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MODELING RISK FOR TRANSMISSION LINE PROJECTS

Alan D. Russell[1] and Diego Orozco[2]

[1] Professor, Department of Civil Engineering, University of British Columbia, and Chair, Computer Integrated Design and Construction, Vancouver, British Columbia, Canada.
[2] MASc. Student, Department of Civil Engineering, University of British Columbia, Vancouver, British Columbia, Canada.

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 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.

Keywords: project representation, risk management, transmission lines projects, data visualization

1 INTRODUCTION

Described in this paper is a holistic, integrated approach to risk management and its application to a large scale infrastructure project. Goals of the paper are three-fold. First, we describe selected features of a highly structured, integrated approach to risk management for large scale projects, with emphasis on linear projects. Second, we demonstrate 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. Third, we overview how data visualization can assist in extracting valuable insights from the large scale data sets that accompany such projects. We conclude with a brief commentary on the practical challenges involved in risk management for large scale, geographically dispersed projects.

The topic of risk management for capital projects has been treated by many academics as well as practitioners (e.g. ICE(2005) 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 and hands-on experience by the first author in developing risk registers for civil engineering infrastructure projects has motivated the search for an enhanced approach to risk management, while building on the best of previous work by others.

2 RISK MANAGEMENT APPROACH OVERVIEW

The approach to risk management overviewed herein has been developed over an extended time period, and its evolution has been documented in part in the work by de Zoysa (2006) and Russell and Nelms (2007), which in turn builds on previous work by Russell and Udaipurwala (2004) focused on the multi-view representation of a project in support of key project/construction management functions, inclusive of risk management. Central to the work described herein are the five project views depicted in Figure 1. An example of their use in practice is illustrated in the case study section of the paper.

The physical (product) view treats the spatial context of a project (e.g. physical work locations and procedural steps in processes such as procurement) as well as the products to be produced both on and offsite 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).

The process (planning and scheduling) view identifies the processes to be used to realize the project. A mapping exists between the physical and product views to answer the question: what gets produced, where, when and by whom.

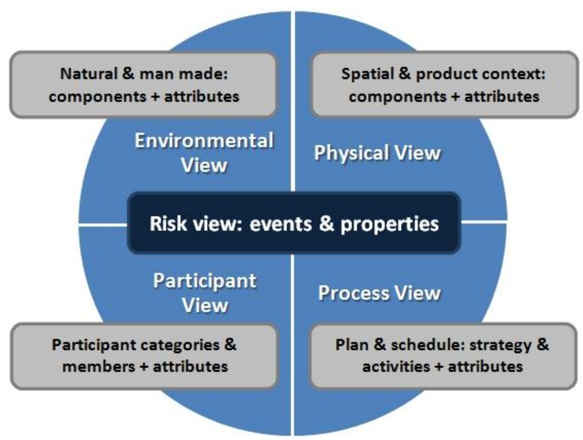


Figure 1: Representation of a project in the form of integrated views

The participant view 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.

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 economic/regulatory/political environments. Environmental components can be mapped onto the project's spatial context.

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 fifth view, the risk view depicted in Figure 1, 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 our experience with past projects, we do not recommend the use of a deep hierarchy. We have 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), 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 response adopted.

