.00	77.96
3.7 Recycle water/closed water system	30.99	52.56	75.34	52.64	100.00
3.8 Water security	6.51	33.76	100.00	33.72	31.21

Table G2

Specialized Survey Results, Consistency Check for N = 16 (Continued)

Level 2 - Risk Reduction Mitigation Strategies, Normalized Weights					
Survey No.	L1	O1	O2	O3	O4
Consistency (%)	8.08	5.51	8.58	7.64	8.85
3 Risk Reduction Strategy			Normalized Weight (%)		
3.1 Carbon capture and storage	5.09	2.03	3.32	5.53	1.60
3.2 Create an EMP	3.45	16.75	12.44	6.14	7.18
3.3 Data collection	34.07	11.39	14.88	11.37	3.33
3.4 Develop a risk hierarchy	2.90	8.11	13.50	2.89	2.12
3.5 Implement risk management strategy	6.29	12.16	8.13	11.07	7.48
3.6 Monitor project regulatory compliance	23.35	11.78	12.59	10.27	38.46
3.7 Recycle water/closed water system	16.02	19.56	20.88	21.09	13.76
3.8 Water security	8.84	18.22	14.26	31.64	26.06
Survey No.	L1	O1	O2	O3	O4
3 Risk Reduction Strategy			Idealized Weight (%)		
3.1 Carbon capture and storage	14.93	10.39	15.89	17.47	4.17
3.2 Create an EMP	10.13	85.67	59.58	19.40	18.67
3.3 Data collection	100.00	58.25	71.30	35.95	8.65
3.4 Develop a risk hierarchy	8.51	41.45	64.68	9.15	5.50
3.5 Implement risk management strategy	18.47	62.16	38.92	34.98	19.46
3.6 Monitor project regulatory compliance	68.54	60.25	60.32	32.45	100.00
3.7 Recycle water/closed water system	47.02	100.00	100.00	66.66	35.78
3.8 Water security	25.96	93.18	68.33	100.00	67.77

Table G3

Specialized Survey Results, Consistency Check for N = 16 (Continued)

Level 2 - Risk Reduction Mitigation Strategies, Normalized Weights						
Survey No.	P1	P2	P3	P4	R1	S1
Consistency (%)	9.29	8.98	9.61	8.84	7.58	7.60
3 Risk Reduction Strategy	Normalized Weights (%)					
3.1 Carbon capture and storage	6.67	1.70	4.76	2.07	3.42	3.13
3.2 Create an EMP	6.52	6.45	10.12	3.15	14.85	10.44
3.3 Data collection	11.12	2.95	14.36	4.09	16.42	9.41
3.4 Develop a risk hierarchy	6.68	2.22	3.17	6.97	10.06	7.19
3.5 Implement risk management strategy	7.62	6.24	8.18	10.17	6.33	8.50
3.6 Monitor project regulatory compliance	10.37	34.10	3.03	3.35	31.74	20.09
3.7 Recycle water/closed water system	24.55	18.07	28.03	22.07	10.09	17.70
3.8 Water security	26.47	28.27	28.36	48.13	7.08	23.54
3 Risk Reduction Strategy	Idealized Weights (%)					
3.1 Carbon capture and storage	25.20	4.97	16.80	4.31	10.79	13.29
3.2 Create an EMP	24.65	18.91	35.68	6.55	46.78	44.36
3.3 Data collection	42.01	8.65	50.65	8.49	51.72	40.00
3.4 Develop a risk hierarchy	25.24	6.51	11.17	14.48	31.70	30.56
3.5 Implement risk management strategy	28.78	18.31	28.84	21.14	19.94	36.12
3.6 Monitor project regulatory compliance	39.17	100.00	10.69	6.95	100.00	85.38
3.7 Recycle water/closed water system	92.78	52.99	98.84	45.86	31.79	75.18
3.8 Water security	100.00	82.90	100.00	100.00	22.30	100.00

