RISK PROFILE MODELING FOR LARGE SCALE PROJECTS: CASE STUDY OF A TRANSMISSION LINE PROJECT

by

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ABSTRACT

Over the next several years in North America, the power grid needs to be revitalized and extended to deal with aging infrastructure, capacity constraints, and the pursuit of renewable energy sources. In Canada, and particularly the province of BC, very significant complexity and risk is involved in the approval, design and construction of such projects given highly variable terrain and weather conditions, the multiplicity of the environmental, First Nations, and third part stakeholder issues involved, and challenging regulatory and procurement processes. Described in this research is a holistic approach to the identification of risk as a function of project context, the representation of which is made difficult in the context of transmission line projects because of their large spatial scope and the vast volume of data of different types to be distilled and analyzed. Central to the approach is the representation of a project within an integrated environment in the form of multiple views of a project – product, process, participant, environment and risk. Treatment of the first four views aids the identification of risk drivers for a risk event. Knowledge of risk drivers assists with expressing likelihood of occurrence of a risk event and the magnitude of impacts should it occur, and selecting the most appropriate risk response. Application of the approach to a 255 km 500 KV design-build transmission line project is featured and challenges involved in developing its risk profile highlighted. How data visualization can assist development of a project’s risk profile and facilitating insights into it is also demonstrated. The use of the holistic approach described for the development of a project’s risk register and mining its contents using data visualization to generate useful insights has proven to be of significant value to project personnel.
PREFACE

A version of Chapter 2 will be submitted for possible publication. Shorter and less fully developed versions of the work presented in Chapter 2 have been submitted and accepted for presentation and inclusion in the proceedings of two conferences: Russell, A., Orozco, D. (2013). Modeling and managing construction risk. *New Developments in Structural Engineering and Construction, ISEC-7*, June 18-23, 2013. Honolulu, U.S.; and Russell, A., Orozco, D. (2013). Modeling Risk for a transmission line project. *4th Construction Specialty Conference, CSCE*, May 29-Jun 1, 2013. Montreal, Canada. I was responsible for the data gathering and analysis of the case study. I conducted the development of the project model views, and the project risk register. As well, I explored data mining through the use of data visualizations. The use of a research tool developed at UBC (Repcon) by Russell, A. was utilized to integrate the risk approach in a complete model and create other built-in visualizations.

A collaboration with the joint venture FLATIRON-GRAHAM© made possible the opportunity to analyze and assess their ongoing design-build project, a 255 km, 500 KV transmission line project named Interior to Lower Mainland (ILM) Project. In-kind contributions of the joint venture to the research effort consisted of access to the project’s data in the project office, and meetings with project personnel to clarify project technical documentation.
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DEDICATION

To my dear family, my parents Pascual and Marcela, and siblings Christian and Monse, as well as to my beloved Mayra, for their constant love, motivation, support, and patience.
CHAPTER 1. THESIS OVERVIEW

1.1 INTRODUCTION

This research thesis is a manuscript-based document describing a holistic, integrated approach to risk management and its application to large scale infrastructure projects, specifically transmission line projects. The work described builds on previous research about risk management, project modeling, data visualization, and knowledge transfer. It seeks to identify and address the challenges involved in risk profiling large scale geographically distributed projects and interpreting the risk profile in order to manage the risks involved.

The specific goals of the thesis are several. First, a description of selected features of a highly structured, integrated approach to risk management for large scale projects, with emphasis on linear projects is provided. Second, application of the approach is demonstrated by way of a case study on a 255 km 500 KV transmission line design-build project currently in progress in British Columbia. Third, an overview of how data visualization can assist in extracting valuable insights from the large scale data sets that accompany such projects is given. Fourth, an approach for structuring potential responses to risks is presented in aid of assisting with selection of a risk response strategy. The thesis concludes with commentaries and discussion on the practical challenges involved in risk management for large scale, geographically dispersed projects and how the use of a structured risk model approach results in significant value for the construction industry.

The topic of risk management for capital projects has been treated by many academics as well as practitioners (e.g., ICE, 2005; WSDOT, 2010; Wideman, 1992; Rolstadås, 2011; and Leung et al., 1998). In most cases, it is treated as a standalone, spreadsheet-based function, which seldom capitalizes on the formal representations of a project used in support of other project management functions. As a result, an opportunity is lost in terms of linking risk events and attendant properties to specific project features expressed in terms of a consistent vocabulary. Also lost is the opportunity to gain insights on how best to respond to individual risk events as well as categories of risks. These observations along with the
complexity of modern large scale infrastructure projects have provided motivation for the work described herein. Introduced in the sections that follow is an analysis on the state-of-art of risk management.

1.2 MOTIVATION & BACKGROUND

The importance of transmission line projects around the globe is noteworthy due to the increasing demand for power (e.g., Europe, Asia and North America are significant energy consumers) (Blanco et al., 2010). For example, over the next several years in North America the power grid will be revitalized and extended to deal with aging infrastructure, new technologies, capacity constraints, forecasted load demands and the pursuit of renewable energy sources such as wind and solar. In the US alone, more than 65,000 miles of transmission line work will be required by 2020. According to the Western Electricity Coordinating Council (WECC) 10-Year Regional Transmission Plan (WECC, 2011), the need to build future transmission and generation projects in Western North America is influenced by recognizing the potential economic benefits of transmission expansion to the grid. Delay in building could result in diminished opportunities to realize these economic benefits, inadequate power supply, and high operational and maintenance costs. WECC has presented a list of 44 major transmission projects to be constructed by 2020, adding at least 5,500 line miles of 200kV and above lines. The estimated capital cost of the projects envisaged totals some $20 billion (WECC, 2011).

In Canada, the increase in demand for electricity is growing quickly leading to the need to rapidly develop generation and transmission capacity. For example, in Alberta the Alberta Electric System Operator (AESO) highlighted in their Long-term Transmission Plan a cost estimate for the projects anticipated to be in service by 2020 of some $13.5 billion (AESO, 2012). In British Columbia, the utility provider BC Hydro is expecting that over the next 20 years the demand for energy could grow by as much as 50% before accounting for savings that could be achieved by current conservation and efficiency or demand-side measures (BC Hydro, 2012).

Other references to upcoming projects in North America include: "$10 billion in transmission lines for wind power proposed in Michigan to bring green power to Wisconsin and several other states from windier
areas, including Minnesota, Iowa and the Dakotas” (Content, 2009), “New Transmission Lines to Link Texas Cities with Future Wind Farm Development” (Russell, 2012), a “company plans to unveil Wyoming-Nevada transmission line plan in March 2013, $3.5 billion 900-mile project capable of transporting 3000MW of wind power)” (Voge, 2013) and, “$2.2 billion CapX2020 project to modernize Minnesota’s electrical grid and capture wind energy” (Neal, 2013).

Particularly for the province of BC, very significant complexity and risk is involved in the approval, design and construction of such projects given highly variable terrain and weather conditions, great sensitivity to environmental issues, First Nations issues, third party stakeholder issues, challenging regulatory processes and offshore procurement of components. Interestingly, the academic and practitioner literature directly relevant to risk management for transmission line projects is small (e.g., Beehler, 2009; Burchett et al., 1999; and Tummala & Burchett, 1999).

Other literature directed at risk identification, mitigation and environmental issues as it relates to transmission line projects includes: Kalkani & Boussiakou (1996), Marshall & Baxter (2002), Yamatani & Jahangir (2011), Blanco et al. (2010), and Public Service Commission of Wisconsin (2011). Also reviewed was literature focused on design and construction challenges dealing with variable geotechnical conditions, environmental permits, temperature conditions in different geographical locations and design flexibility (e.g., McCall et al., 2009; Lakhapati, 2009; and Wyman, 2009).

A risk management approach for large capital construction projects that includes a formal model representation of project context and corresponding components and attributes can be exploited so as to gain value in terms of insights into a project’s risk profile and risk responses. An additional benefit is that expressing the structure of the model in a consistent structure and vocabulary allows the approach to be applied to future projects by benefitting from the capture of lessons learned from current and past projects. Considering the work documented in part by De Zoysa (2006), Russell & Nelms (2007), and Nelms (2012) which in turn builds on previous work by Russell & Udaipurwala (2004), validation and
enrichment of the approach could benefit from its application to a full-scale case study, in this case, a transmission line project.

Treated in the following sections of this chapter are the challenges and detailed contributions of the work. Special attention is focused on identifying key risk issues for each of the project phases, and how the project views with relevant attributes can act as a risk driver for specific risk events. Also important is the documentation of lessons learned about project modeling and the introduction of a risk response register together with exploration of data visualization to generate insights into a project’s risk profile.

1.3 OBJECTIVES

Objectives guiding the research work and the findings related to these objectives, the realization of which in turn corresponds to the thesis contributions, are:

1) Examine challenges involved in **modeling large scale linear projects** for purposes of risk management as well as other construction management functions;

2) Observe current **industry** risk management **practices**;

3) Explore the benefits of a specific **way of thinking** about **Risk Management** in which project context is formally treated;

4) Identify **challenges** involved in:
   a. Articulating potential **risk events**, and identifying factors or **drivers** that create risk events;
   b. **Quantifying** likelihood of occurrence and impact;
   c. Identifying appropriate **risk responses**;
   d. Modifying likelihood and impact estimates given specific risk responses;

5) Explore **data visualization** approaches to extract insights from a project’s risk register in order to determine where to focus management resources and to assist in selecting the most appropriate risk response;

6) Examine how best to **transfer knowledge** gained on one project to future ones – i.e., explore the role of knowledge management to assist with future projects and training of personnel;
7) Provide an **assessment** of the strengths and weaknesses of the way of thinking about risk management adopted and how it assists management personnel; and,

8) Although not a primary objective, comment on user **interface** issues in a multi-view project model that should be addressed in future work.

### 1.3.1 RESEARCH CHALLENGES

The most important challenges for risk management for large scale projects relate to: modeling issues such as how best to structure the model, how to represent variable geographical location conditions, and the lack of homogeneity and significant size of data and information. Related challenges deal with project context complexity (e.g., environmental, regulatory processes, third party stakeholders) and how best to identify and represent this complexity within the model in order to capture the essence of reality. Another challenge is the difficulty in modeling long-linear projects when contractor personnel need to pursue an opportunistic strategy in order to perform the work due to restrictions imposed by environmental windows, third party stakeholder difficulties, permitting difficulties, etc. And finally, there is a considerable challenge in identifying key risk issues, risk drivers, risk events, and relevant explicit attributes of drivers contributing to the existence of a potential risk, as well as quantifying risks and structuring a risk response register.

### 1.4 METHODOLOGY

Research methodology steps pursued to carry out the research are captured in Figure 1.1; each step contains a short description and scope of work. Bounding the scope of the work was important to maximize the usefulness of the results.
For the literature review, the following sources of literature were examined: academic and practitioner literature on the topics of risk management, the anatomy of transmission line projects, risk management approaches for transmission line projects, knowledge management in construction, project modeling, and visualization. The review and analysis of the literature is presented in sections 1.5 Modeling large scale projects, 1.6 Transmission line projects, and 1.8 Procurement mode influence – design build.

The idea to select a case study to apply the risk modeling approach outlined in this research is the best way to test out the approach by working with a representative real scale example of a transmission line project. The case study – Interior to Lower Mainland (ILM) transmission line project– done by the Flatiron-Graham joint venture (JV) was partitioned into 5 sections and each section was partitioned further into a number of subsections by the JV for the practical reasons explained in Chapter 2. In order to facilitate an in-depth understanding, section 1 was selected to be modeled extensively. General components from the other sections were also modeled and analyzed, but a special focus on project and risk modeling work was made only for the first section of the ILM project. Involvement with the project started by way of e-
mail communication with the VP of Engineering of Flatiron. After receiving and reviewing the proposal, Flatiron expressed interest in participating in the research, from which followed a meeting at the ILM site office in March 2012 to discuss the possibility of associating with their project in order to develop a risk profile of the ILM project. The interest of the JV to participate in the research was driven in part by their desire to seek a competitive advantage in the short-term by documenting their experience on this their first transmission line project.

As an in-kind contribution, the JV provided access to project data, involvement in the project office and meetings with project personnel to clarify project documentation. During the following months, relevant project documentation was reviewed including, but not limited to: Environmental Assessment Certificate (EAC), Certificate of Public Convenience and Necessity (CPCN) Application, Environmental management plans, Access management plans, project schedules, contracts, engineering documents (e.g., alignment, clearing, Right-of-Way, environmental protection plans, geotechnical assessment and hazard reports, avalanche assessment reports, foundation and transmission tower drawings), quality control plan, safety plan, and site construction management plan.

During the document review phase, several meetings were held with JV staff members (project controls manager, project engineer and scheduler) in the project site office. Communication continued on an ongoing basis by phone and e-mail to ask questions about ILM project technical information. Parallel to this process, work started on developing the project model context and risk register using the proposed risk management approach. Significant progress in the research was achieved by September 2012. This progress provided an opportunity to get involved in the project site office during 6 weeks on a daily basis with the purpose of refining and expanding the risk modeling work by asking clarifying questions to project personnel (e.g., environmental, safety, construction, controls, and administration managers, First Nations consultants, procurement engineers, project manager, transmission line experts JV staff and project manager of the transmission line work subcontractor), participating in clarification meetings, reviewing further details in project documentation, and seeking feedback on an ongoing basis with respect to risk register contents and project context in order to capture the reality of project conditions.
After gathering all the necessary information, discussing the contents of the risk register for completeness and clarity of information, and presenting preliminary results of the project’s risk profile to project personnel, the research focus was to complete the risk register and project model in order to explore the use of data visualization to: (i) provide insight on the project risk profile during risk identification and assessment, (ii) understand the contents of a risk register, and (iii) assist the process of decision making for the project risk response strategy. The use of a research system tool from UBC (called ‘Repcon’) was used to model the project context views, risk register and data visualization. Additionally, other data mining tools were explored to develop relevant visualizations. Finally, the risk response strategy was developed and represented with the aid of data visualization tools. Documentation of the foregoing facilitates the capture of lessons learned and transfer of knowledge gained for use on future infrastructure projects. Further detail about each of these processes is presented in Chapter 2. The results were shown to the JV personnel by way of a formal presentation. Present were the project director, corporate risk manager, project controls manager, and controls engineer. Goals of the presentation were to communicate the research findings and receive feedback from industry personnel. JV staff members were very satisfied with the results; they found very useful the risk management approach used, especially the risk register structuring content as well as the proposed visualizations in order to provide understanding of project’s risk profile.

1.5 MODELING LARGE SCALE PROJECTS

1.5.1 RISK MANAGEMENT IN INFRASTRUCTURE PROJECTS AND INFORMATION TECHNOLOGY (IT) APPLICATION

Provided in this section of the thesis is an overview of the state-of-art of risk management processes with emphasis on their application to infrastructure projects. The discussion that follows it treats the application of Information Technology (IT) in support of knowledge management, directed at how best to capture lessons learned in a structured way for future use in risk management. Then discussed are the strengths and weaknesses of the state-of-art of risk management processes analyzed. This is followed by the introduction of the holistic risk management approach adopted for the identification of risk as a function of
project context in large scale infrastructure projects. This section concludes with comments on the specific contributions derived from applying the integrated multiple view risk management approach to a sizeable transmission line project case study.

Risk is present in all projects, and can be defined as an uncertain outcome or event that could occur inflicting a favorable or unfavorable effect if it occurs. If the outcome is favorable it is considered an opportunity, and if the event occurrence has an unfavorable outcome then it is considered as a risk (Wideman, 1992). Complementing these definitions, ICE (2005) defines risk as the potential impact of all the threats (and opportunities) which can affect the achievement of the objectives for an investment. A number of frameworks that aim to structure a risk management process have been reviewed in the academic and practitioner literature (e.g., ICE, 2005; Wideman, 1992; PMI, 2008; WSDOT, 2010; Chapman & Ward, 2003; Leung et al., 1998; Rolstadás, 2011; Al-Bahar & Crandall, 1990; Hillson, 1999; and Dey, 2010). The focus of the research is not to describe in detail each of the risk frameworks available in the state-of-art. Nevertheless, it is important to comment on the similarities and differences in approaches proposed, and assess the contribution of these approaches to the field of risk management along with the corresponding limitations.

The Institution of Civil Engineers and the Faculty and Institute of Actuaries (ICE), have developed a comprehensive and systematic process for identifying, evaluating and managing risks in capital investment projects. The process is named RAMP, an acronym for Risk Analysis and Management for Projects; it covers the entire project life cycle (ICE, 2005). The RAMP process includes four activities that subdivide into the specific processes shown in Figure 1.2. Of particular interest are Risk review activity processes which include risk identification to be entered into a risk register, risk assessment by determining the likelihood and impact of a specific risk, identification of potential risk mitigation measures, re-assessment of identified risks, implementation of risk management and risk response plans, and communication which also forms part of knowledge management practices.
The integration of risk management with other project management functions is elaborated upon by Wideman (1992) in his risk management guide book for projects. Poor performance in other project management functions (e.g., cost, quality, scope, and time) is related to the risk of unforeseen and foreseen events not being treated properly. Wideman (1992) breaks down project risk management into four process phases:

1) **Risk Identification** – Identify and classify by category as: external but unpredictable, external predictable but uncertain, internal-non-technical, technical, and legal.

2) **Risk Assessment** – Screening, Probability of occurrence vs. severity of consequences, quantification of risk, modeling, and reports.

3) **Risk Response** – Define system standards, insurance, and planning alternatives.

4) **Risk Documentation** – Collect historical database, current project database, and post-project assessment and archive.