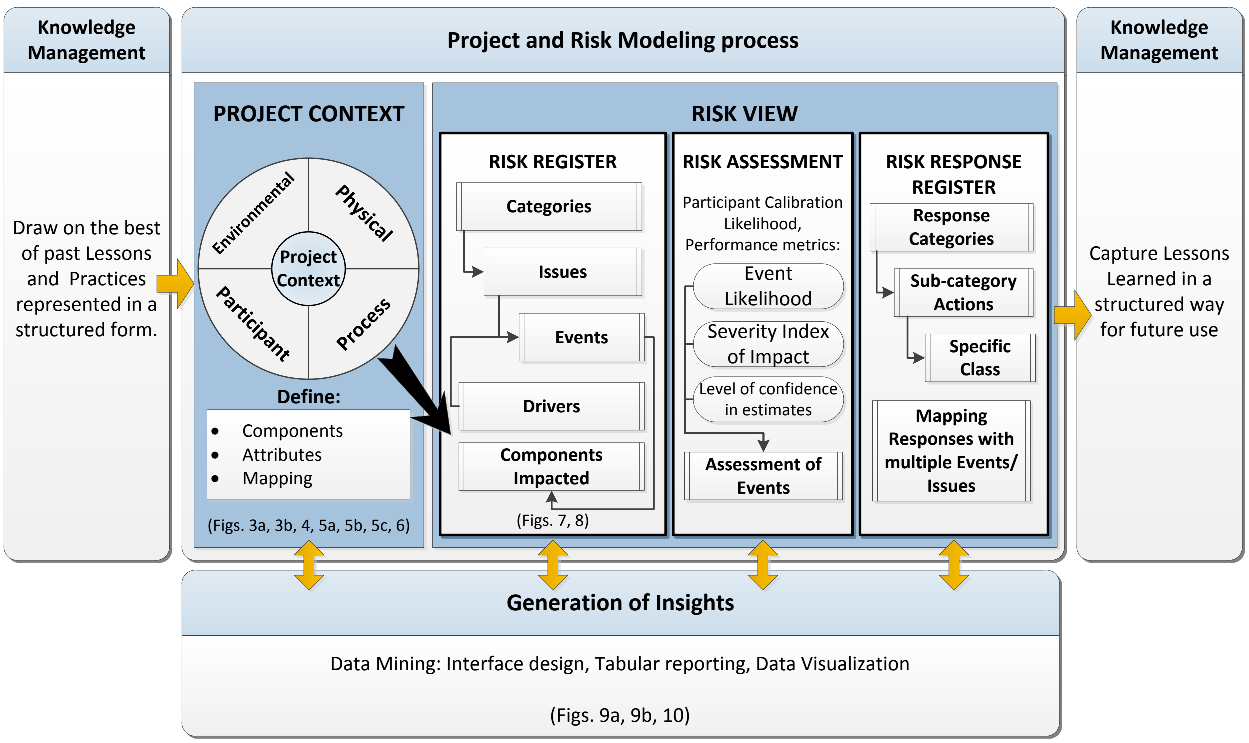


Figure 2: Elements of risk modeling approach

In terms of application of our approach, while multiple pathways of use are supported because practitioners demand flexibility, we recommend based on our experience the following front-end steps as depicted in Figure 2 (figures numbers contained in Figure 2 correspond to those presented in later sections of the paper): (i) define the project context four project views – this is an iterative process which can benefit from lessons learned on past projects; additional important information often gets teased out in a risk identification session which further assists in characterizing a project's context; (ii) set up the structure of the project risk register and define risk issues 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; (iii) identify risk events that apply to the overall project under the relevant risk issue (e.g. macro-economic risks, political risks, contractual risks, etc.) along with relevant drivers; (iv) 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?" If yes, 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; (v) once the risk register has been populated assess likelihood and impacts in a qualitative way, after calibrating risk identification participants. We observe 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. 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. Other steps not elaborated herein include identifying project components affected by the realization of a risk, identification of suitable risk responses, re-estimation of likelihood of occurrence and impact given any responses implemented, and achieving buy-in from selected project participants/decision makers.

3 CASE STUDY

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 our 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, 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 and Burchett 1999).

The 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.

Data gathering and interaction with project personnel was achieved by embedding the second author in the project office for a period of 6 weeks. Also, several visits were made by both authors to present findings, seek feedback and interact with senior personnel.

Depicted in Figure 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 3(b) are the location attributes determined to be of importance for the case study project. Values can be expressed in one of **B**oolean, **Q**uantitative, **L**inguistic, or **D**ate 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. helicopter access only, high elevation, difficult geotechnical conditions and the presence of geotechnical hazards). A partial view of location attributes for section 1A is presented in Figure 4. Having this kind of data readily accessible in a risk identification session can greatly assist in the identification of potential risks.

