Barriers to Applying Probabilistic Risk Analysis in Design and Construction Projects

Christopher SENESI¹, Amy JAVERNICK-WILL², and Keith MOLENAAR³

¹Graduate Research Assistant, Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, 428 UCB, Boulder, CO 80309-0428, PHONE: (303) 492-6382; FAX: (303) 492-7317; EMAIL: christopher.senesi@colorado.edu

²Assistant Professor, Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, 428 UCB, Boulder, CO 80309-0428, PHONE: (303) 492-6769; FAX: (303) 492-7317; EMAIL: amy.javernick@colorado.edu

³Professor, Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, 428 UCB, Boulder, CO 80309-0428, PHONE: (303) 735-4276; FAX: (303) 492-7317; EMAIL: keith.molenaar@colorado.edu

ABSTRACT

Using a case study analysis of Construction Industry Institute (CII) and Project Management Institute (PMI) member companies, this CII-funded research sought to understand the current use of risk management tools in the industry, including deterministic and probabilistic project-control techniques. The results indicate that formal risk analysis is not adopted universally. Given the benefits realized from the use of these tools, this research sought to understand why organizations are not using more formal probabilistic approaches to risk management. The research uncovered several barriers organizations face when trying to implement these probabilistic approaches, including a lack of organizational support, a lack of procedures, a lack of technical expertise to implement and interpret outputs, and a lack of transparency amongst stakeholders. By focusing on overcoming these barriers through training employees, adopting processes and procedures for risk management, and regularly communicating with project stakeholders; organizations can implement more formal project risk management approaches when warranted.

INTRODUCTION

In the design and construction industry, projects are complex and have a high degree of uncertainty. Nontechnical challenges, such as economic, societal, and political issues can overshadow the engineering and construction complexities (Bruzelius et al. 1998; Flyvbjerg 1996; Flyvbjerg et al. 2002). These challenges frequently result in significant cost over-runs, schedule delays, and the misallocation of resources from risk-averse contracting strategies. While a risk-based mentality has become prevalent in the current social and business climate, and tools for identifying, assessing, and managing risk and uncertainty on construction projects are neither new nor unique to the industry (Mak & Picken 2000; CII 2010; Kangari & Riggs 1989); the vast majority of the construction industry applies only a deterministic approach in project controls. These deterministic tools do not consider the uncertainty inherent in engineering and construction projects, nor do they explicitly address the potential
risk. In contrast, probabilistic controls are methods for managing project risk and uncertainty in cost, schedule, and scope, taking into account risk and opportunity events that cannot be adequately defined in the design or construction planning. Given the availability of probabilistic tools in the construction industry, the research sought to understand why these methods are not frequently or widely employed in the construction and engineering industries.

**POINTS OF DEPARTURE**

The design and construction industry has struggled with risk management for years. Generally, risk analysis is either ignored or done subjectively by simply adding a contingency (Mak & Picken 2000). As a result, many major projects fail to meet cost targets and schedule deadlines, causing loss to all involved, including engineers, contractors, and owners. Persistent cost underestimation as well as schedule delays reflects poorly on the industry in general but more specifically on the engineers. One example of poor-handling of risk is evident in Flyvbjerg’s et. al. (2002) study on large-scale transportation projects. The research found that final project costs are underestimated in almost 9 out of 10 projects. Additionally, for a randomly selected project, the likelihood of actual costs being larger than estimated costs is 86%, while the likelihood of incurring equal or lower actual costs than estimated costs is 14%. The data also indicates that non-transportation related projects are just as likely, if not more likely, to have underestimated project costs (Flyvbjerg et. al. 2002).

Further yet, although probabilistic tools have been refined, Flyvbjerg et. al. (2002) concluded that cost underestimation, an indirect cause of poor risk management, has not decreased over time. In fact, today, the underestimation of projects is in the same order of magnitude as it was decades ago. Flyvbjerg et. al. (2002, p286) further states that “if techniques and skills for estimating and forecasting costs of transportation infrastructure projects have improved over time, this does not show in the data. No learning seems to take place in this important and highly costly sector of public and private decision making.” Now, this is not to say that a probabilistic approach to risk analysis will prevent cost and schedule overruns but it will at least give managers a more rational basis on how to make decisions (Kangari & Riggs 1989; Molenaar 2005).