Figure 1.2 – ICE (2005) RAMP process
Wideman’s (1992) guide book is based on Project Management Institute (PMI) standards. And in a similar way, the PMI objectives regarding project risk management are to increase the probability and impact of positive events, and decrease the probability and impact of negative events in a project (PMI, 2008). The PMI provides their framework for project risk management processes, which is as follows:

1) **Plan risk management** – Define how to conduct risk management activities.

2) **Identify risks** – Determine which risks may affect the project and document their characteristics.

3) **Perform qualitative risk analysis** – Prioritize for further analysis or action by assessing and combining their probability of occurrence and impact.

4) **Perform quantitative risk analysis** – Numerically analyze the effect of identified risks on overall project objectives.

5) **Plan risk responses** – Develop options and actions to enhance opportunities and reduce threats to project objectives.

6) **Monitor and control risks** – Implement risk response plans, track identified risks, monitor residual risk, identify new risks, and evaluate risk process effectiveness.

A number of practitioners and researchers have adopted or developed similar structured frameworks. For example, the Washington State Department of Transportation (WSDOT, 2010), has developed its own project risk management guide – a framework based on PMI (2008). The goal is to provide a consistent methodology, techniques and tools, and guidance on how to proactively respond to risks, all while fitting in with the overall project management processes at WSDOT.

Certain risk management tools tend to be very general, making it somewhat difficult to extract meaningful insights from modeling the risk profile of a project. Al-Bahar & Crandall (1990) proposed a risk model providing a formal, logical, and systematic tool entitled Construction Risk Management System (CRMS) with the purpose being to assist contractors in identifying, analyzing, and managing risks in a construction project. Their systematic analytical approach starts with **risk identification** and its mapping, probabilistic **risk analysis and evaluation** of significant risks, the development of alternative **risk response management** strategies, finishing with **system administration** which considers the formulation of
corporate risk policies, and review and monitoring the CRMS model in order to complete the system. The linkage between the processes provides a closed-loop feedback to update information in the system.

There exist newer non-traditional approaches in the project management field that have led to a different concept about project risk. The work by Rolstadås (2011) is a good example of this. He introduces a risk management approach in which three different types of risks exist. Each of them is a function of the interaction within three domains: corporate management, project management, and the project’s environment. The overlapping of the three domains creates what Rolstadås called an “ocean” containing the project risks (Operational, Strategic, and Contextual risks). The project risk approach is referred to as “Bermuda Project Risk Triangle”. Its framework contains three major components: the governance system, the decision process, and strategic planning. This framework proposes a modification of and extension to project management practices in order to implement new risk navigation strategies – how to treat risk throughout the duration of the project. These changes in the process seek to change the mindset of the management team in order to be adaptable, flexible and dynamic. Figure 1.3 illustrates the extended version of the “Bermuda Project Risk Triangle” approach with the representation of the risk navigator framework components and its attributes.
Dey (2010) has been working on developing an integrated framework for managing project risk by analyzing risk across project, work package and activity level risks. His approach not only combines risk management processes (e.g., identification, analysis, and development of responses) in an analytical framework but also integrates them with the entire suite of project management processes that can be applied to complex projects and throughout the project life cycle. It also makes use of the analytic hierarchical process (AHP) to analyze project risk and to select the least risky options at different levels (project, work package, and activity). AHP is a multiple criteria decision-making technique that allows for the consideration of objective and subjective factors. In a typical hierarchy, the top level would be the overall objective of the decision problem, then the elements affecting the decision represents the intermediate levels, and the lowest level comprises the decision options. The effectiveness of the risk management framework proposed by Dey (2010) has been demonstrated through a case study application – a 1500 km oil pipeline construction project. The framework consists of the following steps

1) **Identify alternative projects**;
2) **Analyze project level risks** and select the least risky project using AHP *(Identify risk factors and sub-factors, develop hierarchical model, compare pair wise factor and sub-factor levels in order to develop their importance in terms of probability of occurrence and impact, compare alternative projects with respect to each sub-factor to derive severity of each project, synthesize results across the hierarchy to determine relative severity of projects and risk ranking);*

3) **Develop scope** of selected project using work breakdown structure (WBS);

4) **Analyze work package level risks** using a risk map *(develop a risk map with likelihood or risk occurrence and impact, identify risky work packages, identify risky factors and sub-factors for each work package, derive their severity by placing them on the risk map)*;

5) **Develop risk responses** for each sub-factor at the work package level;

6) **Analyze activity level risks** using the risk map *(identify risky activities within each risky work package, identify risky factors and sub-factors for each activity, derive their severity by placing them on the risk map);* and

7) **Develop risk responses.**

An aspect that also should be considered in risk management frameworks is the knowledge transfer system through which risk management lessons learned could be re-used in new projects. Before discussing the importance of Information Technology (IT) for knowledge management, introduced is a methodology for risk management proposed by Leung et al. (1998) called Risk Management Process (RMP). The RMP starts by **identifying the corporate business plan** together with the associated **project mission, aim and objectives** to outline a strategy that will function as a driver during the RMP methodology.

On the other hand, based on the corporate strategy, **risk identification, risk measurement, and risk assessment** processes constitute the basic set of tools to identify potential risk factors, and enumerate and assess the impact of consequences and likelihood of occurrence of the identified risk factors. The **risk evaluation** process consists of evaluating and taking decisions on alternatives based on the risk profile and choosing the most appropriate responses to contain and control the risks. Finally, the **risk**
control and monitoring process serves to communicate and enhance a periodic review of project progress and status within the project management team.

Information Technology is used to support risk management practices and knowledge transfer. The purpose is to assist the thought process during the project risk and project context modeling process in order to structure a complete project risk profile. IT also has the advantage of capturing risk information in a project-neutral format in order to facilitate re-use on future projects. Leung et al. (1998) introduced the concept of a knowledge-based system (KBS) as a computer program enriched with certain proven human knowledge and expertise to model the problem solving ability of human experts. Leung et al. (1998) explain how KBS is applicable to other areas of study such as construction project management (e.g., cost estimating, claim management, management decision making, and scheduling). The KBS logic stored in a computer system can be used to link and identify relationships between risk factors, corresponding project risks and related work packages. For example, Leung et al. (1998) applied a KBS to develop a structured and comprehensive prototype software tool using the RMP methodology that could be used at any stage of the project life-cycle. Benefits include the lessened time and effort required to identify and assess risks and to develop risk response actions. Modeling the knowledge-based system consisted of three basic steps: (i) cause analysis (input work activities and risk factors based on the current project environment); (ii) project risk identification (searching the knowledge database to identify all potential project risks); and, (iii) identification of risk-related work packages (in relation to the corresponding identified project risks).

The prototype was constructed using as its base project an extra-high voltage (EHV) overhead transmission line construction project. The system provides a way to perform risk management in a more efficient and structured way, assists in reporting to managers the existence of project risks and their relationship with risk factors, and shows the risk-related work packages that correspond to the project risks identified. A system like this one provides an effective and systematic way to transfer knowledge, and collect and update the expertise of users continuously for reuse on future works. Although a system like this requires continuous development and updates according to user needs and technology progress,
it serves to demonstrate the importance of IT in support of the risk management function for large scale projects.

In order to incorporate a knowledge management approach in an IT based risk management framework, it is important to consider not only the technology factor, but also other dimensions of knowledge management. Jashpara (2004) cited the following dimensions of knowledge management: (i) systems & technology; (ii) strategy; (iii) culture; and, (iv) organizational learning. When systems & technology are directly linked to organizational learning (exploration, exploitation, and knowledge sharing) and to strategy (intellectual capital, and organizational performance), and indirectly to culture (change management, and implementation), if the IT system is not developed considering all of the factors involved in the transfer of knowledge within a company, it will encounter barriers for its successful implementation. According to Carrillo & Chinowsky (2006) the main challenges faced in implementing knowledge management in construction companies are:

- Not enough time;
- Organizational culture;
- Lack of standard work processes; and
- Insufficient funding.

Other barriers highlighted are: lack of management support, employee resistance to sharing, poor IT infrastructure, a “Not invented here” culture, accessing/developing knowledge management not being mandatory, and lack of a real-time integrated database. Carrillo & Chinowsky (2006) explored knowledge management practices from an engineering and construction perspective and detected that there is growing recognition of the benefits of knowledge management for construction firms. Some of the assessed firms were able to demonstrate how its knowledge management initiatives had clearly impacted on winning new projects and business growth. However, these results were seen as being attributable to their existing business development processes, rather than to specific knowledge management activities.
The risk management literature is vast and a significant number of tools / procedures are available that range from quite simple to very complex. Although the risk management processes described by various authors vary from each other in terms of different scopes and description of processes and terminology, one can identify certain core elements which are common to all these approaches. These core elements include (i) Risk identification, (ii) Risk assessment, (iii) Risk response, and (iv) Risk control and monitoring. But there are a number of shortcomings in current processes with respect to treating risk within an integrated framework including knowledge management. Amongst these shortcomings is the poor embedment of project risk with project context. This leads to another important issue related to the question, “How best to represent project context?”

Some authors have not attempted to develop a comprehensive risk management approach. Rather, they have focused on treating specific processes that form part of a risk management framework (Leung et al., 1998; Hillson, 1999; Dey, 2010). On the other hand, other authors have proposed extensive risk management frameworks that cover all of the core elements of risk management and include as well additional processes with a series of steps to carefully follow. However, these additional steps may make implementation of the associated framework too difficult to achieve, or if implemented, provide a process that is very tedious and time consuming to use, and without the benefits promised (ICE, 2005; PMI, 2008; Wideman, 1992; Al-Bahar & Crandall, 1990). Non-traditional approaches that involve a significant change in the way to develop a framework for risk management work has some appeal; nevertheless the level of effort to implement such a framework has not yet been tested on actual projects, making it difficult to judge the merits of such a framework (Rolstadås, 2011).

The inability to integrate project risk information with explicit representations of project context also interferes with the attempt to re-use the contents of risk registers for future projects. Even though various authors have proposed frameworks, tools or methodologies for risk identification, analysis, and response development, seemingly little work has been done on developing an integrated risk management approach (e.g., Dey, 2010; De Zoysa, 2006; Leung et al., 1998; and Rolstadås, 2011). Further, there are very few frameworks and accompanying studies that link risk analysis outcomes with risk response
strategies (e.g., Hillson, 1999; Dey, 2010; Al-Bahar & Crandall, 1990). An integrated approach to project risk management not only combines the risk management processes of identification, analysis and development of responses in an analytical framework, but also integrates risk management processes with the entire project management process (Dey, 2010). For example, Leung et al. (1998) developed the RMP methodology (including risk identification, measurement, assessment, evaluation and risk control and monitoring processes) that was applied to a framework for managing cost risk for an EHV transmission line project, but did not integrate cost risk with schedule and project quality related risks. Dey (2010) proposed an integrated framework for project risk management that includes an analytical hierarchical process, which quantifies risk, deals with project time and cost parameters, and considers a few aspects of environment and construction process but doesn’t treat risk by specific locations. As proposed, the framework could be difficult to navigate in pursuit of insights once the risk profile is developed, given the complex structure used to represent each of the project work package and activity levels across each project phase (feasibility, planning, implementation, etc.).

Another shortcoming of current approaches is the structure of risk registers and how to manage them, which makes difficult the task of making modifications to the risk register caused by a dynamic changing project context, a situation particularly relevant to large scale linear projects. Also when a large number of risks are present along with the significant information that accompanies each risk, it becomes difficult to navigate through the risk register, hampering the risk management process and the opportunity to gain insights from the risk register. The lack of use of consistent terminology in defining the risk register and project context during the risk management process and after it when preparing the information for re-use in future projects, could lessen the opportunity to transfer knowledge effectively. Another disadvantage of current approaches is that knowledge is mostly captured as a static instance, also lessening the ability to add lessons learned. This is because large scale project context component modeling including the risk register structure requires an extended period of time to develop due to the sizeable scope of such projects and attendant documentation and number of participants involved and uncertain and changing project conditions.
The support for risk management frameworks through the use of knowledge-based approaches has some limitations. For example, an attempt to develop a rule-based system would likely result in a very large set of rules that would not be readily understood by users and would require experts to maintain it. Typically, knowledge-based systems have been limited by their authors to supporting a subset of project types, such as oil pipelines or transmission lines (Dey, 2010; and Leung et al., 1998). Also, the treatment of project context in knowledge-based systems as described in the literature is thin. The approaches proposed by Leung et al. (1998) and Rolstadås (2011) treat aspects of environmental and organizational components as risk factors, but the components modeled within these systems are few in number compared to the ones that a large scale project would need in order to properly represent project context.

In terms of execution of a risk management method, some risk management frameworks focus only on certain processes and little attention is given to other stages in the overall risk management process. For example, ICE (2005) identifies risk management process limitations as including: concentration of the treatment of risks in the asset creation phase rather than on potentially higher risks in other project stages (e.g., construction, and procurement); lack of a satisfactory method for combining risks when in many cases the risks treated separately are interdependent; little attention to changing risk exposure during the investment life cycle; the tendency to focus on risks which can be most easily quantified without the exercise of proper judgment to get a good feel for other risks involved; and, an inadequate follow through from project risk analysis to the control of risks once project implementation starts.

Despite many useful contributions by others with respect to managing risk and related knowledge, including a number of best practices and lessons learned, a considerable amount of work remains to be done in order to develop an approach that meets most if not all of the challenges encountered in risk management, especially as applied to large scale construction projects. A more detailed literature review and analysis as it relates to the topic of the state-of-art for risk management and knowledge-based methodologies can be found in the work made by De Zoysa (2006).
Before introducing the risk management approach adopted for the research work described herein, it is important to define the terminology for the key concepts used recursively in this thesis. The definitions used have been elaborated from a synthesis of literature references presented in De Zoysa (2006). The term ‘Risk issue’ is used to refer to keywords that represent topic areas of direct relevance to a project, around which uncertainty or lack of predictability may exist. A risk issue may result in multiple risk events, and consequent uncertainty in one or more project performance measures. The term ‘Risk event’ corresponds to the potential variability in a project parameter from its anticipated value, or one or more discrete scenarios in which the possible states of nature that can be realized can be identified, but the one which will actually occur as well as its outcome is not known with certainty. A risk event can apply to the project as a whole, i.e., its sphere of influence is global, or it can be local in terms of its immediate influence and hence treatment. The term ‘Risk Driver’ relates to the components of the physical, process, participant, and environmental domains, the presence of which or characteristics of which make a risk issue relevant to a particular project phase and context component. A risk driver represents the relationship between the project context and the risks of a project.

A brief overview of the holistic risk management approach utilized in support of the research described in this thesis is presented here. This approach has been developed over an extended time period, and its evolution has been documented in part in the work by De Zoysa (2006), Russell & Nelms (2007), and Nelms (2012) which in turn builds on previous work by Russell & Udaipurwala (2004), focused on the multi-view representation of a project in support of key project/construction management functions, inclusive of risk management.

In terms of application of the risk management approach adopted, while multiple pathways of use are supported because practitioners demand flexibility, the following front-end steps provide insights on how the approach can be applied. These steps are also depicted in Figure 1.4:

1) Define the four project context views of product, process, participant and environment (see Figure 1.5): This is an iterative process which can benefit from lessons learned on past projects. It is useful to define the context views prior to holding a risk identification session. Additional important
information often gets teased out in a risk identification session which further assists in characterizing a project’s context.

2) Set up the structure of the project risk register and define risk issues deemed relevant to the applicable project life cycle phases (e.g., macro-economic risks, political risks, contract interpretation risks, etc.). Again this can benefit from documentation of past experience, especially with respect to risk issue headings.

3) Identify risk events that apply to the overall project under the relevant risk issue (e.g., risk event: *bearing conditions significantly different than anticipated* under risk issue: *geotechnical* along with relevant drivers. Risk events are associated with a location, whether a specific location instance (e.g., Tower Location T1001_A), or a location defined to represent a collection of locations (e.g., S1_A for section 1 A of a transmission line project or GLOBAL to reflect the entire project). Assigning risks to a spatial location facilitates the development of a spatial distribution of risks which assist with the overall risk management process.

4) Identify other risk events that directly impact one or more specific project components by walking through one or both of a summary level schedule of the project and the spatial context for the project phase at hand, and ask the question: *Does this risk issue apply?* It is observed that for projects that have a large, complex spatial dimension (e.g., a transmission line project), much of the project’s risk profile is derived from consideration of the spatial context in concert with the environmental view. If the risk issue applies, seek to identify individual risk events; if no, move on to the next risk issue until all risk issues have been examined, including the need to define new ones. Then repeat for other summary activities and/or spatial elements. As part of steps 3 and 4, it can also be helpful to identify which components of the four project views might be impacted should the risk event occur (e.g., activities whose duration could be lengthened, environmental components that could suffer damage, etc.).

5) Once the risk register has been populated, assess likelihood and impacts in a qualitative way, after calibrating risk identification participants in terms of likelihood of occurrence and impact scales. Maintaining velocity in a risk identification session is essential – trying to definitively
quantify risks during the first pass through a risk register results in a loss of momentum and protracted discussion which takes away from the process.

6) Complete the process of associating risk drivers and impacted components to specific risk events.

7) Generate insights into the contents of the project risk register in aid of seeking appropriate responses to risk using various data mining tools (e.g., data visualization) in order to determine the clustering of risks in terms of one or more of time, space, participant, product, process step, environmental component, the relative importance of various view components as drivers of risk, the relative importance of individual risks and risk issues in project phases, etc.

8) Develop a risk response register and identify suitable responses under the response categories of avoid, transfer, share, retain. As part of assigning suitable responses to individual risks or risk issues, seek responses which address drivers associated with multiple risks, thereby leveraging the benefits achieved by each response.