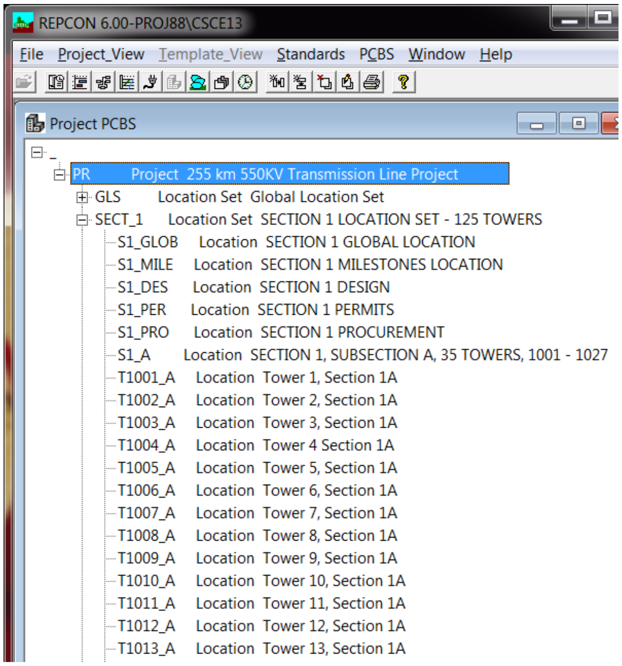


Figure 3(a): Partial spatial (location) context for physical view for case study project

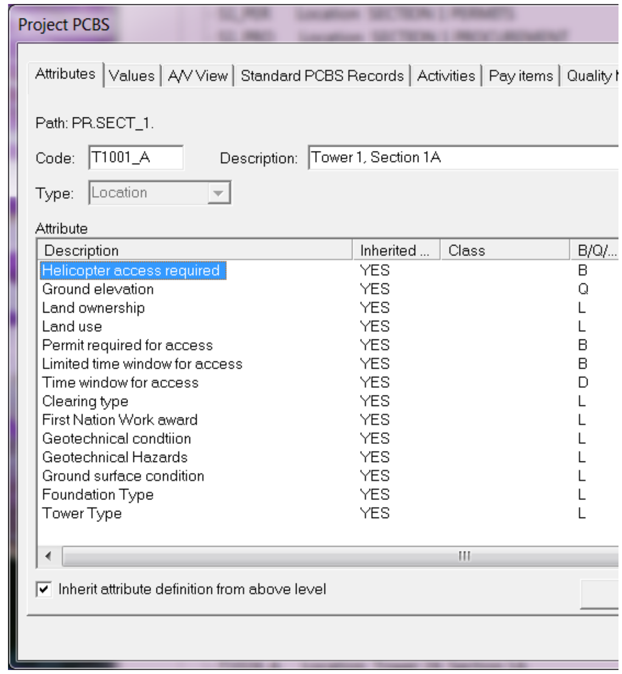


Figure 3(b): Spatial component attributes that are potential risk drivers

Similar to what has been shown for the physical view, representations of the process, participant and environmental views have been created, and attributes defined. Of these, only aspects of the environmental view are shown here because of space constraints. Presented in Figures 5(a) through (c) are, respectively, the subclasses 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 here 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; leaving the foregoing aside, for projects that do proceed, the environmental context can create the potential for multiple risks; and (ii) in modeling the environmental dimension, in many cases it is sufficient to model at coarser granularity than that used for the physical structures. This coarser granularity is achieved by mapping environmental features onto collections of physical locations. Again, being able to visualize aspects of the environmental view 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 6. Rather than supporting graphics for all possible image types within an integrated environment, Figure 6 represents an instance 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 Spotfire®) 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.