In the last decade, organizations have focused more on improving risk management, including probabilistic risk analysis. Several industry organizations (Construction Industry Institute, Project Management Institute, International Standards Organization, and Association for the Advancement of Cost Engineering) have written and published guidelines that specifically address risk management, encouraging design and construction firms to employ probabilistic approaches for their projects. The question then becomes, “given the benefits, why are probabilistic controls not being employed more frequently?” Flyvbjerg et. al. (2002) proposes that other factors, including economic, political and psychological issues, must be addressed when implementing effective risk management strategies. Additionally, Zwikael and Ahn (2010) recommend that a more inclusive approach to risk management and analysis be taken, which focuses on integrating the risk management process, including risk analysis and probabilistic approaches, into the overall project management framework.
The literature also indicates that although there are benefits to using probabilistic approaches over deterministic processes (Akintoye & MacLeod 1997), there are many misperceptions of probabilistic analysis and most project managers do not understand the benefits clearly (Mak & Picken 2000). The obstacle then becomes breaking down the barriers preventing the use of probabilistic approaches in risk analysis procedures.

Given that risk management is essential to minimizing losses and enhancing profitability on construction projects (Akintoye & MacLeod 1997; Flyvbjerg et. al. 2002; Zwikael & Ahn 2010), organizations are beginning to recognize the increasing importance of risk analysis, and a number of large engineering consulting firms now have dedicated divisions for risk management. However, the industry uses few formal techniques of risk analysis and, in most cases, only basic non-probabilistic methods are used. Construction research should address this issue if such techniques are to be of practical value to the design and construction industry (Akintoye & MacLeod 1997).

As a result, this CII-funded research aimed to uncover why organizations are not using probabilistic approaches for risk management, specifically cost and schedule controls. To answer this question, we sought to determine the key barriers preventing the use of probabilistic approaches for cost and schedule risk analysis on design and construction capital projects.

METHOD

Because the primary question aims to answer “why” organizations are not using probabilistic approaches, we employed case studies. In addition to answering explanatory “why” questions, the case study method also allowed for a more in-depth study (Flyvbjerg, 2011). This provided insight into the decisions and issues affecting schedule and cost in construction and engineering projects (Taylor et. al. 2011). Specifically, the research investigated current practices and applications of probabilistic approaches compared to deterministic approaches for risk analysis on design and construction projects.

In order to appropriately select case studies, we conducted a preliminary survey. The goals of the preliminary survey were to (1) attain a better understanding of the current barriers of probabilistic tools within CII and PMI organizations and (2) identify organizations for case studies. The survey contained two sections. The first section asked questions regarding organizational information – type, sector, size, etc. to ensure appropriate representation. The second section focused on risk management and probabilistic control practices. The survey primarily was descriptive, as its purpose was more focused on “how many” (how many organizations use probabilistic controls, etc.) as opposed to seeking explanation (Oppenheim 1992). The survey included some open-ended questions, asking participants to provide reasoning to their answers and offer suggestions. This assisted the research team in developing the case study questions and identifying pertinent concepts that might have been excluded from the survey. The preliminary survey was distributed electronically to a directory of both CII and PMI member companies. There were 137 respondents, representing 104 organizations including owners, EPC firms, contractors, and design firms. Sectors represented including infrastructure, heavy/light industrial, and buildings.
Case Selection

From the preliminary survey, twelve organizations were selected for the case study analysis. The majority of organizations were selected based upon their use of probabilistic risk analysis, in order to better understand the barriers the organizations had to overcome when implementing probabilistic approaches. The case studies represented four defined attributes noted in the survey:

1. **Owner or Contractor** is based on the type of organization. For the purpose of this research, an organization cannot be classified under both categories.

2. **Public or Private** is based on the organization’s funding source for the project(s) being studied in this research. If the organization included both government and private projects, an organization would be classified under both categories.