9) Follow-up steps to the foregoing not elaborated upon here as part of the overall risk management approach are the re-estimation of likelihood of occurrence and impact given any responses implemented, the identification of any additional risks associated with the responses selected, the use of quantitative as opposed to qualitative risk assessment of likelihood and impact, achieving buy-in from selected project participants/decision makers, and documenting and communicating the project’s risk profile to those charged with the tasks of risk control and monitoring.

The risk management context that accompanies the foregoing steps relates to the perspective of the contractor tasked with executing the project, including any design and commissioning duties as part of the contractual form employed. For this context, relative versus absolute value of risk is most important, as construction personnel must determine how best to allocate limited resources. For the case where ‘absolute’ quantitative assessment of risk is required (e.g., public sector comparator analysis as part of determining which project procurement mode to employ), a more fine-grained and quantitative assessment of risk is required. Such an assessment can be very time consuming, and in some cases trying to assign a value to a specific risk can be very problematic.
As presented in the objectives of the research and correlating them with the research contributions described later in this chapter, explored is the use of a risk management approach for large scale projects, specifically a transmission line project, for the purpose of:

- Having the opportunity to test and refine the approach by way of a case study on a full scale project.
- Discerning lessons learned about how best to model a risk profile and how to organize risk management knowledge. This includes the definition of the hierarchical classification structure of a risk register (i.e., category, issues, events) and the use of structured templates for project context views (physical, process, environmental and participant).
- Determining how best to treat complexity when assessing a large scale project, given the very large data sets involved – it becomes important to define and identify what really is relevant for the risk profile of the project in terms of the project context components and their attributes.
- Making a first attempt to define a comprehensive risk response hierarchical classified structure that is useful for affecting knowledge transfer, gaining insights during the risk response strategy.
selection and decision making, and leveraging the responses by classes and ability to treat multiple risk events. Work on risk response to date has not been well developed and defined. The current literature is either too general or inconsistent about the risk response process (e.g., Al-Bahar & Crandall, 1990; Dey, 2010; Hillson, 1999; WSDOT, 2010; PMI, 2008; and ICE, 2005): in most of the cases in the literature no formal structure to plan and develop the risk response for a project is treated.

- Exploring the use of Data Visualization to analyze a project’s context in relation to risk and generate insights from the risk profile during the risk modeling process and to capture knowledge in order to understand the meaning of risk in a project.

1.5.2 PROJECT MODELING FOR RISK MANAGEMENT

Fundamental to the way of thinking about risk management in particular and construction management functions in general is use of an abstracted yet comprehensive representation of a project in terms of multiple views (e.g., product, process, participant, environmental, change, as-built, risk, etc.). Such an approach is of significant value in terms of offering an integrated approach to management functions. It has been described in some detail by Russell & Udaipurwala (2004).

In structuring the views for the risk model approach the use of hierarchical structures proves to be very effective for handling complexity and scale. One can work at different levels of detail or granularity depending on the aspect of the project being analyzed. For example, in describing potential risk events and their properties (e.g., likelihoods, impacts, drivers, etc.), the use of a classification by issues and project phases can help in providing an overview of the project risk register at a managerial level; for detailed risk analysis and assessment, one can drill down into specific details at the individual risk event level.

To represent project context in support of the risk management function, five views are employed as follows:

- Physical – what is to be built and site context;
- Process – how, when, where and by whom;
- Organizational/contractual (participant) - Project teams and parties, contractual obligations & entitlements, insurance, bonding, warranties, and evaluation of participant performance;
- Environmental – the natural and man-made environments that accompany the project; and,
- Risk – project risk and response registers reflecting a specific viewpoint (e.g., client, contractor, overall project) with events that could be encountered, drivers, response measures and outcomes.

These five project views are depicted in Figure 1.5. The use of this multi-view approach is of significant value because risk drivers arise from all five views (including the risk view itself, as additional risks may arise from the risk response strategy adopted). As well, identifying the most appropriate responses to an individual risk can benefit from a thorough understanding of event drivers and their attributes.

![Image of Figure 1.5](image)

**Figure 1.5 – Representation of a project in the form of integrated views**

Regarding project modeling, use is made of IT for knowledge management and operation of the risk management approach through an integrated multi-view project representation (physical, product, participant, environmental, and risk). The supporting data structures have been developed and implemented previously within a research system at UBC called ‘Repcon’. This system is programmed in
C++ and makes use of a Pervasive relational database for data storage, and the API ChartFX tool (Software FX Inc., 2012) to create built-in data visualizations. Further detail on this system tool has been explained and documented by De Zoysa (2006).

Russell & Nelms (2007) analyzed other commercial software tools (e.g., RiskEasy, Risk Radar, PertMaster Project Risk, and RiskCom) to support risk management functions. While these tools are useful for the purpose for which they were designed, a number of shortcomings exist. For example, the disconnection between risk management and other project management functions leads to the inability to integrate a project risk register with project context. This limits the exploitation of knowledge management concepts, and the ability to use visualizations or other cognitive tools to support the identification, assessment and response processes of risk management.

An advantage of the adoption of the Repcon system as an integral part of the research methodology for the work described herein is that it facilitates an integrated approach to the tasks of risk identification and elicitation, and provides a standardized platform in which risk terminology is made explicit by the use of the multi-view representation of a project with hierarchical structures of components, combined with the ability to profile component attributes and the possibility to forge associations amongst view components.

1.5.3 DATA VISUALIZATION FOR INFRASTRUCTURE PROJECTS

Data visualization can play an important role in generating insights into a project’s risk profile both during and post development of a project risk register. This assists with the challenge of interpreting register to facilitate the ongoing management of risks. A virtue of data visualization is its ability to portray large amounts of data in very compact form.

Building on the work of De Zoysa (2006) and Nezafatkhah (2011), one of the themes to develop further is the identification and implementation of advanced data visualization strategies to assist with viewing, navigating and understanding the hierarchical representations of the project context and risk views.
The exploration of the representation of a project by the use of data mining tools (e.g., interactive visualizations) offers the advantage of providing a mechanism to intelligently and visually extract what is relevant to a particular management function such as risk management. If a large amount of information is presented in a tabular or text format, important messages could be concealed or difficult to comprehend by upper levels of management. Goals for the data visualization mining process are to:

- Be able to find patterns and insights;
- Fit required information on a single screen; and
- Effectively show deep and broad data sets on a single screen.

Data visualization techniques can be also used as a risk-based approach to assist in detecting project potential risks and mitigation technique options during the early-lifecycle decision making of a project. For example, Feather et al. (2006) illustrate the use of software visualizations to capture dependencies between a three-layer model – project requirements, risks and mitigation – with examples from spacecraft technologies and systems. Correlating the foregoing approach with the work performed by Nezafatkhah (2011) on visualizing risk management data associated with capital expenditure projects, a number of visualizations were explored for this research in order to select and develop images that could be of high value for extracting information and relevant insights for management teams.

Several visualization techniques exist such as 2D-3D bar and pie charts, scatter plots, heat maps, tree visualization techniques – rooted tree, radial tree, balloon tree, and tree-map layout, tree net analysis, parallel coordinates, force-directed graph, node-link diagram, and hierarchical edge bundling exist to help with visual data mining. The real challenge is not one of finding visualization techniques but of determining which of the images available are relevant to support the analytical processes involved in risk management of large scale projects. The question becomes: “What do I want to visualize in order to generate the insights sought and how?” One has to consider the challenges present within the context of a large scale project, including: large scale data sets, complexity and inconsistency of information, incompleteness and constantly changing data, and management team requirements in order to be useful at that moment and for future use.
For large scale projects, the size of the data sets involved can result in visual images that are cluttered and complex to understand and read. To overcome this, the use of interactive visualizations that enable working at different levels of detail or with subsets of information while looking for specific insights is essential. Techniques such as force edge bundling explained by Holten (2006) to improve data cluttering in hierarchical tree visualization techniques, allow patterns to be shown, making it easier to detect connections between the components used to represent a project (e.g., between physical, participant, process, environmental and risk view components).

Current construction industry practice in data visualization is limited to traditional business graphics tools, restricted mainly by the amount of time and resources that management teams are willing to spend on learning and implementing state-of-the-art technologies. However, the adoption of a new project modeling process that includes these visualization technologies can enable the use of more dynamic and interactive graphics such as real-time charts and dashboards that automatically update as project data changes, as compared to traditional static graphic tools. These technologies also enable the possibility to visualize complex and large amount of data sets. Evelson & Yuhanna (2012) differentiate the use of modern data visualization capabilities from those of static graphics, citing the following advantages for the former as follows:

- Dynamic data content;
- Visual querying;
- Multiple-dimension, linked visualization;
- Animated visualization;
- Personalization; and
- Business-actionable alerts.

1.5.4 MULTIPLE VISUALIZATION TOOLS AVAILABLE FOR POTENTIAL USE

The adoption of the Repcon research system for project modeling as a tool to integrate the risk management approach to other project management functions and knowledge management techniques
as explained in section 1.5.2, allows the creation of system built-in visualizations of different project view component profiles (e.g., physical attribute values at different locations) and risk register visualization reports (e.g., risk assessment (pre-, post-, and actual) linear heat maps at a risk event or issue level, risk expected value graph, and event scenario probability). Several of the features desired of an IT system were identified by Russell & Nelms (2007) include the necessity to give careful attention to interface design when designing a system to facilitate group interaction and understanding of project context amongst users, speedy navigation of project context and project risk register, and ready feedback of available project information in a number of formats. Visualization formats deserve special attention when designing a user interface. Effectively done they can assist with creating a shared image of the project context amongst those charged with developing the project’s risk profile, including the simultaneous access to data from all project views and the ability to understand the linkage of risk drivers with risk events/issues, thus providing insights into a project’s risk profile in aid of decision making.

With respect to data visualization software, the market is characterized by multiple software developers and visualization tools. Choice of which tool to use depends on the functionality desired, technical requirements of the software, practical issues regarding system implementation, and extent of learning required to use effectively. These tools can be very useful to visualize aspects of interest of the different project views (e.g., during risk identification sessions or analyzing relationships amongst risk drivers for a specific risk). Nevertheless it should be clear that by using graphic tools that are not integrated within the system being used to model risk, the opportunity to represent all possible image types within an integrated model will not exist: at best what can be done is export data from the risk management system for use by one of the specialty data visualization tools available on the market. This option is particularly appropriate when relatively static data is involved or when the data results are not likely to change anymore, thus requiring only a one-time visualization of the data. The difference between a static instance of data sets and interaction with data is that even if the data visualization tool can create interactive images; the data sets are not being updated automatically if the project model is modified.
The increasing pace of technological development has a strong influence on the changing availability of data visualization tools. As data visualization technology evolves, industry at large finds data visualization platforms to be essential tools that enable them to monitor business and projects, find patterns, and take action to avoid threats and seize opportunities. According to an assessment presented by Evelson & Yuhanna (2012) of a number of advanced data visualization vendors, it was found that the company leaders in the industry as of fall of 2012 were: Tableau Software, IBM, Information Builders, SAS, SAP, Tibco Software, and Oracle due to the breadth of their data visualization business intelligence (BI) functionality offerings. The next tier of vendors included Microsoft, MicroStrategy, Actuate, QlikTech, Panorama Software, SpagoBI, Jaspersoft, and Pentaho, all of which offer solid functionality to enable users to effectively visualize and analyze data. In addition, a number of open source visualization tools are freely available for anyone that wants to develop personalized data visualizations such as Data-Driven Documents (D3) java scripts (Bostock, 2012), Gephi (Gephi, 2012), InfoVis java scripts (Garcia, 2012), sigma java scripts (Jacomy, 2012), Circos (Krzywinski et al., 2009), Sparklines for Microsoft excel (Rimlinger, 2012), NodeXL networks for Excel (Smith et al., 2010), Orange – data mining (Curk et al., 2005), Google chart tools (Google Developers, 2012), and others.

Research and development in data visualization has received a great deal of attention in the last few years. Educational institutions and large corporations are investing significant resources in this area; academic and independent developers are working together on the development of data visualization tools offering different kinds of advanced applications to facilitate complex systems. For example, the work of General Electric Data visualization laboratories (General Electric, 2012) is focused on deriving insights, innovations and discoveries from large amounts of data in multiple topics through the use of data visualization; the MIT SENSEable City Lab (MIT, 2012) is studying and understanding how cities are being radically transformed along with the impacts on their physical structure.

Other relevant research in different fields of data visualization as it relates to the work described in this thesis includes that of Holten (2006) from the “Technische Universiteit Eindhoven” in the Netherlands (hierarchical edge bundles and visualization of adjacency relations in hierarchical data), Ben

In the search for data visualizations that could assist with extracting insights from a project’s risk register in terms of detecting relationships between risk events and risk drivers, assisting in decision making for determining where to focus resources, and selecting the most appropriate risk response actions; it was found that hierarchical tree structures could be used to represent the different project views in a radial or circular layout. Mappings supported between view components (nodes) can be represented by a series of linking edges. In the context of this research, the interactions shown in the radial view represent a relationship between a risk event in the risk view structure with risk drivers from the other project views. Note that a single risk event could be linked to a significant number of drivers. Of particular interest to construction personnel are risk drivers that are connected to multiple risk events. Such information assists greatly in identifying the most effective risk responses – i.e., select those responses that target risk drivers associated with multiple risks, thereby achieving significant leverage.

The reason for selecting a radial layout for the hierarchical tree structure of the risk management model is because the associated visualizations are capable of clearly showing patterns for the large data sets involved, as well as showing different levels of node detail. As described by Boyd (2012), visualization attempts for large graphs commonly fall within three categories: node-link diagrams, tree maps and radial layouts. A detailed description and presentation of graph and tree visualizations is beyond the scope of the research. The radial layouts used are explained in more detail in this thesis, but further information and comparison of graphs and visualizations for all three graph categories is discussed by Boyd (2012).

The radial layout displays the nodes (components) in a hierarchical outer ring and the edges (links) as curve connectors in the center of the ring. Benefits of the representation are two-fold: first is that it focuses on specific relationships between nodes by cross-scale exploration, rather than the relative
spatial location of nodes (useful in smaller graphs); and second, when using large data sets, the relationship represented by the edges is consistently encoded and bundled allowing the image to convey higher-level meaning – e.g., patterns.

One of the advantages of the radial layout visualization technique is that the aggregation level of detail can be adjusted as desired in order to focus on important or specific project issues. However, this visual representation can lead to a visual cluttering if a large number of edges are represented. Utilizing an edge bundling technique (Holten, 2006; Holten & Wijk, 2009; Gou & Zhang 2011) is an effective way to reduce the visual cluttering and complexity when communicating relationships in dense networks. This technique groups parallel edges or connectors with nearby origin destination as if they were tied, allowing the reading of a large number of similar relationships as a single line thereby assisting with the comprehension of a large data set in order to extract insights. Groupings are of two types: Force-directed edge bundling (Holten & Wijk, 2009) or hierarchical edge bundling when visualizing graphs with a hierarchical structure (Holten, 2006).

Relevant software was evaluated to determine which would be more suitable to use as an external tool to complement the use of the integrated risk management approach within the Repcon system. System data of interest would be exported from Repcon, manipulated or transformed as required, and then accessed by the visualization tool. Besides the functionality features of the visualization tool, other factors such as limitations on the amount of time and resources available to develop the external visualizations had to be considered. In terms of the visualization of interactive graphs and dashboards to represent project context view properties and profiles as well as heat maps and other useful charts, TIBCO Software Inc. (2012) and Tableau Software (2012) were the Business Intelligence tools that fit well for that purpose. In regards to an external tool that could assist in understanding dependencies and the interaction between project components at different levels of hierarchy and across the multiple project views, the use of SolidSX software (Solid Source IT, 2010) provided an excellent solution. Similar tools like NetTreeViz from Pennsylvania State University (Gou & Zhang, 2011) or InProv from Harvard College (Boyd, 2012) were also evaluated. However, SolidSX provided an efficient radial layout with the possibility to adapt easily the
exported data from the project model. SolidSX external tool integration analytics are explained by Telea & Voinea (2008).

In summary, the data visualization tools selected for use as part of the risk modeling and exploration process to fulfill the research objectives are:

- Repcon (UBC research tool) integrated built-in visualizations of project model views;
- SolidSX (Solid Source IT, 2010); and,

1.6 TRANSMISSION LINE PROJECTS

Provision of electrical power to any industry, domestic user or any other final users requires a fully developed electrical system, which consists of three main parts: generation, transmission and distribution. Together, they combine to create, transport and distribute the electricity. This research is focused on electrical transmission infrastructure projects. An overhead power line is an electric power transmission line suspended by towers, referenced in this research as “transmission line”. The main purpose of these infrastructure projects is to transport electrical power from one location to another through a transmission grid. Nevertheless, the electrical transmission system is more complex and dynamic than other utilities, such as water or natural gas (Public Service Commission of Wisconsin, 2011; WECC, 2011).

Electricity flows from power plants, through transformers, transmission lines to substations, distribution lines and then to the consumer. The transmission system is highly interconnected, not just transmission lines to load centers but also to other transmission lines to assure the smooth flow of power in the grid. The power entering the system flows along all available paths, not just from point A to point B. This means that the system doesn’t recognize divisions between service areas, estates or countries.

Transmission line power source include a diversity of sources, for example, coal, nuclear, natural gas, oil, or renewable energy sources such as hydropower, biomass, wind, or solar power. Considering that each generation source provides a fraction of the power being delivered to the grid, the reason to develop a
network is to achieve high reliability for power delivery to meet instantaneous demand requirements. And the main reasons to construct a new transmission line are to fulfill the actual and future demand of electricity for a particular distribution area, to revitalize aging infrastructure, to optimize transmission energy efficiency with new technology, and to pursue renewable energy sources.