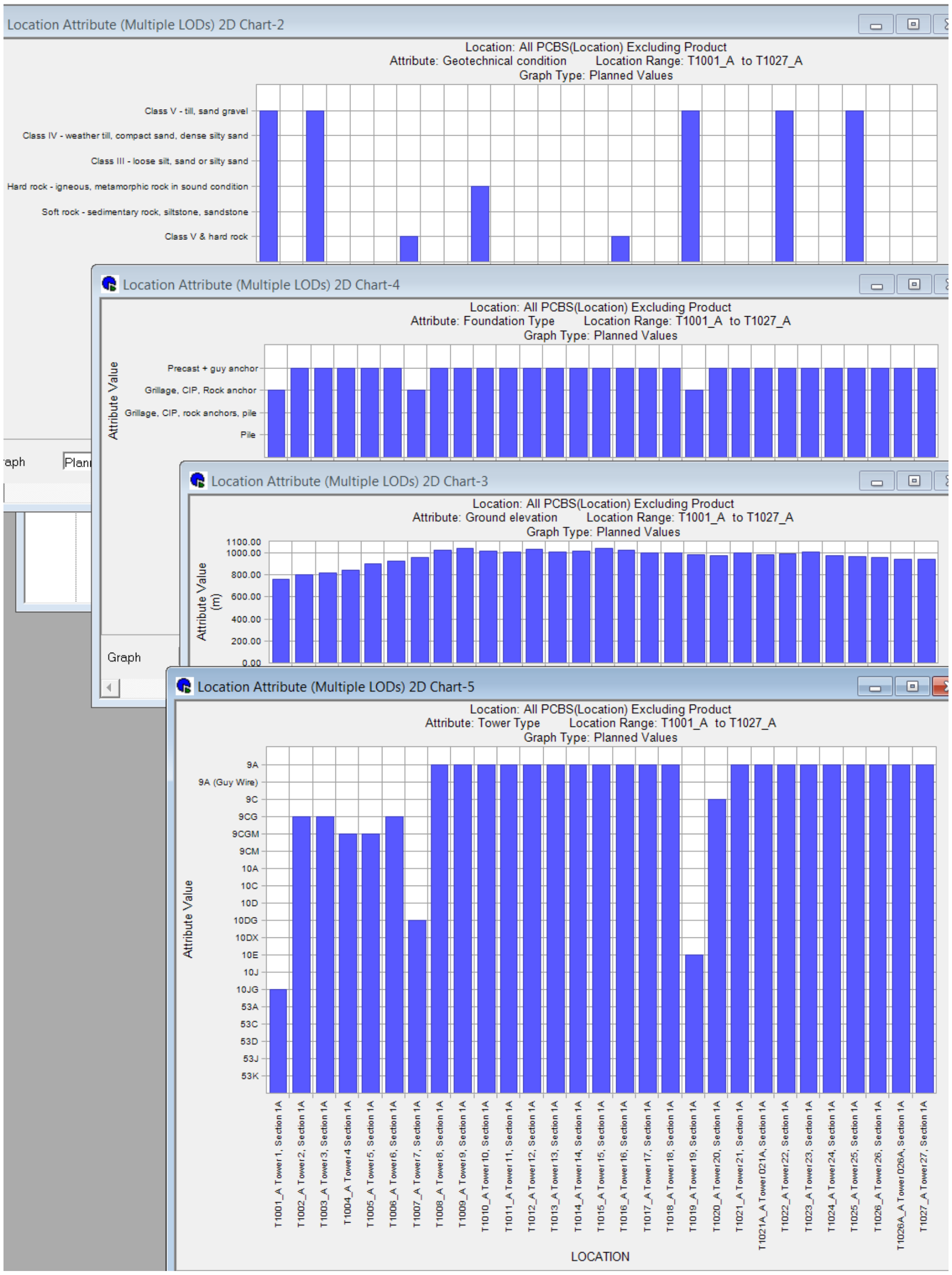