Table G4

Mitigation Strategies: Aggregated Weights for N = 16, Statistical Information

Level 1 - Alternative Mitigation Strategies	Arithmetic Mean	Geometric Mean	Maximum	Minimum	σ^2	σ
			%			
1 Risk acceptance	13.38	10.14	39.88	4.31	1.25	11.87
2 Risk avoidance	17.93	12.75	44.79	4.53	2.19	15.71
3 Risk reduction	27.69	27.08	38.53	19.93	0.59	6.17
4 Risk transfer	13.31	10.55	35.68	3.89	0.90	9.98
Level 2 - Alternative Risk Reduction Strategies	**Arithmetic Mean**	**Geometric Mean**	**Maximum**	**Minimum**	**σ^2**	**σ**
			%			
3.1 Carbon capture and storage	1.25	0.96	5.34	0.41	0.01	1.21
3.2 Create an EMP	3.47	2.60	8.67	0.78	0.07	2.75
3.3 Data collection	2.85	2.31	7.71	0.81	0.04	1.97
3.4 Develop a risk hierarchy	1.62	1.32	4.92	0.58	0.01	1.16
3.5 Implement risk management strategy	2.41	2.33	4.03	1.43	0.02	0.63
3.6 Monitor project regulatory compliance	5.43	3.97	12.31	0.76	0.15	4.08
3.7 Recycle water/closed water system	5.19	4.94	7.60	2.69	0.03	1.62
3.8 Water security	5.49	4.33	14.34	0.56	0.11	3.44

Table G5

Level 1 Alternative Mitigation Strategies, Results from AHP Analysis per Survey, Normalized, N = 16

Survey no.	Consistency	Level 1 - Alternative Mitigation Strategies			
		1 Risk Acceptance	2 Risk Avoidance	3 Risk Reduction	4 Risk Transfer
		(%)			
A1	6.27	8.07	10.25	33.91	47.78
C1	3.86	15.24	7.37	62.68	14.71
C2	0.39	11.42	12.25	39.59	36.74
E1	3.86	15.24	7.37	62.68	14.71
H1	4.07	5.53	55.24	28.31	10.91
L1	7.19	51.55	14.16	29.26	5.03
O1	1.63	9.55	55.96	24.96	9.55
O2	4.95	9.77	25.60	57.29	7.33
O3	9.57	8.81	56.21	27.16	7.83
O4	0.00	12.50	12.50	37.50	37.50
P1	5.79	12.50	12.50	37.50	37.50
P2	0.01	52.71	6.24	33.38	7.67
P3	2.22	37.36	10.22	42.44	9.98
P4	0.93	30.31	12.97	38.90	17.83
R1	3.31	7.63	32.57	48.32	11.49
S1	5.92	6.59	50.86	24.90	17.66

Table G6

Specialized Survey Results for Mitigation Strategies, Limiting Weights for Surveys 1 to 6

Mitigation Strategy Criteria	Aggregated Weight (%) for *N* = 16	Aggregated Ranking *N* = 16	Survey No. / Limiting Weights (%)					
Level 1 - Alternative Mitigation Strategy			A1	C2	C3	E1	H1	L1
1 Risk Acceptance	10.14	4	6.02	9.37	8.18	4.31	39.88	7.64
2 Risk Avoidance	12.75	2	7.65	4.53	8.77	43.05	10.96	44.79
3 Risk Reduction	27.08	1	25.32	38.53	28.36	22.07	22.64	19.97
4 Risk Transfer	10.55	3	35.68	9.04	26.32	8.50	3.89	7.64
Level 2 – 3 Risk Reduction								
3.1 Carbon capture and storage	0.96	12	5.34	0.90	2.08	0.48	1.15	0.41
3.2 Create an EMP	2.60	8	8.66	8.38	1.00	3.08	0.78	3.35
3.3 Data collection	2.31	10	1.56	1.58	1.63	4.47	7.71	2.27
3.4 Develop a risk hierarchy	1.32	11	0.93	2.20	1.02	1.27	0.66	1.62
3.5 Implement risk management strategy	2.33	9	4.03	2.62	2.80	2.55	1.42	2.43
3.6 Monitor project regulatory compliance	3.97	7	1.54	12.26	3.80	3.81	5.29	2.35
3.7 Recycle water/closed water system	4.94	5	2.68	6.45	6.89	4.89	3.63	3.90
3.8 Water security	4.33	6	0.56	4.14	9.15	1.53	2.00	3.64

Table G7

Specialized Survey Results for Mitigation Strategies, Limiting Weights for Surveys 7 to 11