In order to understand the scope of transmission line projects, introduced here are the components involved and how best to model or represent such a project. Project context and transmission line specific components are described in different references with different scopes and levels of detail (e.g., BCTC, 2007; BCTC, 2008; Blanco et al., 2010; and ESKOM, 2004). The anatomy of a transmission line project, after analyzing the references and industry practices, can be represented by the following components:

- Project alignment land;
- Right-of-way (ROW);
- Access roads;
- Clearing areas;
- Fly-staging yards;
- Batch plants;
- Storage, temporary facilities, and tower assembly areas;
- Foundations;
- Transmission towers and line (specific components);
- Capacitor stations; and
- Substation terminations.

Specific components of a transmission tower and line (Blanco et al., 2010) are:

- Transmission towers;
- Conductors;
- Earth wires;
- Insulators; and
- Wave traps and other hardware.
Conductors consist of a wire or group of wires not insulated from each other, suitable for carrying an electrical current. For High Voltage (HV) transmission lines the common conductor material types are: ACSR (Aluminium Conductor Steel Reinforced) and AACSR (Aluminium Alloy Conductor Steel Reinforced). Transmission towers provide support for the overhead conductors. Towers are commonly made of steel lattice structures. Two structural configurations are typically used: Delta configuration (three phases arranged in triangular configuration) and Flat configuration (three phases arranged in a horizontal or flat configuration). Both structural configurations can be designed as guyed and self-supporting depending on terrain and weather loading conditions. Delta configuration can be used when taller structures are required in order to reduce the right-of-way (ROW) and clearing widths, to increase power transfer capability and to reduce electric and magnetic fields. The flat configuration is commonly used in heavy ice-loading condition areas because of strength, or if shorter structures are required to reduce visual impact (BCTC, 2008).

Knowing the components that are involved in a transmission line project, two questions need to be addressed: first, how best to model such a project in terms of the relevant project views; and, second, how to relate transmission line project context to risk management practices. Blanco et al. (2010) explain how transmission and distribution industry major risks encountered during the design and construction of transmission lines can affect the insurer party under a Construction-All-Risk/Erection-All-Risk (CAR/EAR) policy. But this reference as well as other publications (e.g., Daoulas, 2011; Leung et al., 1998; McCall, 2009; Marshall & Baxter, 2002; and Tummala & Burchett, 1999) do not treat the integration of project components and attributes with a risk management approach in a way that allows management to overview the entire project and gain insights during the development of the project risk register.

Transmission line components are located along highly variable and complex geographical locations that include different types of terrain and climate conditions, and ownership by private individuals or firms and where the utility provider maintains specific rights governing transmission line ROW. Agreement to own these lands allows utilities to construct, maintain and replace facilities, as well as preserve space for
future developments (BC Hydro, 2010). Physical systems then, should be defined properly in order to address the scope of how, and what kind of work will relate to each of the physical locations. The following systems are considered to be present in a transmission line project:

- Contract;
- Submittals – plans, drawings, other documents;
- Clearing;
- Access;
- Foundations;
- Tower assembly;
- Tower erection;
- Line work; and
- Site restoration.

It is important to model the system structure depending on factors related not only to its physical attributes but also considering project context (e.g., environmental context, permit and regulatory processes, community and First Nations consultation, project participants and third party stakeholders, procurement processes, work execution strategy). The project context model as depicted in Figure 1.5 (Integrated multiple-views form) is directly applicable to transmission line projects.

1.6.1 PROJECT CONTEXT AND COMPLEXITY

High voltage transmission line projects are large scale, geographically dispersed ones, which entail the presence of highly variable conditions and participation of multiple stakeholders involved in their approval, design, procurement and construction. Consideration of the geotechnical conditions, weather conditions, sensitivity to environmental issues, First Nations and third party stakeholder issues, regulatory processes, offshore procurement, a new relationship with the client, communication and coordination issues, and lack of experience of project personnel with project type, provides a big picture overview of the complexity of project content that must be treated. The complexity comes from the combination of these factors along the project alignment together with the strategy pursued to coordinate and execute the work.
involved. General contractor teams required to manage high voltage transmission line projects can vary from 10 to 50 in staff and more, depending on specific project properties.

1.6.2 PROJECT SCALE AND STRUCTURING
Scale becomes an important issue in transmission line projects because of the need to analyze in detail all aspects of the project components and context along the transmission line corridor. The result of this is reflected in the production of a significant amount of information (e.g., correspondence, permits, consultation agreements, assessment reports, engineering reports, drawings, plans, and spreadsheets); considerable inconsistency can exist in terms of level of detail in this information, level of completeness, usage of language, etc.

The need to structure hierarchically the project context and the risk view allows management staff to work at different levels of detail, from bundled information at the highest level down to information at the individual component/location level, thereby assisting with obtaining insights from the large scale of information involved.

1.6.3 PHYSICAL VIEW
The physical (product) view treats the spatial context of a project (e.g., physical work locations and procedural steps in processes such as procurement, permits, and drawings) as well as the products to be produced both on and off site and in different phases of a project’s life cycle. A mapping exists between the spatial context and products (e.g., at what locations is a specific product to be installed, such as a particular foundation type for a transmission tower). For large scale linear projects, the need exists to define locations at different levels of granularity (e.g., overall project, project section, individual work location).

1.6.4 PROCESS VIEW
The process (planning and scheduling) view identifies the processes to be used to realize the project (e.g., regulatory, review, design, procurement, construction, commissioning, restoration processes). A
mapping exists between the physical and product views to answer the question: what gets produced, where, when and by whom.

1.6.5 PARTICIPANT VIEW

The participant view (organizational/contractual) details the categories of parties involved, and within each category, specific organizations, groups or individuals that have a direct or indirect relationship with the project. Often overlooked in risk identification sessions are project participants who can be a significant source of risk for reasons such as lack of experience, insufficient capacity, or outright opposition to the project. A mapping exists between project participants and activities that comprise the process view.

1.6.6 ENVIRONMENTAL VIEW

The environmental view reflects both the natural and man-made environments in which a project is immersed. The former relates to the weather, geotechnical, flora, fauna, and other conditions that characterize the site and surrounds. The latter relates to the project’s social / economic / regulatory / political environments. Environmental components can be mapped onto the project’s spatial context.

1.6.7 RISK VIEW

The risk view contains the project risk register as well as a risk response register, with a mapping between the two. The risk register can be structured in a hierarchical manner, thus assisting with the task of navigating a large register. It has been found that a three level hierarchy of phase, issue and event to be particularly useful and one that aids knowledge transfer between projects. Many of the issues or categories of risk tend to repeat from one project to the next, although individual risk events can be very different. At the individual event level, a number of properties can be associated with each event, ranging from risk drivers, qualitative and/or quantitative assessment of the likelihood of the risk event and performance measures impacted if the risk occurs (e.g., time, capital cost, O&M cost, severity index, etc.), measured on a pre-risk response, post-risk response or actual basis, and the risk responses adopted.
Similar to the project risk register, a risk response register in the form of a hierarchical structure comprised of category, subcategory, class and response can be defined. At the individual response level, it is possible to associate particular risk responses to individual risk events as well as risk issues.

1.6.8 CONSTRAINTS
Many constraints accompany transmission line projects. Many of them relate to the environmental view, since the natural and man-made environments address several issues to be considered while the project is planned and executed (e.g., environmental work time windows, endangered species areas, environmental work avoidance zones, geotechnical and topographical restrictions, weather conditions, black-out times due to temperature, bog or golf areas, and regulatory specifications). Other constraints relate to contract provisions, such as intermediate milestone dates as well as overall project completion, restoration requirements, etc.

1.6.9 FLEXIBILITY
Transmission line projects are required to have flexibility in terms of design, permits, construction processes and strategy during execution of the work because conditions in these projects are not always as anticipated. As the project unfolds, there might be a need to re-design components (foundations, towers), re-sequence the execution of work, re-structure component breakdown structures, adapt construction methods and cope with changed accessibility to work areas. Lessons learned from other transmission line projects (McCall, 2009) suggest that the best way to overcome project context challenges such as geotechnical, environmental and schedule coordination issues is to be prepared for all foreseeable situations in design, so that construction can proceed as scheduled. In practice, project context constraints could trigger a major impact for both cost and schedule if there is not a proper risk response action plan.

1.7 ILM TRANSMISSION LINE PROJECT PROFILE
The project is a 500 KV, 255 km long transmission line, located in British Columbia, Canada, connecting the Merritt and Coquitlam Substations, and involves some 680 towers (the number of locations involved in
representing the project is in excess of 700). It is the first transmission line of this scale built in more than 25 years in BC, with personnel involved in other similar projects having retired several years ago. The client is a public utility, a crown corporation. A design-build (DB) procurement mode has been mandated. The scope of work entails design, clearing, access roads, foundation construction, tower procurement, assembly and erection, line stringing, and restoration of the land. Geotechnical, wildlife, weather, and land ownership and use conditions are highly variable along the corridor. Blackout windows exist for several parts of the corridor because of wildlife breeding and endangered species considerations. The work corridor traverses or touches upon the land of some 60 First Nations groups, all who require a significant level of consultation. Several private landowners are also involved, as alignment of the transmission line crosses their property. Towers are being procured offshore, which in turn leads to communication, quality control, transportation and exchange rate issues. Details about the physical locations are presented in Table 1.1 and the general layout of the case study project is shown in Figure 1.6.

### Table 1.1 – ILM Transmission Line Project Alignment - Physical locations

<table>
<thead>
<tr>
<th>Section</th>
<th>Subsections No.</th>
<th>Area Description</th>
<th>EAC Segment Nodes</th>
<th>From tower</th>
<th>To tower</th>
<th>Km marker</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>Nicola Substation to Salem Creek Logging Road</td>
<td>A – B</td>
<td>1001</td>
<td>1125</td>
<td>0 km to 47 km</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>Salem Creek Logging Road to Gilt Creek Branch</td>
<td>B – F1</td>
<td>2001</td>
<td>2140</td>
<td>47 km to 97 km</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>Gilt Creek Branch to Ruby-Lougheed FSR</td>
<td>F1 – O1</td>
<td>3499</td>
<td>3607</td>
<td>98 km to 145 km</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>Ruby-Lougheed FSR to Lower Hoover Road</td>
<td>O1 – S</td>
<td>4001</td>
<td>4150</td>
<td>155 km to 208.5 km</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>Dewdney Trunk to Meridian Substation</td>
<td>S – V</td>
<td>5000</td>
<td>5111</td>
<td>*208.5 km to 248.5 km</td>
</tr>
</tbody>
</table>

*Note that the length of 248.5 km corresponds to a newer revision of the project alignment compared to the 255 km from the original project proposal.*
1.8 PROCUREMENT MODE INFLUENCE – DESIGN BUILD

The client assigned a Design-build (DB) contract to the main contractor, a joint venture (JV) for this project, an approach that is somewhat unconventional for the utility, resulting in some adjustment of roles and responsibilities for its personnel. Failure to complete the project in a timely manner will invoke very substantial liquidated damages.

Considering that the relationship between the client and main contractor is new, a number of issues have arisen as the project has unfolded (at the time of writing of this thesis, the project is still in progress), leading to communication challenges and challenges related to receiving fast turnaround of responses to JV queries for information or decisions. A major factor influencing the risk profile of the project is the lack
of experience of the client with a design-build delivery mode for this type of project (their preferred mode being design-bid-build (DBB)), and this being the first transmission line project for the JV. A DB contract can present a series of advantages and disadvantages depending on how the division of responsibilities and scopes are assigned and if this division of responsibilities is respected (Daoulas, 2011; Beehler, 2009).

The major impact for the contractor of a DB procurement mode is the risk allocation, particularly, if the project involves highly variable site conditions which could result in actual subsurface conditions being significantly different from those considered during the bid or proposal phase of the project. In addition, far more consultation than envisaged at the outset of the project might be required with land owners or First Nations groups, affecting work sequences, resources required, and challenges with meeting timelines. Further, complex regulatory processes could impact the work schedule and plan of works. Under a DBB contract most of these risks are allocated to the client/consultant; in a DB contract, these risks are allocated between the contractor and the client as a shared risk in terms of cost and/or time as defined by specific contract language.

Geotechnical risks as well as the risks mentioned above play a very important role in assessing the feasibility, cost, schedule, and successful long term performance of a DB project (Daoulas, 2011). Such risks concern both the client and the DB contractor since they can have a significant impact on cost and schedule contingencies included in bid proposals; their realization could increase the potential for unforeseen costs and time delays in a project.

1.9 MODELING PROCESS REALITY

A very significant challenge is reflecting the reality and complexity of the project in a process model view of the project. The reality for transmission line projects as it is for other linear projects such as pipelines is that, except for certain activities like line stringing works, the spatial sequence of work can cause problems during the modeling process. Due to the varying specific situation of each spatial location or set of locations and the presence of other constraints (e.g., permits, regulatory and natural constraints to
access the site locations and perform clearing works), is nearly impossible to perform the works in an easily predicted ordered location sequence. This complicates the preparation of a strategic plan and schedule of works projected in terms of ordered linear sequences. Because of this reality, the optimal strategy to perform the works involves adopting an opportunistic process strategy – i.e., determine the rate at which work needs to be conducted for the various physical components, but execute the work in a spatial sequence that reflects availability of access in terms of environmental windows, negotiations with owners for site access, etc.

1.10 CONTRIBUTIONS OF THE WORK

A summary of research contributions claimed for the work described in this thesis is as follows:

1) **Conducting a detailed case study that provides insights into:**
   a. The complexities of transmission line projects because of environmental, geographical (physical), participant and process dimensions (the 4 views and their attributes).
   b. How to model the 4 project context views and attributes of direct relevance to risk identification.
   c. Identifying risk issues relevant to the different phases of a transmission line project.
   d. Identifying risk events relevant to the various risk issues in each phase.
   e. Challenges in expressing likelihood and impact of a risk event.
   f. Risk management in practice – what a contractor does – the formality vs. informality of their approaches and why.

2) **Lessons learned about modeling**
   a. The need to work at different levels of granularity – e.g., both fine-grained (towers) and coarse grained (environmental) locations.
   b. Model at different levels of detail as a function of the project dimension being examined.
   c. ‘Quantifying’ risks is a real challenge – very difficult to estimate time and cost for individual risks – use of a surrogate measure can be helpful – e.g., severity index.
   d. Capacity to present a flexible but structured model that could be used in future projects capturing relevant lessons learned.
3) Risk response and data mining

a. A first step has been taken toward developing a risk response register. A thin literature exists that treats the topic in generalities (e.g., Hillson, 1999; Dey, 2010; Al-Bahar & Crandall, 1990; PMI, 2008; WSDOT, 2010; ICE, 2005). Structuring and compiling a risk response register is a challenge – an initial contribution to organizing knowledge for this risk dimension has been made.

b. The role that data visualization can play in generating insights into a project’s risk profile has been explored.

1.11 THESIS STRUCTURE

This thesis has been written as a manuscript based thesis, with an ‘extended draft-paper’ manuscript corresponding to Chapter 2 of the thesis. The thesis is structured as follows.

Chapter 1 Thesis overview: Presented in this chapter is motivation for the thesis focus, research objectives and methodology, literature review about risk management, project modeling for construction management, data visualization, and general features of transmission line projects. The chapter closes with the introduction to the case study and the contributions to the research work.

Chapter 2 Modeling risk for transmission line projects: This chapter contains an extended draft manuscript-based paper on the topic of risk management for construction, adopting a risk modeling approach for large scale, long linear projects, and application of the approach to a case study of a 255km, 500 KV transmission line project. It also focuses on the search of meaningful insights into a project’s context and risk register using data visualization. As well, a structured approach to project risk response is described. Chapter 2 is the core of the thesis and describes in detail the research work. A version of Chapter 2 will be submitted for possible publication. The authorship of this chapter is Diego Orozco Mojica – Graduate student at the Department of Civil Engineering – UBC, and Alan David Russell – Professor, Department of Civil Engineering, UBC, and Chair, Computer Integrated Design and
Construction – UBC. There is a considerable overlap between Chapters 1 and 2, as Chapter 2 is meant to stand alone, but without as extensive a treatment of the relevant literature as presented in Chapter 1.

**Chapter 3 Conclusions:** This chapter describes lessons learned and contributions of the research, along with suggestions for future work related to this research area.
CHAPTER 2. MODELING RISK FOR TRANSMISSION LINE PROJECTS

2.1 INTRODUCTION

Large scale geographically distributed infrastructure projects consist of substantial complexity, scope, and vast volume of data of different types to be distilled and analyzed. Significant risk is involved during the approval, design and construction of such projects given highly variable terrain and weather conditions, restricting working time lines, the multiplicity of the environmental, First Nations, land ownership, and third part stakeholder issues involved, and challenging regulatory and procurement processes. These infrastructure projects embrace transmission lines, pipelines, water diversion projects, high speed transit projects, etc. The association of the project context, scale, and constraints with the specific project components is essential for effective analysis and understanding of these. The dimensionality of the risks involved, identifying them along with their corresponding properties (i.e., likelihood, impact, drivers, components impacted, etc.) can be a very significant challenge, and the stakes can be extraordinarily high for project participants, specially client, contractor, users, and third party stakeholders. Improvements in risk management practices can result in significant benefits for the parties involved. The question: “How to achieve such improvements?” is addressed in this paper.