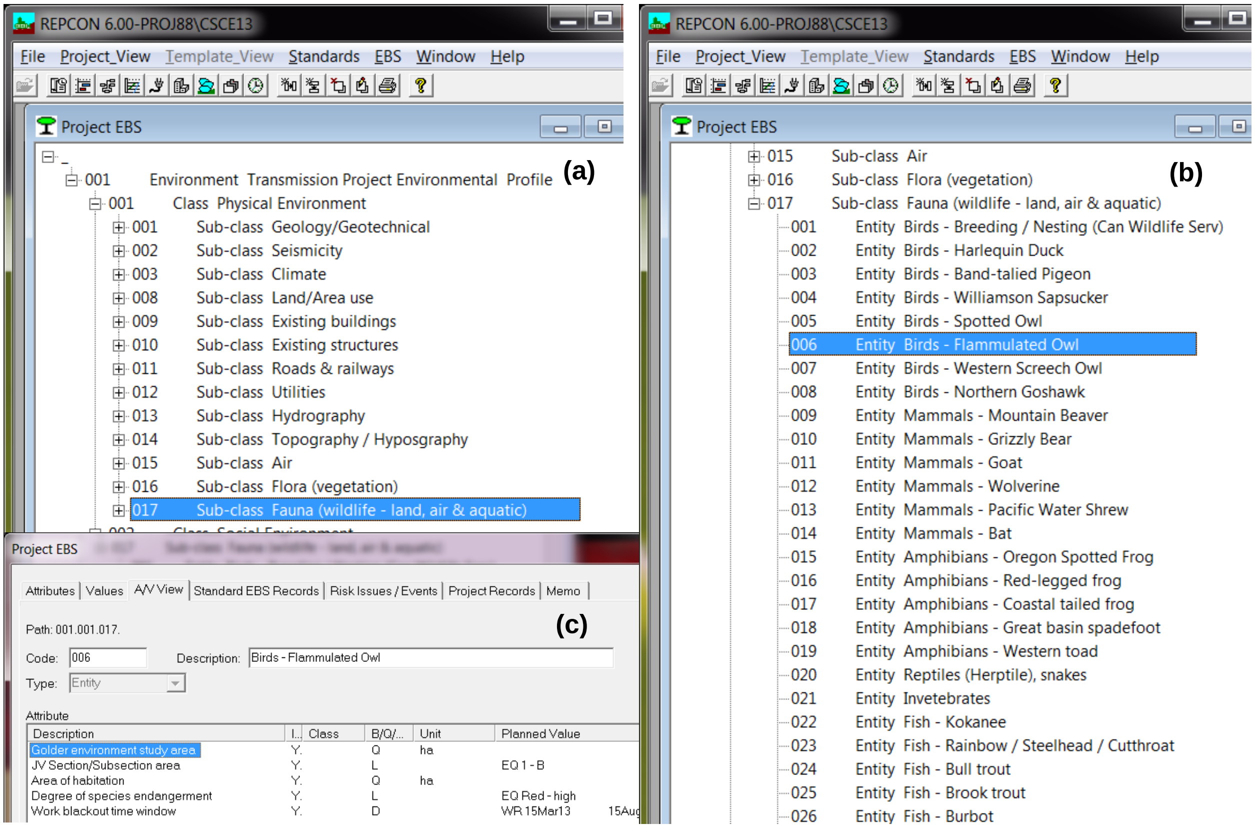