3. **Construction Industry Institute (CII) Member** is based on organizational membership within the professional society (CII).

4. **Type** is based on the type of project(s) studied in each organization for this research. As such, an organization can be classified under multiple types of projects. Types included: horizontal (e.g. roads, bridges, pipelines), vertical (e.g. buildings, stadiums), and process (e.g. refinery, manufacturing, power generation).

The case studies were selected for theoretical and literal replication to ensure roughly equal representation of the attributes amongst the cases. Table 1 shows the twelve case studies, based on the defined attributes.

<table>
<thead>
<tr>
<th>Organizations</th>
<th>Owner or Contractor</th>
<th>Public or Private</th>
<th>CII Member</th>
<th>Type (Horz, Vert, or Process)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>C</td>
<td>Pu</td>
<td>Pr</td>
</tr>
<tr>
<td>Company 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Company 2</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 3</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Company 4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Company 6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 7</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 8</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 9</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 10</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 11</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Company 12</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>
Data Collection

After cases were selected and the organizations agreed to participate, data was collected through interviews, documentation and site visits. Interviews were semi-structured, meaning that the interviews had a specific objective but there could be some variability in meeting those objectives to allow for interviewees to expand upon their answers and guide portions of the interview. Prior to conducting the interviews, the interview scope was defined, including identifying and mapping key questions to subtopics (Singleton & Straits, 2004). The interview scope was developed from literature review and the responses to the preliminary survey and focused on benefits and barriers to using probabilistic risk analysis. Three questionnaires were developed for different interviewees within the organization focusing on:

- Enterprise level – including risk management structure, enterprise risk management, and policies and procedures.
- Portfolio level – including communication structure, tools, and portfolio contingency.
- Project level – including project controls, attributes, and project contingency.

In addition to the interviews, documents were collected from each organization including policies and procedures, processes, reports, and forms, all relating to risk management and probabilistic controls. The documents allowed the research team to visualize the organization’s risk management framework, which helped to both supplement and validate the interviews. Finally, site visits were conducted, which allowed the research team to observe organizations practicing probabilistic risk analysis. This then allowed the research team to triangulate the data and conduct a holistic analysis of each organization.

Case Analysis

Throughout the case study process, all but one interview (interviewee did not permit recording) were recorded and transcribed. In order to ensure transparency and thoroughness of the case study data, it was necessary that the data be managed and organized accordingly (Miles & Huberman, 1994; Creswell, 1998; Seale, 1999). To do this, the use of qualitative data analysis software, QSR NVivo, was used. The use of such software is highly recommended in case study analysis, as it adds rigor to the qualitative analysis (Richards and Richards, 1991). QSR NVivo is a widely used program and allowed the researcher to set attributes, assign codes, and manage and analyze the data. After the data was uploaded into NVivo, the data was coded by defined “categories” based on the research objective. For instance, a majority category was benefits of employing a probabilistic approach to risk management, with subcategories of specific benefits indicated in the interviews. This allowed the data to be filtered to more manageable components for analysis. The actual process of the data coding was iterative and detailed notes were taken, to ensure consistency and reproducibility.
KEY FINDINGS

In order to address why organizations are not using a probabilistic approach to risk analysis, the results presented focus exclusively on the barriers to adopting this approach. Future publications will focus on the benefits received from applying probabilistic approaches as well as the process for implementing these approaches within an organization. The case studies allowed for open-ended discussion, which was valuable in collecting a comprehensive list of barriers organizations have or continue to face when implementing probabilistic risk analysis. Barriers identified during the case studies were coded using NVivo and a matrix query was performed to determine the relative frequency of each of the barriers mentioned in the case studies. These are displayed in Table 2.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational Culture</td>
<td>16%</td>
</tr>
<tr>
<td>Lack of Familiarity or Understanding</td>
<td>15%</td>
</tr>
<tr>
<td>Communication, Transparency with Project Stakeholders</td>
<td>13%</td>
</tr>
<tr>
<td>No Policy or Procedures</td>
<td>9%</td>
</tr>
<tr>
<td>No Accountability of Implementation</td>
<td>8%</td>
</tr>
<tr>
<td>No Support from the Top</td>
<td>6%</td>
</tr>
<tr>
<td>Availability of Resources</td>
<td>5%</td>
</tr>
<tr>
<td>No Technical Support</td>
<td>5%</td>
</tr>
<tr>
<td>Not Enough Historical Data</td>
<td>5%</td>
</tr>
<tr>
<td>Not Meaningful</td>
<td>5%</td>
</tr>
<tr>
<td>Project Attributes</td>
<td>5%</td>
</tr>
<tr>
<td>Varied Perception</td>
<td>5%</td>
</tr>
<tr>
<td>No Push from the Bottom</td>
<td>3%</td>
</tr>
</tbody>
</table>