The topic of risk management for capital projects has been treated by many academics as well as practitioners (e.g., ICE, 2005; WSDOT, 2010; Wideman, 1992; Rolstadås, 2011; and Leung et al., 1998). In most cases, it is treated as a standalone, spreadsheet-based function, which seldom capitalizes on the formal representations of a project used in support of other project management functions. As a result, an opportunity is lost in terms of linking risk events and attendant properties to specific project features expressed in terms of a consistent vocabulary. Also lost is the opportunity to gain insights on how best to respond to individual risk events as well as categories of risks. These observations along with the complexity of modern large scale infrastructure projects have provided motivation for the work described herein.
Examined is a holistic, integrated approach to risk management which seeks to address the question posed previously. From the perspective of this paper, features sought in an integrated approach include a rich characterization of project context, direct connectivity with other project management functions, a comprehensive risk modeling capability, data mining, and knowledge transfer.

Use of the approach is illustrated through its application to a large scale linear infrastructure project, specifically a transmission line project. Topics treated are ordered as follows. First, motivation for the work described in terms of its application to large scale infrastructure projects is provided by way of a short overview of the demand for transmission line projects in North America for the next several years. Then, given is a description of key features of a highly structured, integrated approach to risk management. Emphasis is placed on the explicit treatment of project context, given its very important role both in helping to identify risk drivers as well as how best to respond to risks. Third, demonstrated is the application of the approach by way of a case study on a 255 km 500 KV transmission line design-build project currently in progress in British Columbia. Teased out are important lessons with respect to modeling risk for large, geographically dispersed projects. Fourth, how data visualization can assist in extracting valuable insights from the large scale data sets that accompany such projects is examined. Fifth, an approach for structuring potential responses to risks is overviewed in aid of assisting with selection of a risk response strategy. The paper concludes with some observations on the practical challenges involved in risk management for large scale, geographically dispersed projects and how the use of a structured risk model approach results in significant value for the construction industry.

In terms of the research methodology employed, it consisted of: (i) extensive review and use of the academic and practitioner literature as it relates to risk management in general and transmission line construction in particular; (ii) use of a risk management approach previously developed by De Zoysa (2006), Russell & Nelms (2007), and Nelms (2012), and enhanced further as part of the work described herein; (iii) application of the approach to a transmission line project currently in progress, including embedment of one of the authors in the project office for a period of six weeks; and, (iv) extensive review of the data visualization literature, and the use of state-of-the-art visualization tools to help develop and
explore the contents of the project risk register, including risk event properties. Validation of the work was pursued through a detailed review of the approach and findings in the context of the study project with senior project personnel. Literature examined is cited as appropriate in the relevant sections of the paper.

An important challenge involved in carrying out the research was working with a case study project that was in progress, especially a fast-tracked design-build project. This required one to deal with a lack of available information and constant updates of documents, which was compounded by the significant size of the data sets involved, given the scale of the project. At the same time, project modeling was a task that took a long time to develop, and made more difficult by the need to continuously update and modify it to reflect changing conditions of the project, all of which was necessary to capture the essence of the project in a comprehensive model. The approach for modeling long-linear projects is intensive when contractor personnel need to pursue an opportunistic strategy in order to perform the work due to imposed project restrictions (e.g., environmental windows, third party stakeholder difficulties, permitting difficulties, and off-shore procurement).

2.2 TRANSMISSION LINE PROJECTS

The importance of transmission line projects around the globe is noteworthy due to the increasing demand for power (e.g., Europe, Asia and North America are significant energy consumers) (Blanco et al., 2010). For example, over the next several years in North America the power grid will be revitalized and extended to deal with aging infrastructure, new technologies, capacity constraints, forecasted load demands and the pursuit of renewable energy sources such as wind and solar. In the US alone, more than 65,000 miles of transmission line work will be required by 2020. According to the Western Electricity Coordinating Council (WECC) 10-Year Regional Transmission Plan (WECC, 2011), the need to build future transmission and generation projects in Western North America is influenced by recognizing the potential economic benefits of transmission expansion to the grid. Delay in building could result in diminished opportunities to realize these economic benefits, inadequate power supply, and high operational and maintenance costs. WECC has presented a list of 44 major transmission projects to be
constructed by 2020, adding at least 5,500 line miles of 200kV and above lines. The estimated capital cost of the projects envisaged totals some $20 billion (WECC, 2011).

In Canada, the increase in demand for electricity is growing quickly leading to the need to rapidly develop generation and transmission capacity. For example, in Alberta the Alberta Electric System Operator (AESO) highlighted in their Long-term Transmission Plan a cost estimate for the projects anticipated to be in service by 2020 of some $13.5 billion (AESO, 2012). In British Columbia, the utility provider BC Hydro is expecting that over the next 20 years the demand for energy could grow by as much as 50% before accounting for savings that could be achieved by current conservation and efficiency or demand-side measures (BC Hydro, 2012).

Transmission line projects are located along highly variable and complex geographical locations that include different types of terrain, climate conditions, and land ownership. There are a number of risks associated with transmission line projects regarding: (i) project context and complexity (e.g., geotechnical conditions, sensitivity to environmental issues, regulatory processes), (ii) project scale and structuring (e.g., significant amount of information, lack of data consistency), and (iii) project constraints (e.g., natural and man-made environment, contractual terms, and time lines). Similar profiles can be made for other large scale, geographically distributed infrastructure projects such as pipelines, water diversion projects, high speed transit projects, etc. Many of the issues addressed in this paper apply to these projects as well.

2.3 RISK MANAGEMENT APPROACH OVERVIEW

2.3.1 INTRODUCTION TO RISK MANAGEMENT PROCESS

Provided in this section is an overview of the state-of-the-art of risk management processes with emphasis on their application to infrastructure projects along with a discussion of the strengths and weaknesses of the state-of-the-art. This is followed by comments on the specific contributions derived from applying the integrated multiple view risk management approach described and espoused herein to
model a project’s profile. The section concludes with the introduction of the holistic risk management modeling approach adopted for the identification of risk as a function of project context.

Risk is present in all projects, and can be defined as an uncertain outcome or event that could occur inflicting a favorable or unfavorable effect if it occurs. If the outcome is favorable it is considered an opportunity, and if the event occurrence has an unfavorable outcome then it is considered as a risk (Wideman, 1992). Complementing these definitions, ICE (2005) defines risk as the potential impact of all the threats (and opportunities) which can affect the achievement of the objectives for an investment. A number of frameworks that aim to structure a risk management process have been reviewed in the academic and practitioner literature (e.g., ICE, 2005; Wideman, 1992; PMI, 2008; WSDOT, 2010; Chapman & Ward, 2003; Leung et al., 1998; Rolstadás, 2011; Al-Bahar & Crandall, 1990; Hillson, 1999; and Dey, 2010). It is beyond the scope of this paper to describe in detail each of the risk frameworks available in the state-of-art. Nevertheless, it is important to comment on the similarities and differences in approaches, and assess the contributions to the field of risk management along with corresponding limitations of the risk model approaches presented.

The risk management literature is vast and a significant number of tools / procedures are available that range from quite simple to very complex. Although the risk management processes described by various authors vary from each other in terms of different scopes and description of processes and terminology, one can identify certain core elements which are common to all these approaches. These core elements include (i) Risk identification, (ii) Risk assessment, (iii) Risk response, and (iv) Risk control and monitoring. However, there are a number of shortcomings in current processes with respect to treating risk within an integrated framework including knowledge management. Amongst these shortcomings is the poor embedment of project risk with project context. Framed another way, an important question is: “How best to represent project context to support risk management?”

To date, several researchers have focused on treating specific processes that form part of a risk management framework (Leung et al., 1998; Hillson, 1999; Dey, 2010) while have proposed extensive
risk management frameworks that cover all of the core elements of risk management and include as well additional processes with a series of steps to carefully follow. However, these additional steps may make implementation of the associated framework too difficult to achieve, or if implemented, provide a process that is very tedious and time consuming to use, and without the benefits promised (ICE, 2005; PMI, 2008; Wideman, 1992; Al-Bahar & Crandall, 1990). Non-traditional approaches that involve a significant change in the way to develop a framework for risk management work has some appeal; nevertheless the level of effort to implement such a framework has not yet been tested on actual projects, making it difficult to judge the merits of such a framework (Rolstadås, 2011).

The inability to integrate project risk information with explicit representations of project context also interferes with the attempt to re-use the contents of risk registers for future projects. Even though various authors have proposed frameworks, tools or methodologies for risk identification, analysis, and response development, seemingly little work has been done on developing an integrated risk management approach (e.g., Dey, 2010; De Zoysa, 2006; Leung et al., 1998; and Rolstadås, 2011) that embraces the core elements identified previously plus direct connectivity with project context and other project management functions (e.g., planning and scheduling), knowledge management and data mining. Further, there are very few frameworks and accompanying studies that link risk analysis outcomes with risk response strategies (e.g., Hillson, 1999; Dey, 2010; Al-Bahar & Crandall, 1990). An integrated approach to project risk management not only combines the risk management processes of identification, analysis and development of responses in an analytical framework, but also integrates risk management processes with the entire project management process (Dey, 2010). For example, Leung et al. (1998) developed the RMP methodology (including risk identification, measurement, assessment, evaluation and risk control and monitoring processes) that was applied to a framework for managing cost risk for an EHV transmission line project, but did not integrate cost risk with schedule and project quality related risks. Dey (2010) proposed an integrated framework for project risk management that includes an analytical hierarchical process, which quantifies risk, deals with project time and cost parameters, and considers a few aspects of environment and process but doesn’t treat risk by specific locations. As proposed, the framework could be difficult to navigate in pursuit of insights once the risk profile is developed, given the
complex structure used to represent each of the project work package and activity levels across each project phase (feasibility, planning, implementation, etc.).

Another shortcoming of current approaches is the structure of risk registers and how to manage them, which makes difficult the task of making modifications to the risk register caused by a dynamic changing project context, a situation particularly relevant to large scale linear projects. Also when a large number of risks are present along with the significant information that accompanies each risk, it becomes difficult to navigate through the risk register, hampering the risk management process and the opportunity to gain insights from the risk register. The lack of use of consistent terminology in defining the risk register and project context during the risk management process and after when preparing the information for re-use in future projects, could lessen the opportunity to transfer knowledge effectively. Another disadvantage of current approaches is that knowledge is mostly captured as a static instance, also lessening the ability to add lessons learned. This is because large scale project context component modeling including the risk register structure requires an extended period of time to develop due to the sizeable scope of such projects and attendant documentation, number of participants involved, and uncertain and changing project conditions.

The support for risk management frameworks through the use of knowledge-based approaches has some limitations. For example, an attempt to develop a rule-based system would likely result in a very large set of rules that would not be readily understood by users and would require experts to maintain it. Typically, knowledge-based systems have been limited by their authors to supporting a subset of project types, such as oil pipelines or transmission lines (Dey, 2010; and Leung et al., 1998). Also, the treatment of project context in knowledge-based systems as described in the literature is thin. The approaches proposed by Leung et al. (1998) and Rolstadâs (2011) treat aspects of environmental and organizational components as risk factors, but the components modeled within these systems are few in number compared to the ones that a large scale project would need in order to properly represent project context.
In terms of execution of a risk management method, some risk management frameworks focus only on certain processes and little attention is given to other stages in the overall risk management process. For example, ICE (2005) identifies risk management process limitations as including: concentration of the treatment of risks in the asset creation phase rather than on potentially higher risks in other project stages (e.g., construction, and procurement); lack of a satisfactory method for combining risks when in many cases the risks treated separately are interdependent; little attention to changing risk exposure during the investment life cycle; the tendency to focus on risks which can be most easily quantified without the exercise of proper judgment to get a good feel for other risks involved; and, an inadequate follow through from project risk analysis to the control of risks once project implementation starts.

Despite many useful contributions by others with respect to managing risk and related knowledge, including a number of best practices and lessons learned, a considerable amount of work remains to be done in order to develop an approach that meets most if not all of the challenges encountered in risk management, especially as applied to large scale construction projects. A key issue is the ability of the approaches described by various researchers to cope with full-scale projects – what appears to work on small scale model projects might not translate well to large scale ones. A more detailed literature review and analysis as it relates to the topic of the state-of-art for risk management and knowledge-based methodologies can be found in the work made by De Zoysa (2006).

2.3.2 PROJECT MODELING FOR LARGE SCALE INFRASTRUCTURE PROJECTS

Fundamental to the way of thinking about risk management in particular and construction management functions in general is use of an abstracted yet comprehensive representation of a project in terms of multiple views (e.g., product, process, participant, environmental, change, quality, as-built, risk, etc.). Such an approach is of significant value in terms of offering an integrated approach to management functions. It has been described in some detail by Russell & Udaipurwala (2004).

In structuring the views for the risk model approach the use of hierarchical structures proves to be very effective for handling complexity and scale. One can work at different levels of detail or granularity.
depending on the aspect of the project being analyzed. For example, in describing potential risk events and their properties (e.g., likelihoods, impacts, drivers, etc.), the use of a classification by issues and project phases can help in providing an overview of the project risk register at a managerial level; for detailed risk analysis and assessment, one can drill down into specific details at the individual risk event level.

To represent project context in support of the risk management function, five views are employed as follows:

- Physical – what is to be built and site context;
- Process – how, when, where and by whom;
- Organizational/contractual (participant) - Project teams and parties, contractual obligations & entitlements, insurance, bonding, warranties, and evaluation of participant performance;
- Environmental – the natural and man-made environments that accompany the project; and,
- Risk – project risk and response registers reflecting a specific viewpoint (e.g., client, contractor, overall project) with events that could be encountered in the project phases of interest, drivers, response measures and outcomes.

Important to the foregoing views is the ability to define attributes and corresponding values for the components that make up project views. The fundamental question to be addressed is: “What do I really need to know in order to carry out the functions of interest?” Making those attributes explicit and how best to define them in as parsimonious a manner as possible is a non-trivial yet very important task, especially with respect to meaningful knowledge transfer from one project to the next. Often they are considered on an implicit or intuitive basis when judgments are offered, especially in the realm of risk management. Real value accrues from making them explicit. Compounding the challenge of capturing component attribute values is that they are often dynamic as opposed to static as a project unfolds. Thus, versioning becomes important during the life of a project, both in terms of the composition of the various project views as well as for attribute values.
The five project views are depicted in Figure 2.1. The use of this multi-view approach is of significant value because risk drivers arise from all five views (including the risk view itself, as additional risks may arise from the risk response strategy adopted). As well, identifying the most appropriate responses to an individual risk can benefit from a thorough understanding of event drivers and their attributes.

![Figure 2.1 – Representation of a project in the form of integrated views](image)

2.3.2.1 PHYSICAL VIEW

The physical (product) view treats the spatial context of a project (e.g., physical work locations and procedural steps in processes such as procurement, permits, and drawings) as well as the products to be produced both on and off site and in different phases of a project’s life cycle. A mapping exists between the spatial context and products (e.g., at what locations is a specific product to be installed, such as a particular foundation type for a transmission tower). For large scale linear projects, the need exists to define locations at different levels of granularity (e.g., overall project, project section, project subsection, or individual work location) in order to model effectively the project views of interest.

2.3.2.2 PROCESS VIEW

The process (planning and scheduling) view identifies the processes to be used to realize the project (e.g., regulatory, review, design, procurement, construction, commissioning, and restoration processes).
A mapping exists between the physical and product views to answer the question: what gets produced, where, when and by whom.

2.3.2.3 PARTICIPANT VIEW

The participant (organizational/contractual) view details the categories of participants involved (e.g., suppliers, First Nations, regulatory agencies, etc.), and within each category, specific organizations, groups or individuals that have a direct or indirect relationship with the project. Often overlooked in risk identification sessions are project participants who can be a significant source of risk for reasons such as lack of experience, insufficient capacity, or outright opposition to the project. A mapping exists between project participants and activities that comprise the process view.

2.3.2.4 ENVIRONMENTAL VIEW

The environmental view reflects both the natural and man-made environments in which a project is immersed. The former relates to the weather, geotechnical, flora, fauna, and other conditions that characterize the site and surrounds. The latter relates to the project’s social / economic / regulatory / political environments. Environmental components can be mapped onto the project’s spatial context.

2.3.2.5 RISK VIEW

The risk view contains the project risk register as well as a risk response register, with a mapping between the two. The risk register can be structured in a hierarchical manner, thus assisting with the task of navigating a large register. Based on past experience with projects, it is not recommended to use a deep hierarchy. It has been found a three level hierarchy of phase, issue and event to be particularly useful, and one that aids knowledge transfer between projects. Many of the issues or categories of risk tend to repeat from one project to the next, although individual risk events can be very different. At the individual event level, a number of properties can be associated with each event, ranging from risk drivers, components from one or more project views along with attributes that constitute the specific source of the risk (if the user chooses to work at this level of granularity), view components impacted by the risk should it occur, qualitative and/or quantitative assessment of the likelihood of the risk event and
performance measures impacted if the risk occurs (e.g., time, capital cost, O&M cost, severity index, etc.), measured on a pre-risk response, post-risk response or actual basis, and risk responses adopted.

Similar to the project risk register, a risk response register in the form of a hierarchical structure comprised of category, subcategory, class and response can be defined. At the individual response level, it is possible to associate particular risk responses to individual risk events as well as to risk issues.