Mitigation Strategy Criteria	Aggregated Weight (%) for N = 16	Aggregated Ranking N = 16	Survey no. / Limiting Weights (%)				
Level 1 - Alternative Mitigation Strategy			O1	O2	O3	O4	P1
1 Risk Acceptance	10.14	4	6.21	6.93	9.09	9.09	39.52
2 Risk Avoidance	12.75	2	16.28	44.20	9.09	9.09	4.68
3 Risk Reduction	27.08	1	36.42	21.36	27.27	27.27	25.03
4 Risk Transfer	10.55	3	4.66	6.16	27.27	27.27	5.75
Level 2 – 3 Risk Reduction							
3.1 Carbon capture and storage	0.96	12	1.21	1.18	0.44	0.46	1.19
3.2 Create an EMP	2.60	8	4.53	1.31	1.96	1.76	2.53
3.3 Data collection	2.31	10	5.42	2.43	0.91	0.80	3.59
3.4 Develop a risk hierarchy	1.32	11	4.92	0.62	0.58	0.61	0.79
3.5 Implement risk management strategy	2.33	9	2.96	2.36	2.04	1.70	2.05
3.6 Monitor project regulatory compliance	3.97	7	4.59	2.19	10.49	9.30	0.76
3.7 Recycle water/closed water system	4.94	5	7.60	4.50	3.75	4.93	7.01
3.8 Water security	4.33	6	5.20	6.76	7.11	7.71	7.10

Table G8

Specialized Survey Results for Mitigation Strategies, Limiting Weights for Surveys 12 to 16

Mitigation Strategy Criteria	Aggregated Weight (%) for N = 16	Aggregated Ranking N = 16	Survey no. / Limiting Weights (%)				
Level 1 - Alternative Mitigation Strategy			P2	P3	P4	R1	S1
1 Risk Acceptance	10.14	4	26.23	21.82	5.14	5.28	9.37
2 Risk Avoidance	12.75	2	7.18	9.33	21.96	40.72	4.53
3 Risk Reduction	27.08	1	29.80	28.00	32.58	19.93	38.53
4 Risk Transfer	10.55	3	7.00	12.84	7.74	14.14	9.04
Level 2 – 3 Risk Reduction							
3.1 Carbon capture and storage	0.96	12	0.62	1.87	1.12	0.62	0.91
3.2 Create an EMP	2.60	8	0.94	1.83	4.84	2.08	8.41
3.3 Data collection	2.31	10	1.22	3.11	5.35	1.88	1.63
3.4 Develop a risk hierarchy	1.32	11	2.08	1.87	3.28	1.43	2.04
3.5 Implement risk management strategy	2.33	9	3.03	2.13	2.06	1.69	2.63
3.6 Monitor project regulatory compliance	3.97	7	1.00	2.90	10.34	4.01	12.30
3.7 Recycle water/closed water system	4.94	5	6.58	6.88	3.29	3.53	6.47
3.8 Water security	4.33	6	14.34	7.41	2.31	4.69	4.15

Table G9

Specialized Survey Results for Level 2 criterion Risk Reduction Strategies – Normalized, N = 16

Survey no.	3.1 Carbon capture and storage	3.2 Create an EMP	3.3 Data collection	3.4 Develop a risk hierarchy	3.5 Implement risk management strategy	3.6 Monitor project regulatory compliance	3.7 Recycle water/ closed water system	3.8 Water security
					%			
A1	21.09	34.22	6.18	3.68	15.93	6.07	10.60	2.23
C2	2.34	21.75	4.09	5.71	6.81	31.83	16.73	10.75
C3	7.33	3.52	5.74	3.60	9.88	13.40	24.29	32.25
E1	2.35	21.83	4.23	5.28	6.82	31.92	16.80	10.76
H1	2.18	13.95	20.24	5.76	11.54	17.27	22.15	6.91
L1	5.09	3.45	34.07	3.00	6.29	23.35	16.02	8.84
O1	2.03	16.75	11.39	8.11	12.16	11.78	19.56	18.22
O2	3.32	12.44	14.88	13.50	8.13	12.59	20.88	14.26
O3	5.53	6.14	11.37	2.89	11.07	10.27	21.09	31.64
O4	1.60	7.18	3.33	2.12	7.48	38.46	13.76	26.06
P1	1.705	6.45	2.95	2.22	6.24	34.10	18.07	28.27
P2	4.77	10.12	14.36	3.17	8.18	3.03	28.03	28.36
P3	2.07	3.15	4.09	6.97	10.17	3.35	22.07	48.13
P4	6.67	6.52	11.12	6.68	7.62	10.37	24.55	26.47
R1	3.42	14.85	16.42	10.06	6.33	31.74	10.09	7.079
S1	3.13	10.44	9.41	7.19	8.50	20.10	17.70	23.54

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I like to adopt/adapt a table with the 1 to 9 scale in my dissertation.