Figure 4: Partial view of location attributes of section 1A.

Once the four views have been created (they evolve over time as more information becomes available), attention is directed to development of the project's risk register. Except for the project's construction and commissioning phases, risk issues for the different project phases of interest are shown in Figure 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.

Shown in Figure 8 is an expansion of the risk register to individual risk events under the Migratory birds and diligence risk issue in the construction phase. Once risk events have been identified, their likelihood of occurrence and potential impact on performance need to elicited from the most appropriate members of the project team, a non-trivial task. Two observations here are that personnel were comfortable with



Figures: (5a) Components of the Physical Environment Class; (5b) Individual items in the Fauna sub-class; (5c) attributes and values for section 1-B for entity Birds-Flammulated Owl

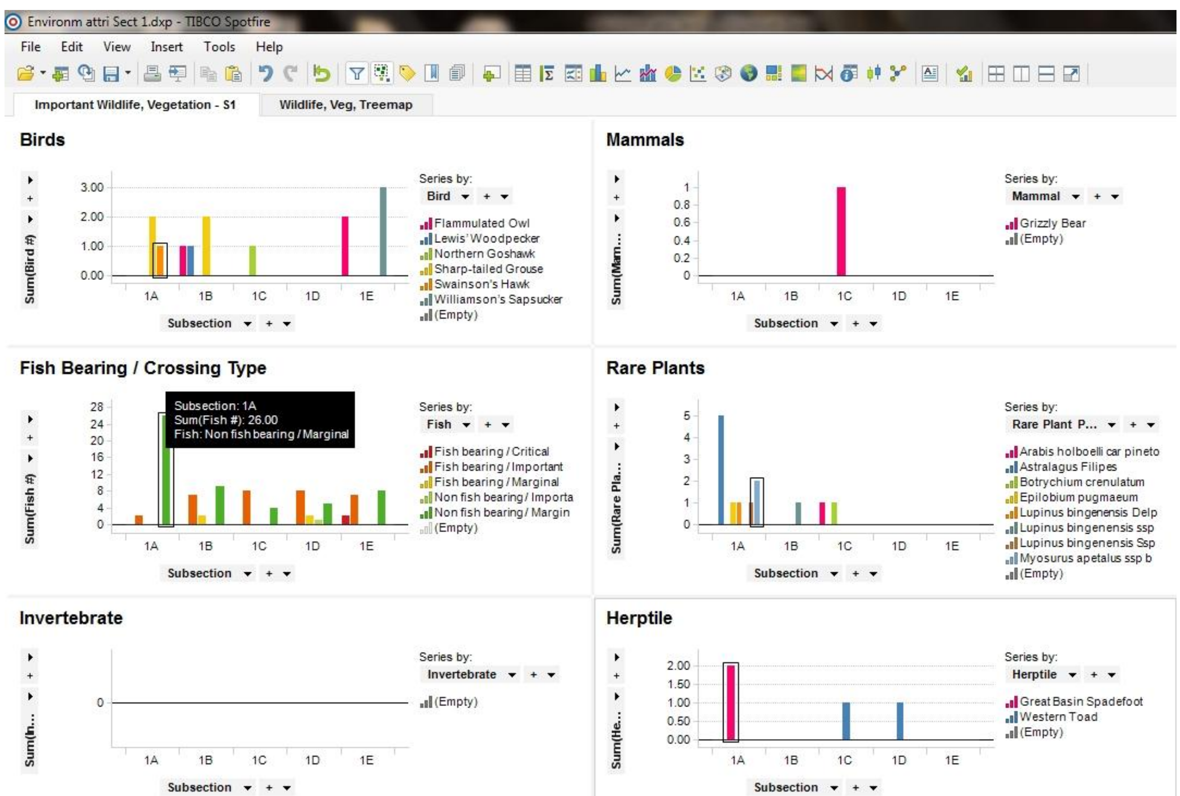


Figure 6: Aspects of environmental view – spatial mapping granularity corresponds to subsections, not individual tower locations

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. 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. Expressing relative severity of impact sufficed to identify the risks of greatest concern. Not treated herein because of space constraints is the determination of the most risk appropriate responses at the event and issue levels, and re-estimation of likelihoods and impacts on a post-response basis.

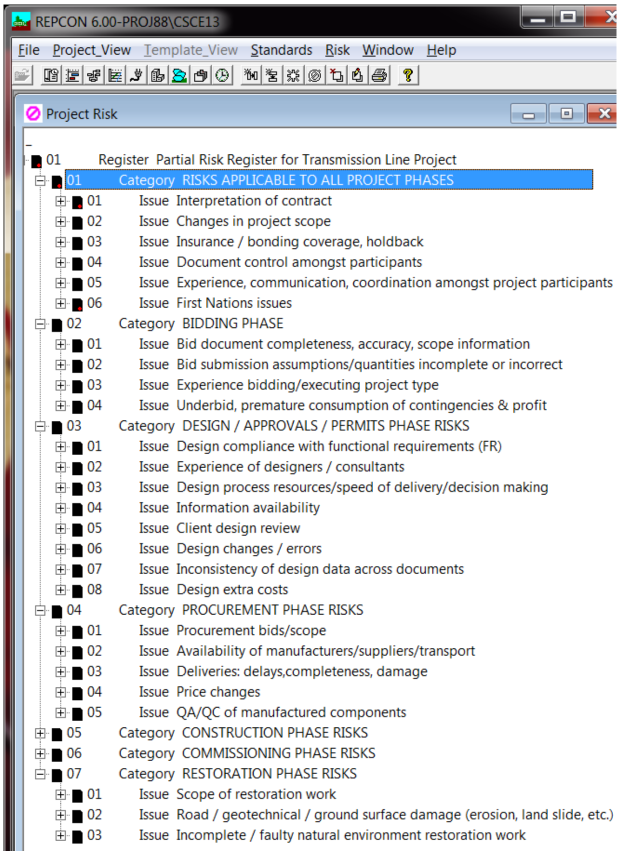


Figure 7: Risk issue categories for project phases exclusive of the construction phase