2.3.2.6 RISK KEY CONCEPTS

Before introducing the risk management approach adopted, it is important to define the terminology for the key concepts used. The definitions used have been elaborated from a synthesis of literature references presented in De Zoysa (2006). The term ‘Risk issue’ is used to refer to keywords that represent topic areas of direct relevance to a project, around which uncertainty or lack of predictability may exist. A risk issue may result in multiple risk events, and consequent uncertainty in one or more project performance measures. The term ‘Risk event’ corresponds to the potential variability in a project parameter from its anticipated value, or one or more discrete scenarios in which the possible states of nature that can be realized can be identified, but the one which will actually occur as well as its outcome is not known with certainty. A risk event can apply to the project as a whole, i.e., its sphere of influence is global, or it can be local in terms of its immediate influence and hence treatment. The term ‘Risk Driver’ relates to the components of the physical, process, participant, and environmental domains, the presence of which or characteristics of which make a risk issue relevant to a particular project phase and context component. A risk driver represents the relationship between the project context and the risks of a project.

2.3.3 RISK MODEL APPROACH

Described here is a brief overview of the holistic risk management approach utilized in support of the research. This approach has been developed over an extended time period, and its evolution has been documented in part in the work by De Zoysa (2006), Russell & Nelms (2007), and Nelms (2012) which in
turn builds on previous work by Russell & Udaipurwala (2004) focused on the multi-view representation of a project in support of key project/construction management functions, inclusive of risk management.

In terms of application of the risk management approach adopted, while multiple pathways of use are supported because practitioners demand flexibility, the following front-end steps provide insights on how the approach can be applied. These steps are also depicted in Figure 2.2:

1) Define the four project context views of product, process, participant and environment (see Figure 2.1): This is an iterative process which can benefit from lessons learned on past projects. It is useful to define the context views prior to holding a risk identification session. Additional important information often gets teased out in a risk identification session which further assists in characterizing a project’s context.

2) Set up the structure of the project risk register and define risk issues (e.g., macro-economic risks, political risks, contract interpretation risks, etc.) deemed relevant to the applicable project life cycle phases. Again this can benefit from documentation of past experience, especially with respect to risk issue headings.

3) Identify risk events that apply to the overall project under the relevant risk issue (e.g., risk event: bearing conditions significantly different than anticipated under risk issue: geotechnical along with relevant drivers. Risk events are associated with a location, whether a specific location instance (e.g., Tower Location T1001_A), or a location defined to represent a collection of locations (e.g., S1_A for section 1 A of a transmission line project or GLOBAL to reflect the entire project). Assigning risks to a spatial location facilitates the development of a spatial distribution of risks which can aid with the overall risk management process.

4) Identify other risk events that directly impact one or more specific project components by walking through one or both of a summary level schedule of the project and the spatial context for the project phase at hand, and ask the question: “Does this risk issue apply?” It is observed that for projects that have a large, complex spatial dimension (e.g., a transmission line project), much of the project’s risk profile is derived from consideration of the spatial context in concert with the environmental view. If the risk issue applies, seek to identify individual risk events; if no, move on.
to the next risk issue until all risk issues have been examined, including the need to define new ones. Then repeat for other summary activities and/or spatial elements. As part of steps 3 and 4, it can also be helpful to identify which components of the four project views might be impacted should the risk event occur (e.g., activities whose duration could be lengthened, environmental components that could suffer damage, etc.).

5) Once the risk register has been populated, assess likelihood and impacts in a qualitative way, after calibrating risk identification participants in terms of likelihood of occurrence and impact scales. Maintaining velocity in a risk identification session is essential – trying to definitively quantify risks during the first pass through a risk register results in a loss of momentum and protracted discussion which takes away from the process.

6) Complete the process of associating risk drivers and impacted components to specific risk events.

7) Generate insights into the contents of the project risk register in aid of seeking appropriate responses to risk using various data mining tools (e.g., data visualization) in order to determine the clustering of risks in terms of one or more of time, space, participant, product, process step, environmental component, the relative importance of various view components as drivers of risk, the relative importance of individual risks and risk issues in project phases, etc.

8) Develop a risk response register and identify suitable responses under the response categories of avoid, transfer, share, retain. As part of assigning suitable responses to individual risks or risk issues, seek responses which address drivers associated with multiple risks, thereby leveraging the benefits achieved from each response.

9) Follow-up steps to the foregoing not elaborated upon here as part of the overall risk management approach are the re-estimation of likelihood of occurrence and impact given any responses implemented, the identification of any additional risks associated with the responses selected, the use of quantitative as opposed to qualitative risk assessment of likelihood and impact, achieving buy-in from selected project participants/decision makers, and documenting and communicating the project’s risk profile to those charged with the tasks of risk control and monitoring.
As applied in this paper, the risk management context that accompanies the foregoing steps relates to the perspective of the contractor tasked with executing the project, including any design and commissioning duties as part of the contractual form employed. For this context, relative versus absolute value of risk is most important, as construction personnel must determine how best to allocate limited resources. For the case where ‘absolute’ quantitative assessment of risk is required (e.g., public sector comparator analysis as part of determining which project procurement mode to employ), a more fine-grained and quantitative assessment of risk is required. Such an assessment can be very time consuming, and in some cases trying to assign a value to a specific risk can be very problematic.

2.4 CASE STUDY

2.4.1 CASE STUDY INTRODUCTION

Aspects of the foregoing approach are illustrated here in the context of their application to a major transmission line project in British Columbia (BC), Canada as part of a detailed case study directed at developing a greater understanding of the challenges involved in modeling very large scale linear projects.
including the risk dimension, and for validating the usefulness of the approach to risk management. The motivation for the lead contractor in the joint venture firm (JV) to participate is two-fold: they are interested in enhancing their processes, and more fundamentally as described previously, a very large market in transmission line construction is unfolding in North America. Because of the latter, they seek a competitive advantage by documenting their experience on this their first transmission line project.

Interestingly, the academic and practitioner literature directly relevant to risk management for transmission line projects is small (e.g., Beehler, 2009; Burchett et al., 1999; and Tummala & Burchett, 1999). Other literature directed at risk identification, mitigation and environmental issues as it relates to transmission line projects includes: Kalkani & Boussiakou (1996), Marshall & Baxter (2002), Yamatani & Jahangir (2011), Blanco et al. (2010), and Public Service Commission of Wisconsin (2011). Also reviewed was literature focused on design and construction challenges dealing with variable geotechnical conditions, environmental permits, temperature conditions in different geographical locations and design flexibility (e.g., McCall et al., 2009; Lakhapati, 2009; and Wyman, 2009). Nevertheless, from a practitioner perspective, the available literature is thin, especially for firms wishing to enter this market segment and who have no prior experience with transmission line projects.

The case study project is a 500 KV, 255 km long transmission line, and involves some 680 towers (the number of locations involved in representing the project is in excess of 700). It is the first transmission line of this scale built in many years in BC, with personnel involved in other similar projects having retired several years ago. The client is a public utility, a crown corporation. A design-build (DB) procurement mode has been mandated, an approach that is somewhat unconventional for the utility, resulting in some adjustment of roles and responsibilities for its personnel. Failure to complete the project in a timely manner will invoke very substantial liquidated damages. The scope of work entails design, clearing, access roads, foundation construction, tower procurement, assembly and erection, line stringing, and restoration of the land. Geotechnical, wildlife, weather, and land ownership and use conditions are highly variable along the corridor. Blackout windows exist for several parts of the corridor because of wildlife breeding and endangered species considerations. The work corridor traverses or touches upon the land
of some 60 First Nations groups, some of whom wish to achieve training/employment opportunities, others with concerns on archeological and other cultural issues, all who require a significant level of consultation. Several private landowners are also involved, as alignment of the transmission line crosses their property. Towers are being procured offshore, which in turn leads to communication, quality control, transportation and exchange rate issues.

2.4.2 PROJECT CONTEXT MODELING

Before describing how project context is modeled for the risk management approach used, it is insightful to discuss the approach used by the contractor of the case study. From the project documentation, correspondence and other files available at the project office, the use of structured construction management practices can be inferred (i.e., use of a number of large spreadsheets to address different issues and keep records, assignment of multiple individuals to specific dimensions of the project in order to become knowledgeable in certain areas, and treatment of issues and agreements pooled through multiple meetings). These practices worked sufficiently well for the contractor, but a number of opportunities are lost, one of them being the ability to oversee and communicate the project status in a structured consistent way, another being to reflect on project context through multiple integrated views. With respect to the latter the ability to do this was a contribution of the research to the project.

2.4.2.1 PROJECT CONTEXT AND COMPLEXITY

High voltage transmission lines are large scale geographically dispersed projects, which entail the presence of highly variable conditions and participation of many stakeholders involved in their approval, design, procurement and construction. Consideration of geotechnical conditions, weather conditions, sensitivity to environmental issues, First Nations and third party stakeholder issues, regulatory processes, offshore procurement, a new relationship with the client, communication and coordination issues, lack of experience of project personnel with this project type, provides some appreciation of the dimensions of project context. Complexity comes from the combination of these factors along the project alignment together with the strategy to coordinate and execute the work.
2.4.2.2 PROJECT SCALE AND STRUCTURING

Scale becomes an important issue in transmission line projects because of the need to analyze in detail all aspects of the project components along the transmission line corridor as reflected in the representation of the project’s spatial context. The result of this is reflected in the production of a significant amount of information (e.g., correspondence, permits, consultation agreements, assessment reports, engineering reports, drawings, plans, and spreadsheets) which lacks consistency in terms of granularity and depth of treatment with how project components of different types are represented. The ability to structure project context hierarchically including the risk view allows one to work at different levels of information as required for the task at hand, making possible the ability to obtain insights from the large volumes of information involved both in terms of input information and information generated.

2.4.2.3 CONSTRAINTS

Significant sources of the challenges involved in a transmission line project are constraints that affect the execution of the work. Many of these constraints relate to the environmental view, since the natural and man-made environments address several issues to be considered while the project is planned and executed (e.g., environmental work time windows, endangered species areas, environmental work avoidance zones, geotechnical and topographical restrictions, weather conditions, black-out times due to temperature, bog or golf areas, and regulatory specifications). Others relate to contractual issues in terms of time lines (intermediate and overall completion milestones), regulatory approvals, client approvals, and protocols dealing with communication with third parties.

2.4.2.4 FLEXIBILITY

Flexibility in the formulation of execution strategy for transmission line projects is in terms of design, permits, procurement, logistics and construction processes because project conditions do not always unfold as anticipated. This results in the need to re-design selected physical components (e.g., footings), re-structure component breakdowns (e.g., substitute one tower type for another), and adapt construction methods and accessibility to working areas. Lessons learned from other transmission line projects (McCall, 2009) indicate that the best way to overcome challenges associated with project context such as
geotechnical, environmental, and schedule coordination issues is to be prepared for all foreseeable situations as part of the design process, so that construction can proceed as scheduled. In practice, project context constraints could trigger a major cost and schedule impact if there is not a proper risk response action plan.

2.4.2.5 PROJECT CONTEXT VIEWS MODELING PROCESS

The process to model the physical, participant, process, and environmental views could require an intensive level of effort depending on the level of detail at which the project is modeled. One has to ask the question: ‘What components in each view are relevant to risk management functions, how to structure each of the views, and what do I need to know about these components?’ Depicted in Figure 2.3 (a) is part of the spatial context (section 1A) of the project’s physical view. Noteworthy is the need to define different levels of granularity – sections (there are 5), subsections within a section (5 – 8) and individual locations within a subsection. Different levels of aggregation are used for different monitoring and reporting needs by the JV. For example, it is sufficient to model clearing work in terms of subsections, while foundation and tower work requires treatment on a location by location basis. Of concern for both overall management of the project and specifically for risk management are the attributes for each individual location. Depending on their value, singly or in combination with other attributes and possibly the properties of components from other project views, they could suggest the potential for a risk event.

Shown in Figure 2.3 (b) are the location attributes determined to be of importance for the case study project. Values can be expressed in one of Boolean, Quantitative, Linguistic, or Date terms. As a side benefit, attribute values vs. location can be displayed in visual terms, providing additional insights quickly on potential problem areas, especially the confluence of undesirable values for a number of attributes (e.g., location attributes of geotechnical conditions, foundation type, tower elevation, and tower type). A partial view of location attributes for section 1A is presented in Figure 2.17 in the section of the paper that treats the topic of data visualization. Having this kind of data readily accessible in a risk identification session can greatly assist in the identification of potential risks.
Figure 2.3 – (a) Partial spatial (location) context for physical view for case study project
(b) Spatial component attributes that are potential risk drivers

Similar to what has been shown for the physical view, representations of the process, participant and environmental views have been created, and attributes defined. For example, as shown in Figure 2.4 (a), the participant view has been profiled in a two level hierarchical structure, with the first level corresponding to participant classes (e.g., client, engineering consultants, First Nations, contractor, suppliers, regulatory agencies, etc.) and the second level treating individual participants in a class. Shown in Figure 2.4 (b) is the ability to define attributes and corresponding values for each class participant: depending on attribute values, a participant could be a significant source of risk for a project. For example, lack of experience on the part of the client with a design build procurement mode can pose responsibility challenges early in the life of a design build project.
Figure 2.4 – (a) View of project participant classes’ structure (b) Project participant role attributes

The environmental view model consisting of the natural and man-made environment context has been modeled using a hierarchical structure starting with five classes: physical (corresponding to natural environment), social, economic, political, and regulatory (corresponding to man-made environment). Each class contains sub-classes, and every sub-class is comprised of a number of entities. Presented in Figure 2.5 (a) and (b), and Figure 2.6 are, respectively, the sub-classes used to model the project’s physical environment, membership in the sub-class Fauna (*wildlife – land, air & aquatic*), and attributes and values for the sub-class entity *Birds – Flammulated Owl* in project subsection 1B. Two observations are: (i) very significant environmental challenges accompany long linear projects such as transmission lines and pipelines, often rendering them infeasible because of potential damage to the environment or because of third party stakeholder opposition; (ii) for projects that do proceed, the environmental context can create the potential for multiple risks. In modeling the environmental dimension, in many cases it is sufficient to model at a coarser level of granularity than that used for the physical structures. This coarser granularity is achieved by mapping environmental features onto collections of physical locations – for the case study project, on subsections within a section (e.g., subsection 1A (S1_A) for towers T1001_A to T1027_A) or at the section level (e.g., section 1 (S1_GLOB) for towers T1001_A to T1125_E).
Figure 2.5 – (a) View of project participant classes’ structure (b) Project participant role attributes identification that could be a source of risk

Figure 2.6 – Attributes and values for section 1-B for entity Birds-Flammulated Owl
There are significant complexities to deal with when modeling the environmental dimension, as conveyed in the question previously posed, namely: "What components in each view are relevant to risk management functions, how to structure each of the views, and what do I need to know about these components?" It is not always clear what components are important and what attributes are relevant to identify as they relate to the risk management process. It is important that one extract only the necessary information from the massive number of voluminous studies/reports/documents that accompanies the environmental dimension in order to have an operational model that can be created within a reasonable amount of time and effort. Having said that however, the responsibility for overlooking environmental information that could affect methods, work timing, etc. resides with the contractor, and predictability of actual field conditions is fraught with uncertainty. In practice, modeling the environmental dimension require a great flexibility in terms of breadth of components treated and the most appropriate level of granularity; compounding the challenge is the a continued evolution of environmental information during the course of the project.

Again, being able to visualize aspects of the environmental view, as well as the other project context views during a risk identification session can be very helpful. Selected data for sections 1A through 1E of the case study project is shown in Figure 2.18 in the data visualization section of the paper. Rather than supporting graphics for all possible image types within an integrated environment, Figure 2.18 and Figure 2.19 represent instances where it is best to export data from the risk management system and use one or more visualization tools available in the market (e.g., TIBCO Software Inc., 2012) to create an image of the data. This is particularly appropriate when relatively static data is involved and the image only has to be created once.

2.4.3 RISK PROFILE MODELING

Once the four project context views have been drafted (they continue to evolve over time as more information becomes available), attention is directed to development of the project risk register. The issue of how to structure the risk profile in order to maximize understanding for the project at hand and ease with which knowledge transfer can be affected for use on future projects must be treated carefully.
Several authors have presented their findings on how to structure a risk register. Examples include the RAMP process (ICE, 2005), PMBOK (PMI, 2008), SHAMPU process (Chapman & Ward, 2003), Risk management approach (Wideman, 1992), and RMP process (Tummala & Burchett, 1999). Common classifications to categorize risks during the risk identification process vary. Examples include: (i) external unpredictable, external predictable, internal non-technical, technical, and legal (Wideman, 1992); (ii) financial & economic, political & environment, design, site construction, physical, and acts of God (Tummala & Burchett, 1999); (iii) by cause: political, business, economic, project, natural, and financial (ICE, 2005); (iv) by investment stage: investing planning and preparation, asset creation, operation, and close-down (ICE, 2005). These classifications, while seemingly useful at first glance, are not particularly helpful when developing a detailed risk profile for a large scale geographically distributed project which is action oriented and which reflects the breakdown of construction personnel responsibilities.

The approach adopted to structure the risk profile for the case study project involves categorizing risks in a hierarchical manner (not unlike the categorization schemas recommended by other authors), firstly into the different project-life cycle phases, then identifying risk issues within each of the project phases, and finally identifying specific risk events relevant to each risk issue. The reason to adopt this approach is at least three fold: (i) it assists in the allocation of responsibility for managing risk; (ii) it assists with identifying appropriate risk responses; and (iii) it provides an organized way to transfer knowledge. The categories (phases) selected to structure the transmission line project risk register are: risks applicable to all phases, design/approval/permits risks, procurement risks, construction risks, commissioning risks, and restoration risks. Except for the project’s construction and commissioning phases, risk issues for the different project phases of interest are shown in Figure 2.7. Development of an inclusive list of issues is a time consuming exercise, but once done, it has significant value not only for the project at hand but for future projects as well. The list of risk issues shown reflects review of the literature, consultation with project personnel, and experience drawn from participating in risk identification sessions for other projects. Shown in Figure 2.8 is an expansion of the risk register to individual risk events under the Migratory birds & level of due diligence risk issue in the construction phase. This risk issue and associated potential risk events were of significant concern for the project studied.
During the process of risk identification, support is provided for the user to associate risk drivers from one or more of the four views – product, process, participant and environment, first with risk issues and then with individual risk events, and for the latter, it is also possible to identify components from the four views impacted by the risk event should it occur. Figure 2.9 illustrates how drivers can be mapped onto risk issues. At the risk event level, relevant drivers can be selected from the risk issue drivers, and on an optional basis, to provide greater insight, specific driver attributes that constitute the source of the risk flagged.