Curriculum Vitae

Roux Izak Johannes

[Izak.Roux@rouxengineer.com]

EDUCATION

Doctorate in Business Administration (in progress) - *Walden University*

- Dissertation: “Applying the Analytic Hierarchy Process to Oil Sands Environmental Compliance Risk Management”

M. Engineering (Mechanical) - *University of Pretoria, South Africa*

- Thesis: System Engineering applied to early Prototyping and Testing.

B. Engineering (Mechanical) Honours - *University of Pretoria, South Africa*

B. Engineering (Mechanical) - *University of Pretoria, South Africa*

Advanced Executive Programme, University of South Africa (equivalent to Executive MBA)

- Dissertation: Product Development.

Production Management Diploma - *Damelin College, Johannesburg, South Africa*

PROFESSIONAL AFFILIATIONS

Registered Professional Engineer, Alberta, Saskatchewan, Manitoba and NWT

Member, American Society of Mechanical Engineers

Committee Member, ASME code PCC3 (RBI) and subgroup Welding repairs for PCC2 (Repair and Testing)

Sub-Committee Member, APEIA 2014 & 2015 conference

Boiler and Pressure Vessel Technical Council Member, Safety Codes Council, Vice Chair, July 2010 – present

Committee Member, Canadian Standards Association B51 Boiler, Pressure Vessel and Pressure Piping Standard, 2010 – present

Senior Member, Aerospace and Aeronautical Institute of America (until 2012)

Member, Edmonton Transportation Board, 2012 – present

Member, South African Institute of Mechanical Engineers 1976 – 2004

Member, South African Council of Engineers, 1976 – 2004

PAPERS AND PRESENTATIONS

"Applying the **Analytic Hierarchy Process** to Oil Sands Environmental Compliance Risk Management" International Symposium Analytic Hierarchy Process 2014, Washington DC

"Total Asset Integrity for a new SAGD Project" NACE Conference 2013, Victoria, BC

"Risk Assessment Doing Phased Array UT vs. Radiography – Based on Field Results", Oil and Gas Expo & Conference, North America 2011, Calgary, Alberta.

"Risk Assessment Doing Phased Array UT vs. Radiography – Based on Field Results", IPEIA Conference, Banff, 2011

"Total Integrity Programs in Alberta, Canada", API Inspection Summit, Galveston, Texas, 2011

"There's a Crack in My Vessel! A first order assessment criterion of crack-like flaws to be used by field inspectors", IPEA Conference Banff, 2007

"Unusual Inspections of Pressure Equipment", API Inspection Summit, Galveston, Texas, 2007

"Total Asset Integrity Management", IPEA Conference, Banff, 2004

"Total Asset Integrity implementation", Power Conference, Toronto, 2004

"Evaluation and Testing of Complex Logistics Systems", SOLE International Conference, 1996

"Fatigue Analysis of Helicopters", South African International Aeronautical Conference, 1986

PROFESSIONAL EXPERIENCE (PARTIAL LIST)

Roux Consulting Edmonton, Alberta, CA

2013- present

Focus on Engineering, Operational and Risk management. Implementation and development of business, engineering, risk and quality management systems.

RAE Engineering & Inspection Ltd. Edmonton, Alberta, CA

President 2008-2013

Technical Manager 2003-2013

Denel Aviation South Africa

Engineering Manager (Chief Designer Rooivalk Helicopter Project) 2000-2002

RSAT	South Africa
Manager and Chief Engineer	1988-2000
Lautus Developments Ltd	South Africa
Owner/Director	1989-1995
Atlas Aircraft Corp.	South Africa
Structural Analysis Manager and Project Engineer	1984-1987
Projects Expedited Ltd	South Africa
Mechanical Engineer. NDE Manager	1980-1984
Atlas Aircraft Corp.	South Africa
Mechanical Engineer	1979-1980
South African Air Force	South Africa
Engineering Officer	1977-1978