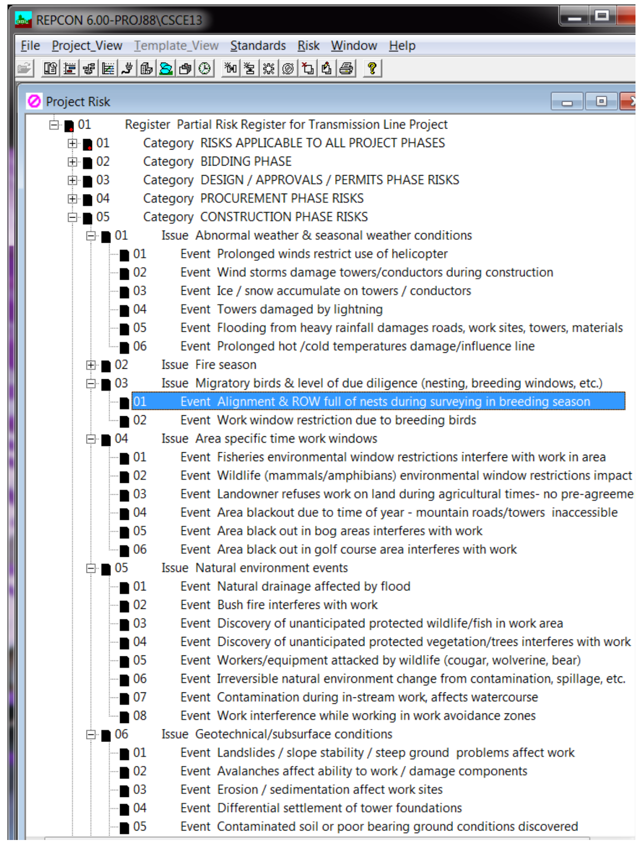


Figure 8: Risk events for construction phase risk issue Geotechnical/subsurface conditions

4 EXTRACTING INSIGHTS FROM RISK DATA

Given the development of a risk register, a challenge becomes one of interpreting its contents in order to maximize the insights possible to facilitate the ongoing management of risks. Data visualization provides a powerful tool for generating such insights, given its ability to portray large amounts of data in very compact form. We present here two visualizations that have proved helpful and were enthusiastically embraced by project personnel. Ongoing work is directed at expanding the repertoire of useful visualizations including the aggregation of lower level data. Shown in Figure 9 (a) and (b) is a linear heat map that can be generated very quickly at any point in the risk elicitation process, showing assessments to date and items of special significance. This image in which risk issues and events appear in the same order as in the risk register (9(a)) can be quickly rearranged to order risks in ascending or descending order with respect to one of expected value (9(b)), impact or likelihood, thus helping personnel to focus on the more significant risks. The option exists to include post risk response and actual outcomes on the image to provide as complete a picture as possible throughout the duration of the project.

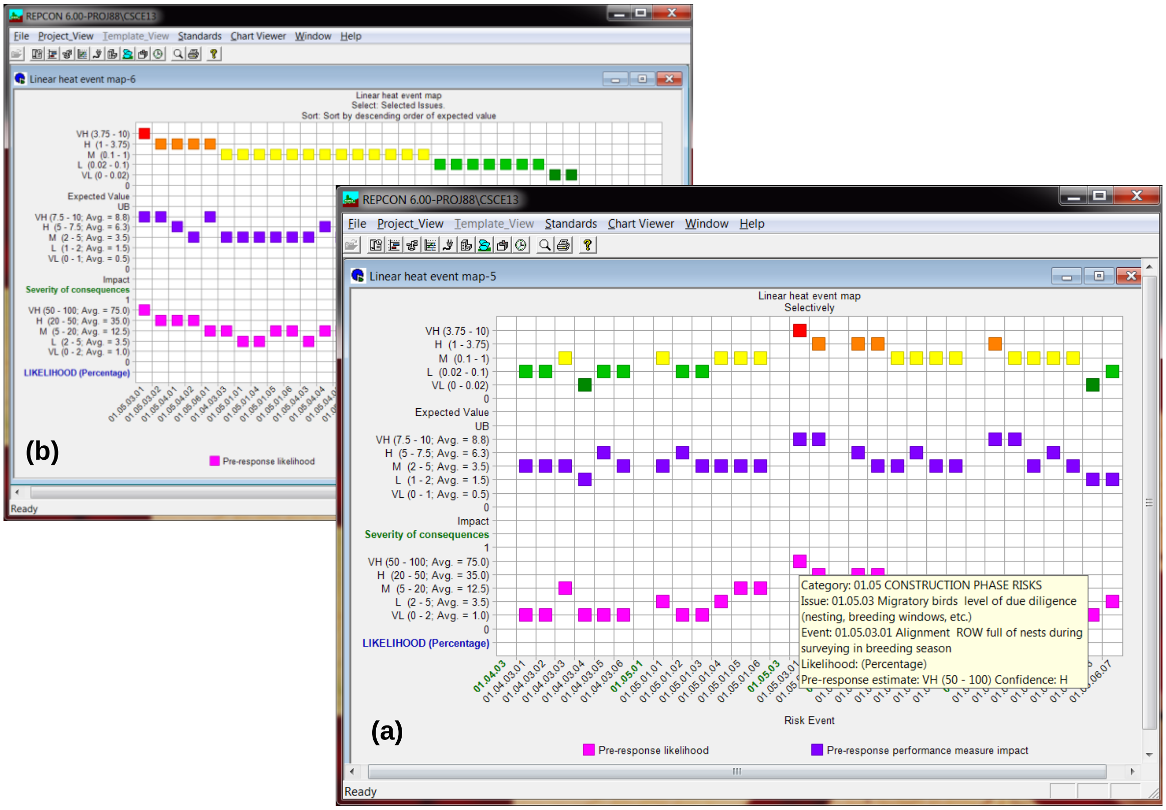


Figure 9 (a) and (b): Examining pre-response estimates of likelihood and impact for selected risk issues/events