Figure 2.7 – Risk issue categories for project phases exclusive of the construction and commissioning phases
Once risk events have been identified, their likelihood of occurrence and potential impact on performance need to be elicited from the most appropriate members of the project team, a non-trivial task. The option exists to provide either a qualitative or quantitative assessment of both likelihood and impact. The former was deemed sufficient for the case study – the goal was to determine the most problematic risks. Two
observations are that project personnel were comfortable with estimating likelihood, but in terms of impact, it was expressed in terms of a severity of impact scale as opposed to cost, time or safety consequences, even though qualitative assessments were used. Personnel were comfortable expressing judgment as to the relative severity of the impact of a risk, which was sufficient to determine where to focus extra management attention. This reflected the reality that trying to quantify the consequences of a risk event in terms of the latter three metrics was an almost impossible task without an overwhelming level of effort. Another reason to adopt a qualitative assessment process is that the project context is subject to continued significant changes – time spent re-estimating quantitative impacts in terms of time and cost impacts, even if done qualitatively, was not viewed as being a good use of precious management resources. Given the assessment of the relative severity of risks, attention could then be focused on selecting appropriate risk response measures. In special cases, decisions could also be made as to the value of conducting further analysis, specifically whether or not an effort should be made to quantify cost, time or safety consequences for the most severe risks. The important topic of how best to perform the risk assessments (e.g., qualitative, or quantitative) during the risk management process for construction projects has been addressed by others (e.g., Chapman & Ward, 2003; ICE, 2005; and Wideman, 1992); there is no consensus on how best to make assessments. The authors do venture the opinion, however, that some of the literature is overly optimistic about the ability of personnel to make estimates with great precision, and or their willingness to engage in elaborate processes to make assessments. The scale of large projects and constantly changing project conditions renders impractical complex assessment processes.
Before performing risk assessment in terms of estimating likelihood and impact, it is necessary to calibrate those providing assessment when linguistic scales are used. For the case study, this meant calibration had to be performed for the performance measure severity of consequences as well as probability of occurrence. The calibration schema employed is shown in Figure 2.10. Once criteria and likelihood calibration is done, the risk pre-response estimate for each is performed for all the risk events, including also an assessment of the level of confidence in each estimate. This process is partly shown in Figure 2.11; also note from this figure the ability to make post-response assessments along with the ability to record actual results (risk did or did not occur), and the ability to make quantitative assessments. Once the assessment of risk is performed at the event level, the ability exists to roll up risk event expected values to the issue level as well as the category or project phase level, assisting management with determining where to focus the greatest attention. The generation of insights into the most significant problem areas can be facilitated through the use of data visualization, as shown in Figure 2.21 and Figure 2.22 in the section of the paper that treats the topic of data visualization.
Figure 2.10 – Risk assessment performance measure units and linguistic calibration

Figure 2.11 – Qualitative risk pre-assessment on risk event
After the pre-response assessment of risk and the exploration of the results to determine areas of greatest interest, strategies to mitigate or respond to project risks, either in terms of individual risk events or risk issue categories need to be determined. This process is aided by the development of a comprehensive hierarchically structured risk response register that uses consistent terminology, which aids knowledge transfer from one project to the next. Research in this area of risk (e.g., Al-Bahar & Crandall, 1990; Dey, 2010; Hillson, 1999; WSDOT, 2010; PMI, 2008; and ICE, 2005) has not been well developed and defined; the current literature is sparse and lacks depth. Where it is described, no formal structure to plan and develop the risk response for a project is given. Presented in Figure 2.12 is the risk response register developed for the case study – it represents a work in progress and is based on the literature reviewed and consideration of lessons learned from past experiences of the authors. The implementation of the risk response categories represent project phases, subcategories are risk response strategies (avoid, transfer, mitigate, accept or retain, and share), classes represent specific types of actions that can be taken, and within a class, individual responses reflect specific actions that might be taken. The authors are not convinced of the need to break responses down by categories or project phases, as it might lead to extensive duplication of responses between phases. Ongoing work is directed at exploring how best to structure the response register, and at identifying a comprehensive list of classes for each response sub-category.
The ability to focus on modelling risk responses in a structured way allows one to associate risk drivers within multiple risks to a specific response, thereby achieving leverage (i.e., treating multiple risks with a single risk response) – For example, shown in Figure 2.13 is how an specific risk response (in this case: Master communications plan - JV with client/consultants/supplier/trades) is associated to multiple risk events (i.e., Slow response times between parties - internal & external, First Nations threaten legal action if perceive JV not fulfilling expectations/commitments, Client very slow in design review - lack of experience & new relationship, and Tower failure during testing, need to wait until testing company has an available date for a new tower test) and the ability to assign specific relationships to components in different project views (e.g., participants, environmental, etc.), being able to understand which project
views constitute a source of risk drivers. Again, as demonstrated in the following section of the paper, is how the use of data visualization can assist in understanding the linkage between risk responses and risk events/issues - see Figure 2.26 and Figure 2.27. Other processes that follow the implementation of risk response strategies are the revision of the assessment of risk by way of a post-risk response assessment. Once the assessment and response processes are completed, including assessment of any new risks given a response strategy, then the need exists to document and communicate findings in the form of a risk brief that treats project context, risk register, risk response register, and various data mining reports (e.g., tabular reports, dashboards, and data visualizations). During the control phase, the information should be updated on an ongoing basis, and lessons learned captured in a form useful for future projects – i.e., the knowledge management aspect of an integrated risk management system.

Figure 2.13 – Association of particular risk responses to a number of risk events/issues. Leverage in assessing efficacy of risk responses for selection decision; possibility to assign a relationship also with specific properties treated
2.5 EXTRACTING INSIGHTS FROM RISK DATA VISUALIZATION

2.5.1 INTRODUCTION TO DATA VISUALIZATION

The role that data visualization can play in generating insights into a project's risk profile during the risk management process given its ability to portray large amounts of data in very compact form is to facilitate the development and interpretation of the risk register. Data mining through the use of data visualization within risk management entails a challenge on how to visualize relevant information in order to maximize understanding of the messages within risk management datasets in aid of identifying potential risks and reasons for them, understanding the distribution of risks in various dimensions (e.g., time, space, participant, etc.), pinpointing quickly highest priority risks as a function of performance dimension impacted, and examining how risks have been responded to. The importance of integrating visualization into risk management comes from the idea of communicating key information to management personnel quickly yet in a manner which is both comprehensive and accommodating of the need to explore the risk profile of a project at different levels of data granularity in support of decision making. This is very difficult to achieve when data is presented in tabular or text form, which can result in important messages being concealed or at least hard to comprehend because of the volume of data involved and the difficulty of representing associations amongst data elements. Figure 2.14 depicts several roles for data visualization in aid of the risk management function. The focus here is on interactive and dynamic data visualization strategies that can assist in viewing, navigating and understanding the representations of the project context and risk views with their corresponding modeling components, attributes and relationships.

A number of academics and practitioners have documented how interactive visualizations may communicate risk information better than plain tabular or text reports amongst experts and decision makers. (e.g., Eppler & Aeschimann, 2008; Bartlett, 2006; Feather et al., 2006; Gou & Zhang, 2011; Evelson & Yuhanna, 2012; and Nezafatkah, 2011). Cutter (2008) focused on how to communicate natural hazard risks to a various stakeholders and listed specific requirements for visualizations, namely, to be clear, simple, readily interpretable and truthfully represented. Thus, the purpose of the data mining process is to:
• Be able to find patterns and insights in data visualization;
• Fit required information of visualization in a single screen; and
• Effectively show deep and broad data sets in a single screen.

Figure 2.14 – Roles of data visualization in project’s risk profile for large scale projects

Feather et al. (2006) illustrates experience using software visualizations to help in the early phases of project planning, capturing dependencies between a three-layer model – project requirements, risks and mitigation – with examples from spacecraft technologies and systems. Bartlett (2006) introduced a visualization technique for risk management called ‘risk concept mapping’ enabling management to appreciate the total risk for a project, a valuable tool when used in early stages of a project. The map shows pathways from risk drivers to risk events and risk outcomes. It also shows risk increasing in severity towards a final outcome. Input for this map is derived from teamwork during the risk management sessions, making easier the tasks of assigning risk ownership and planning risk mitigation strategies. The idea of ‘risk concept mapping’ can be very valuable, especially since the process involved in building the map is simple to understand. However, when treating a large scale project without the support of an intelligent system, it would be very difficult to develop such a map, which would be further complicated by
data cluttering due to the large amount of data involved in large scale projects, a topic treated later in this section.

One feature important to the use of data visualization within the risk management function is that of interactivity, in order to maximize the assistance offered to analysts and decision makers. Evelson & Yuhanna (2012) differentiate the use of interactive data visualization tools compared to the use of static graphs in terms of the following increased capabilities:

- Dynamic data content;
- Visual querying;
- Multiple-dimension, linked visualizations;
- Animated visualization; and
- Personalization of user interface.

Risk management sessions conducted to identify risks or determine responses can be an individual activity or involve several people in different ways: interviewing individuals, groups, or using group processes such as brainstorming and decision-conferencing processes (Chapman & Ward, 2003). Smith et al., (2006) also suggested three differing methodologies for risk identification processes: brainstorming sessions along lines similar to value management workshops, analysis of historical data for similar projects, and use of industrial checklists. These processes can be enhanced through the use of data visualization. During a creative brainstorming session with individuals of different backgrounds and experience, too many potential issues might be identified, overwhelming the project team and causing it to lose focus. Chapman & Ward (2003) explain how decision-conferencing techniques are designed to improve the efficiency and effectiveness of group processes involving the exploration of problems and decision-making situations. This technique usually involves a facilitator and a real-time IT computer support system operated by one or more analysts. The facilitator manages the group’s deliberations, guiding discussion in appropriate directions as necessary. Hence the importance of developing an interactive, simple and intuitive interface aided by dynamic and flexible project views, with the possibility
of navigating various visualizations of project context and risk and response registers during the risk modeling process.

In developing a user interface to support risk management processes, a number of properties should be addressed in order to fully capitalize on the strengths offered by data visualization. Using the risk modeling approach described previously, the following are relevant properties that a user interface should possess in order to assist risk management sessions effectively:

- Ability to seamlessly move from one project view to another (physical, process, environmental, participant, and risk) – see Figure 2.15;
- Ability to personalize dashboards according to the needs of the risk management discussion during the session – see Figure 2.16;
- Ability to filter view data – drill down to specific areas of interest (use of hierarchical structures, project components, attributes and their mapping) – see Figure 2.23;
- Ability to roll-up or aggregate view data – i.e., roll-up to issue level in the risk register and capture a global idea of risk in a category – see Figure 2.22 and Figure 2.23;
- Ability to order – e.g., for a user specified risk profile (e.g., a subset of risk issues within a project phase), display risks in ascending or descending order of one of expected value, impact if the risk occurs and likelihood of occurrence – see Figure 2.21;
- Ability to superimpose various properties of data components using a common data dimension – see Figure 2.17;
- Ability to support data visualization for all project views in one system, (e.g., support different formats, support various data transformation, and aggregation functions) – see Figure 2.18 and Figure 2.19;
- Support the ability to export information out to other tools in order to explore data – see Figure 2.24; and
- Provide access to rich data representations at any point in time in a risk management session, which in some cases may be best done by exporting data and then representing it directly or adapting it using other visualization environments.
In developing a support tool for risk management that integrates project context as represented through multiple views with data visualization, two observations merit consideration:

1) It is not practical to support the full spectrum of data visualizations possible for all project views in one system. As part of the work described herein developing several of the visualizations presented later, the authors have examined what is readily achievable within the context of an integrated system and what is best done outside the confines of a single system. Guiding this thought process is the need to be aware of developments in the area of data visualization, given the recent proliferation of very useful commercial tools (e.g., Evelson & Yuhanna, 2012; and Nezafatkhah, 2011) and open source tools (e.g., Data-driven-document java scripts libraries). In order to capitalize on their features it is best to be able to export data to them. It is not feasible or cost effective to recreate and integrate them within an integrated system, especially a research system designed for the exploration of concepts.

2) Exporting data out of the integrated system to other visualization tools in order to explore further messages within the data leads to loss of some interactive abilities in that the data is no longer dynamic but just represents an instance in time. Thus, to the extent possible, visualizations directed at data which is in a constant state of flux should be incorporated within the integrated system. Where data is relatively static, enhanced data visualizations are best achieved by exporting to the latest state-of-the-art data visualization tools.

2.5.2 THE ROLES OF VISUALIZATION IN DEVELOPING THE RISK REGISTER

One of the most important benefits of using data visualization is the possibility to explore and identify potential scenarios that could lead to risks – e.g., the presence of undesirable conditions within a single view or the confluence of conditions from 2 or more views that could contribute to the potential for a risk event. Visualization tools are helpful for exploring the entire project context and its corresponding properties by navigating across the entire project model (see Figure 2.15), through to the exploration of individual project components in order to detect if one or a combination of factors may cause a risk event. For example, see Figure 2.16 in which the risk is identified as a function of context, in this case, the
elevation property of tower locations is plotted along with work schedule showing when work has to be done and where. While the risk register is under development, it is possible to determine if the spatial properties of the components could be a risk (e.g., a tower constructed at a higher elevation and scheduled for erection in winter when access to the location is not possible).

Figure 2.15 – Access to all 5 project views and the ability to move back and forth easily; within a view it is possible to drill down into the properties of individual components

Another benefit of visualization during the development of the risk register is the exploration of properties aided by the ability to juxtapose the attribute values of specific physical elements. As an example, shown in Figure 2.17 are location attribute values for the locations in section 1_A of the case study project for the purpose of identifying potential problem locations, especially the confluence of undesirable values for a number of attributes (e.g., foundation and tower types, tower elevation, geotechnical conditions, presence of geotechnical hazards, and helicopter access only). Having this kind of data readily accessible in a risk identification session can greatly assist in the identification of potential risks.
Figure 2.16 – Personalized interface with direct access to visualize data from various views simultaneously. Note the flexibility to show different details and properties of specific view components; i.e., shown is physical data (elevation of tower locations) and process data in the form of a bar chart indicating when work of a specific type is scheduled for execution.

Figure 2.18 and Figure 2.19 deal with the situation where it is desired to visualize multi-dimensional data (e.g., spatial, temporal species, etc.) in compact form (selected data for sections 1A through 1E of the case study project is shown) as a back drop to the elicitation of potential environmental risks. The ability to enhance decision-making using visualizations of certain factors of the other project views during a risk identification session can be very helpful. This is an example of a case when instead of using the supporting graphics available within the integrated environment, it was best to export data from the integrated risk management system and use a visualization tool available in the market (e.g., TIBCO Software Inc., 2012) to create an image of the data. This is particularly appropriate when relatively static data is involved and the image only has to be created once, which corresponds to the case at hand. Exporting data however, is not without its challenges, because each external visualization tool has its own logic and system that requires re-arranging or processing of the data involved in order to prepare it to be received and displayed by the external tool.
Figure 2.17 – Juxtaposition of selected attributes (e.g., location attributes of geotechnical conditions, foundation type, tower elevation, and tower type) of data components (e.g., locations)
Figure 2.18 – Aspects of environmental view; spatial mapping granularity corresponds to subsections not individual tower locations

Figure 2.19 – Visualization dashboard of multiple attributes vs. locations. Section 1, physical view of project
Another challenge involves learning to use the visualization tool in order to be able to represent in a compact form the large data set that feeds the visualization. The advantages of developing the visualization of a relatively static data set in a formal way is that the data could be later exported again and updated easily in the external tool. This allows one to use all of the powerful features possessed by the tool (e.g., interactivity, filters, rich representations in terms of graph type, attributes categorized by color, size, form, etc.). Some of the more recent advantages of these tools is the ability to share the information created in the form of data visualizations as an online resource; the interactive dashboards can be exported and shared for review by others online at the same time; and properties and interactivity of the dashboards can be preserved and stored for further decision making and communication sessions.

2.5.3 THE ROLES OF VISUALIZATION IN INTERPRETING THE RISK REGISTER

The role of visualization in interpreting the risk register while being developed, during risk assessment, and during development of the risk response register is to provide continuous and instant feedback. As the risk register unfolds, the ability to explore risk register properties in real time is a powerful tool for identifying hot spots (see Figure 2.20) and refining register contents (e.g., show preliminary risk profiles, detect incompleteness of the risk register, and seek additional feedback during risk management sessions with experts and management team personnel present).

Shown in Figure 2.21 (a) and (b) is how a feature of the data visualizations tool allows re-arranging of a linear heat map representation according to expected risk assessment values. This linear heat map can be generated very quickly at any point in the risk elicitation process, showing assessments to date and items of special significance. In this figure risk issues and events appear in the same order as in the risk register (Figure 2.21 (a)) and can be quickly rearranged to order risks in ascending or descending order with respect to the expected value (Figure 2.21 (b)), impact or likelihood, thus helping personnel to focus on the more significant risks. The option to include post risk response and actual outcomes on the images is available in order to provide as complete a picture as possible throughout the duration of the project.
Figure 2.20 – Instant feedback on findings to date on project’s risk register; ability to explore in real time what has been done so far to improve understanding

Figure 2.21 – Examining pre-response estimates of risk expected value, likelihood and impact for selected risk issues/events, (a) in same order as original risk register, (b) sorted in descending order with respect to expected value
Another important role of visualization in understanding the project’s risk profile is to have the ability to create graphics that show an overview of risk events by rolling-up to a risk issue or a risk category level. Shown in Figure 2.22 is how the heat map representing the estimates for expected values, severity of consequences and likelihood of risk events, can be also visualized in a graph denoting the numeric equivalent value of risk expected values for risk events and the rolled-up value for the corresponding risk issue (in purple color). The value of this visualization lies in the opportunity to obtain insights at a higher level of relative risk and understand which risk issues are particularly significant, in order to focus attention and resources for determining risk responses and monitoring performance.

A contribution of the research is the introduction of a visualization that could assist in generating insights on the relationship between risk events and risk drivers, assist in decision making as to where to focus resources and select the most appropriate risk response actions. The use of hierarchical tree structures is used to represent the different project views in a radial or circular layout. Mappings supported between view components (‘nodes’) can be represented by a series of linking edges. In the context of this research, the interactions shown in the radial view represent a relationship between risk events in the risk view structure with risk drivers from the other project views. Note that risk drivers could be common to multiple risk events and issues; in a similar way, a single risk event could be linked to a significant number of drivers. Of particular interest to construction personnel are risk drivers that are connected to multiple risk events. Such information assists greatly in identifying the most effective risk responses – i.e., select those responses that target risk drivers associated with multiple risks, thereby achieving significant leverage.

The reason for selecting a radial layout for the hierarchical tree structure models is because the large data sets involve require the ability to visualize clearly patterns within them, as well as to show different levels of components (‘nodes’). As described by Boyd (2012), visualization attempts for large graphs commonly fall within three categories: node-link diagrams, tree maps and radial layouts. The radial layout displays the nodes (components) in a hierarchical outer ring and the edges (links) as curves connectors.
in the center of the ring. Benefits are two-fold: first is the focus on specific relationships between nodes by cross-scale exploration, rather than by the relative spatial location of nodes (useful in smaller graphs); and second, when using large data sets, the relationships represented by the edges are consistently encoded and bundled allowing the image to convey higher-level meaning – e.g., patterns.

Figure 2.22 – Rolling-up information to higher levels to determine relative importance of issues (purple color bars), showing numeric equivalent of linguistic expected values.
Another advantage of the radial layout visualization technique is that the aggregation level of detail can be adjusted as desired in order to focus on important or specific project issues. However, this visualization can lead to a visual cluttering if a large number of edges are represented. Utilizing an edge bundling technique (Holten, 2006; Holten & Wijk, 2009; and Gou & Zhang, 2011) is an effective way to reduce the visual cluttering and complexity when communicating relationships of dense networks. This technique groups parallel edges or connectors with nearby origin destination as if they were tied, allowing the user to ‘read’ a large number of similar relationships as a single line, thereby assisting in the comprehension of large data set to generate insights. Bundling can be of two types: Force-directed edge bundling (Holten & Wijk, 2009) or hierarchical edge bundling technique when visualizing graphs with a hierarchical structure (Holten, 2006). The hierarchical structure and edge connections are colour coded to make it easier to analyze which risk drivers have the potential to drive more risk events or for each risk event which are the specific drivers in all the project views.

One of the greatest challenges in developing a radial layout visualization is in: (i) selecting the most appropriate external tool, and (ii) preparing the data set from the data export from the integrated system to the language of the external tool. The external tool that could best support understanding dependencies and interactions between project components at different levels of hierarchy and across the multiple project views was selected as SolidSX (Solid Source IT, 2010). It provided the most convenient solution. SolidSX external tool integration analytics are explained in the work by Telea & Voinea (2008). Similar tools were also evaluated (e.g., NetTreeViz (Gou & Zhang, 2011), InProv (Boyd, 2012), Gephi (Gephi, 2012), Node XL for excel (Smith et al., 2010), and other open source graphical tools). However, SolidSX provided an efficient radial layout with the possibility to adapt the exported data from the project model with a reasonable level of effort. The process to adapt the data exported from the integrated system to be able to use SolidSX required creation of an XML code file. It was necessary to declare each view component as a unique ‘node’, define the hierarchical structure by linking nodes and finally declaring the dependency links as ‘edges’ between nodes.
Figure 2.23 presents the interface used for overviewing the risk register and drilling down into specific risk issues and risk events properties. In this case, a risk event has been selected and the identification of risk drivers for the four project context views allows the user to navigate and select project components easily. Such risk driver relationships are shown in Figure 2.24 for eight sample risk events. Note that the significant number of drivers for these events is represented as a radial network diagram. The use of this kind of visualization conveys in a single screen a very large amount of data in a compact form making it easy to understand and explore. Since the visualization tool is dynamic in the context of the data exported to it, the levels of aggregation details in each of the project views can be adjusted, depending on the desire to display information in more detail. Figure 2.25 shows the radial dependency network in the mode of a detailed aggregation level for all project views, revealing dependencies between risk drivers and risk events.

Figure 2.23 – Navigating at different levels of risk register and properties; identification of risk drivers in the four views for a risk event
As mentioned before, understanding the relationship between risk drivers and events could provide information to assist in identifying the most effective risk responses – data visualization can help with understanding this relationship. By understanding the project’s risk profile, the risk management team can develop the risk response register structure (see Figure 2.26). An important role that data visualization can play in understanding the risk register is to assess the efficacy of risk responses. As stated previously, one seeks to select those risk responses that target risk drivers associated with multiple risks, thereby achieving leverage (see Figure 2.13). Thus, use of a radial layout visualization that incorporates risk responses and associations with risks helps with: (i) understanding the relationship of a particular risk response with associated risk events/issues, and (ii) providing support to determine how to gain leverage from risk responses (i.e., treating multiple risks) – see Figure 2.27.
Figure 2.25 – Exploration of relationships at different aggregation levels (All views)
Figure 2.26 – Building the risk response register; visualizing relationships of risk response actions and risk events to assess efficacy of responses
Figure 2.27 – Visualization of association of risk responses to risk events; ability to treat multiple risks

2.6 CONCLUSIONS

Conclusions are summarized as follows:

1) The risk management approach adopted to develop a risk register and mine its contents using data visualization in order to generate insights into a project’s risk profile has proven to be of
significant value, as measured by feedback received from the contractor for the transmission project and the increased understanding of the project’s risk profile by management.

2) Substantial **challenges exist in modeling large scale projects** dispersed over variable geographical locations. One must deal with complexities related to specific project components and attributes as they pertain to the various views/dimensions of a project (product, process, participant and environmental), and work at different levels of granularity, depending on the project dimension being treated.

3) Considerable thought is required to **identify relevant component attributes** that may signify the presence of one or more risks. In order to assimilate project information in an efficient way, one has to differentiate between what is really important to know about the project and what would be nice to have but can’t readily be modeled because collecting and processing the information would be a very resource consuming task without a commensurate level of benefits.

4) The use of a surrogate **impact measure** such as **severity of consequences** can assist in:
   a. Addressing the reluctance of personnel to express potential time and cost consequences without the aid of detailed time and cost models because of the significant time and resource commitment required;
   b. Helping to maintain momentum in a risk identification session; and,
   c. Serving as a fast way to conduct preliminary screening of risks in order to determine which risk issues and related risk events require more-in depth assessment with respect to their cost, time, safety, etc. consequences.

5) The role that **data visualization** serves in generating insights into a project’s risk profile during the risk management process through **interpretation of the risk register** has proven to be of significant value. Data visualization provides the ability to portray large amounts of data in very compact form.

6) **Data visualization** is of **greatest value** when accompanied by **interactive, dynamic, simple and intuitive interfaces** for viewing project context views, including the risk view. Achievement of this value requires that a number of **challenges** be overcome related to knowledge management and consistent use of terminology (see items 7 and 8 below) along with the ability to
make use of leading edge data visualization software tools that are too costly to recreate within the confines of an integrated risk management system.

7) **Knowledge management** should be an integral component of the risk management approach in order in a highly structured way to build on past lessons learned and to capture lessons gained during application of the risk management process on future projects. The assistance of IT in knowledge transfer can assist greatly the risk management process, improving exploration, development, and recording (e.g., model structure interface, tabular reporting, and data visualization) of a project’s risk profile.

8) The **lack of consistent terminology** when defining a project’s risk register and context directly affects the opportunity to transfer knowledge effectively. A disadvantage of current approaches is that **knowledge is mostly captured as a static instance**, lessening the ability to add lessons learned. For the case of large scale projects in particular, their context and risk register (and also the response register) require an extended period of time to develop, and they undergo continued change as more knowledge becomes available, conditions change, etc.
CHAPTER 3. CONCLUSIONS

3.1 CONCLUSIONS

The research concludes with a number of observations in relation to its objectives, followed by comments on challenges encountered, lessons learned, and recommendations for future work. Conclusions are summarized as follows:

1) The **risk management approach** adopted to develop a risk register and mine its contents using data visualization in order to generate insights into a project’s risk profile has proven to be of significant value, as measured by feedback received from the contractor for the transmission project and the increased understanding of the project’s risk profile by management.

2) Substantial **challenges exist in modeling large scale projects** dispersed over variable geographical locations. One must deal with complexities related to specific project components and attributes as they pertain to the various views/dimensions of a project (product, process, participant and environmental), and work at different levels of granularity, depending on the project dimension being treated.

3) Considerable thought is required to **identify relevant component attributes** that may signify the presence of one or more risks. In order to assimilate project information in an efficient way one has to differentiate between what is really important to know about the project and what would be nice to have but can’t readily be modeled because collecting and processing the information would be a very resource consuming task without a commensurate level of benefits.

4) The use of a surrogate **impact measure** such as **severity of consequences** can assist in:
   a. Addressing the reluctance of personnel to express potential time and cost consequences without the aid of detailed time and cost models because of the significant time and resource commitment required;
   b. Helping to maintain momentum in a risk identification session; and,
c. Serving as a fast way to conduct preliminary screening of risks in order to determine which risk issues and related risk events require more-in-depth assessment with respect to their cost, time, safety, etc. consequences.

5) The role that **data visualization** serves in generating insights into a project’s risk profile during the risk management process through **interpretation of the risk register** has proven to be of significant value. Data visualization provides the ability to portray large amounts of data in very compact form.

6) **Data visualization** is of **greatest value** when accompanied by **interactive, dynamic, simple and intuitive interfaces** for viewing project context views, including the risk view. Achievement of this value requires that a number of **challenges** be overcome related to knowledge management and consistent use of terminology (see items 7 and 8 below) along with the ability to make use of leading edge data visualization software tools that are too costly to recreate within the confines of an integrated risk management system (see section 3.2).

7) **Knowledge management** should be an integral component of the risk management approach in order in a highly structured way to build on past lessons learned and to capture lessons gained during application of the risk management process on future projects. The assistance of IT in knowledge transfer can assist greatly the risk management process, improving exploration, development, and recording (e.g., model structure interface, tabular reporting, and data visualization) of a project’s risk profile.

8) The **lack of consistent terminology** when defining a project’s risk register and context directly affects the opportunity to transfer knowledge effectively. A disadvantage of current approaches is that **knowledge is mostly captured as a static instance**, lessening the ability to add lessons learned. For the case of large-scale projects in particular, their context and risk register (and also the response register) require an extended period of time to develop, and they undergo continued change as more knowledge becomes available, conditions change, etc.
3.2 CHALLENGES

One of the main challenges involved in carrying out the research was working with a case study project that was in progress, especially a fast-tracked design-build project. This required one to deal with a lack of available information and constant updates of documents, which was compounded by the significant size of the data sets involved, given the scale of the project. At the same time, project modeling was a task that took a long time to develop, and made more difficult be the need to continuously update and modify it to reflect changing conditions of the project, all of which was necessary to capture the essence of reality as much as possible in a comprehensive model. The approach for modeling long-linear projects is intensive when contractor personnel need to pursue an opportunistic strategy in order to perform the work due to imposed project restrictions (e.g., environmental windows, third party stakeholder difficulties, permitting difficulties, and off-shore procurement). Regarding the development of the risk register, significant challenges exist in identifying and structuring key risk issues, risk drivers, risk events, and relevant explicit attributes of drivers contributing to the existence of a potential risk, as well as quantifying risks and structuring a risk response register.

Challenges related to data mining of risk and response registers require considerable thinking effort as to the best way to visualize and understand relevant information of risk in order to maximize the benefits that can be derived from data visualization. The approach pursued in developing visualizations was to think about what images would be useful in interactive risk management sessions when a number of experts are in attendance. Specifically, what advanced visualizations could aid risk identification brainstorming and decision making processes as well as determining effective risk response measures. Issues that need to be addressed include: (i) determining what is readily achievable within the context of an integrated system and what is best done outside the confines of a single system for risk management, (ii) selecting the most appropriate external data visualization tools, and, (iii) assessing the level of effort and time involved with processes needed to export data and transform a data set to fit with data formats compatible for use with external visualization tools, thereby allowing richer representations of project context and risk data.
3.3 LESSONS LEARNED

Lessons learned which relate directly to the research contributions are summarized as follows:

1) Lessons learned from using a detailed case study (transmission line project) to implement and evaluate the risk management approach.
   a. Large scale infrastructure projects, especially long linear ones such as a transmission line project need special understanding to appreciate fully their complexity (e.g., large scale data sets associated with their environmental, geographical (spatial), participant, product and process dimensions as well as relationships amongst these dimensions);
   b. In order to model project context and a project’s risk register, and to cope effectively with project scale, it is necessary to structure the models in a comprehensive hierarchical manner in order to be able overview each project view and make possible effective model revision;
   c. The use of calibrated likelihood and the use of a surrogate performance measure such as severity of consequences for the risk assessment of events, made it possible to provide a quick pre-assessment process with project personnel engineers and managers when analyzing a very large number of risk events – the notion espoused in the literature that the impact of risk events should they occur be measured in terms of performance dimensions such as time, cost, safety, environmental impact, etc. can be readily estimated is simply not accurate – what can be estimated with reasonable confidence is the relative importance of different risks; and,
   d. The ability to roll-up information (e.g., risk expected values from risk events to a risk level issue) is of great value for understanding a project’s risk profile, especially to improve communication of information to higher management levels and to other parties (e.g., client).

2) Lessons learned regarding modeling – project context and project risk profile.
   a. Project context views were modeled in a way that made it possible to work at different levels of granularity depending on the project dimension to be examined and the type of risk involved (e.g., a risk that is applicable to a specific location instance of a project component versus a risk that is applicable to an entire subsection of a project); and,
b. The surrogate performance measure of severity of impact provided a practical work around of the challenge of doing complex estimating of risk quantification (e.g., time and cost) for the entire project risk profile, a work around that was very acceptable to project personnel.

3) **Lessons learned using data visualization and structuring risk responses.**

   a. The development of useful data visualizations is a process that requires a long time and considerable effort (e.g., exploration of alternative images) especially if an individual visualization needs a number of features to be available in order to be truly insightful – this is especially the case if the image is implemented within the integrated risk management system, thereby allowing the user to obtain feedback on an ongoing basis based on the most current state of the data set;

   b. It is essential that one be aware of the accelerated developments in the area of data visualization in the form of useful commercial software and open source tools that are applicable to a many disciplines (engineering, medicine, security, business, etc.). In order to capitalize on the features of these tools it is best to be able to export data to them. It is not feasible to recreate them and integrate them into the system unless an Application Programming Interface (API) exists. In some cases, writing an interface so that they can be called from within the parent risk modeling system is either very difficult to do or simply impossible; and,

   c. Exporting information out of the risk management system to other tools in order to explore data in greater depth leads to the loss of some interactive abilities in that project data is no longer dynamic (i.e., changes in risk modeling system will not be updated automatically). On the other hand, when relatively static data is involved or when the data results are not likely to change anymore, it is best to export data from the risk management system for exploration with other tools, especially when different data aggregations and superpositions are desired.
3.4 FUTURE WORK

The approach pursued as part of the research on risk management modeling for large scale construction projects still requires further work in order to address challenges encountered. Within the scope of this research, the recommendations for future work are:

1) Examine user interface issues in the multi-view project model that could assist with the creation of flexible, dynamic and comprehensive dashboards to aid users to view and navigate in real time the hierarchical structures for project context and risk register components;

2) Adapt, adopt and integrate interactive visualization tools and strategies available in external tools and used in other disciplines. The challenge is one of selecting the right visualization tools, and then deciding how is best to implement them into the system so that they are as dynamic as possible;

3) Conduct further work on the notion of a project risk response register in terms of contents, structure, re-estimation of likelihood and impact at the risk event level, and visual evaluation of response register contents;

4) Show how post-response risk assessment can provide a better understanding on how to plan response strategies, and how to implement and monitor them adequately;

5) Enhance further the constructs and accompanying interfaces to capture and manage knowledge pertaining to modeling project context, formulating a project’s risk and response registers, and assessing the likelihood and impacts of individual risk events; and

6) Conduct additional case studies on full-scale projects in order to enhance further the practicality of the risk modeling approach and its responsiveness to the realities of the construction industry.
REFERENCES


ESKOM. (2004). *Transmission line towers and line construction, Transmission specification (TRMSCAAC1, Rev.3)*, South Africa.