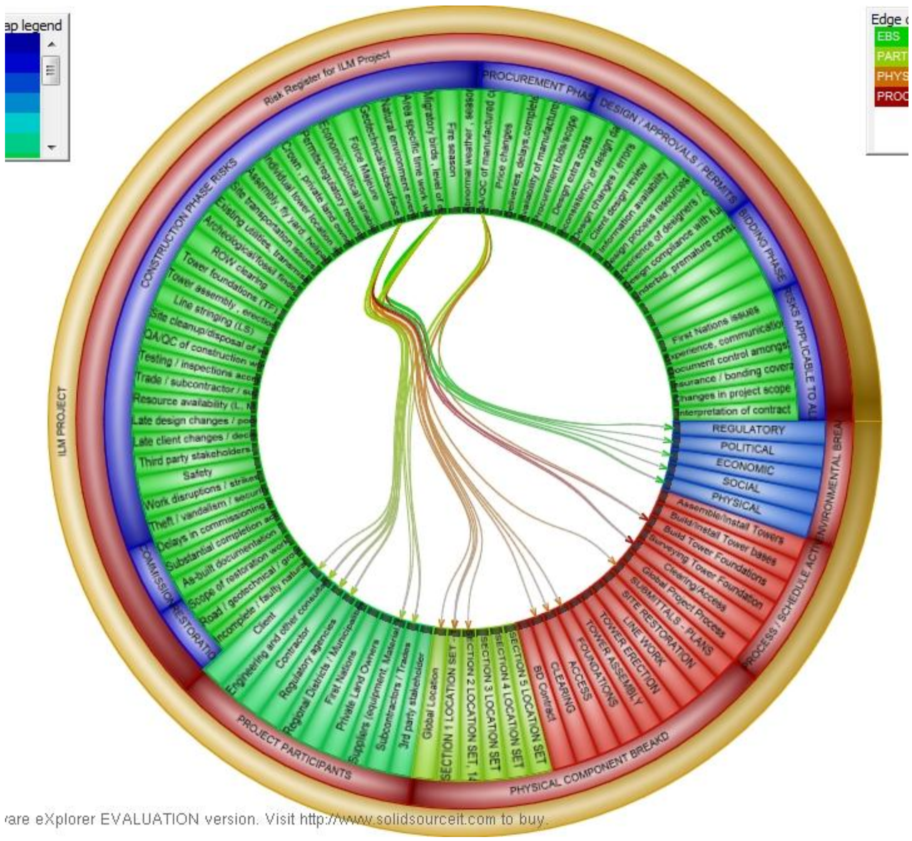


Figure 10: Comprehending the relationship between risk events and drivers

The hierarchical tree structures used to represent the various project views allow their components to be represented as unique nodes in a radial or circular layout as depicted in Figure 10 which was generated using Solid Source IT® SolidSX software. The mappings supported between view components (nodes) are represented by a series of linking edges. In our context, we use the interactions shown in the radial view to represent a relationship between a risk event in the risk view with risk drivers from the other project views. These relationships are shown in Figure 10 for three sample risk events. Note the significant number of drivers for these events. 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 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 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 visualization can lead to a visual cluttering if a large number of edges are represented. An edge bundling technique (Gou and Zhang 2011) is an effective way to reduce the visual cluttering and complexity.

5 CONCLUSIONS

We conclude here with a very small number of observations. First, our approach to development of a project's risk register and mining its contents using data visualization to generate useful insights into a project's risk profile has proven to be of significant value. Second, there are very substantial challenges in modeling large scale projects dispersed over significant distances. One must work at different levels of granularity, depending on the project dimension being treated. Third, considerable thought is required to identify component attributes that may signify the presence of one or more risks. Fourth, the use of a surrogate impact measure such as severity of consequences can assist in addressing the reluctance of personnel to express potential time and cost consequences without the aid of detailed time and cost models as well as helping to maintain momentum in a risk identification session. Finally, knowledge management should be embedded in the approach to capture lessons learned for use on future projects.

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