\[ n = 129 \]

The research identified thirteen different barriers, all of which were nontechnical in nature. As witnessed in Table 2, the top three most frequently cited barriers were: communication and transparency with project stakeholders, lack of familiarity or understanding, and organizational culture. These barriers were cited by a majority of respondents and were mentioned at least once in every organization. After initially coding the barriers into these macro categories, the research analyzed each barrier in-depth. This allowed us to identify barriers that could be addressed strategically by other organizations wishing to employ probabilistic risk analysis. The five identified barriers are defined below:

*Difficulty Interpreting Results*

One of the major barriers cited was “difficulty interpreting results”, which refers specifically to how project managers and team members comprehend and then use the outputs of probabilistic tools. This barrier primarily resulted from the original
barrier identified in the case studies as “lack of familiarity or understanding”. One employee, stated “Our biggest challenge is not really the technical part of the quantitative, it was selling it, it was promoting it, marketing it, how does it fit into the organization, how do you present it such that people don’t phase out. So that was one of our biggest challenges.” Being able to conduct the analysis is one thing, but then to be able to get people to interpret, accept, and take action on the results is critical in order to adequately use, and subsequently gain benefits from probabilistic analysis tools.

Lack of Organizational Support
The second most frequently cited barrier was the lack of support from upper management, which was necessary for wide acceptance across the organization. In general, one upper level executive stated: “there needs to be executive sponsorship from the top down, in order to institutionalize something in an organization.” If there is no push from management, and no evidence of leadership support for the use of the probabilistic risk management approach, there is little chance of employee buy-in and thus use, of the approach. The majority of the cases cited organizational support as extremely critical to successfully implement probabilistic analysis, let alone any type of new practice, within an organization.

Lack of Policy or Procedures
Directly related to the “lack of organizational support”, the third barrier identified in this research was the “lack of policy or procedures” in regards to risk management and probabilistic controls. As one might imagine, if an organization doesn’t have support from upper management, there is a good chance the organization does not have defined risk management policies, even though some projects are implementing risk processes. Or, vice versa, an organization might have the policy and procedures in place but there may be little to no enforcement. This was a major barrier identified within our case studies. One specific example was that some projects within the organization were implementing robust risk techniques, but because corporate had not yet defined the policy, many project managers did not know the appropriate steps to take within the organization. “What happened is we had a number of our projects within our various business unit have some really good grassroots efforts and have some very mature risk registers procedures and processes about how they go about doing this. But it has not been adopted corporately yet to promulgate it across the business. I go to projects today and ask for risk registers and I get the deer in the headlights look, it is still disconcerting, but that is kind of where we are.”

Lack of Technical Expertise
The fourth most frequently cited barrier related to two barriers, “no technical support” and “lack of familiarity or understanding”. After further reviewing these categories, the researchers classified the barrier as the lack of technical know-how to conduct probabilistic risk analysis. Overall, the case studies noted that having an internal employee versed in risk management, probabilistic risk analysis, and
the overall process, was critical for implementation. Other organizations noted that outsourcing the probabilistic analysis techniques and facilitation of meetings to an external risk management consultant was also acceptable.

*Lack of Transparency amongst Stakeholders*

The final barrier identified in this research was “lack of transparency amongst stakeholders”, a subcategory of the original category, and “communication/transparency with project stakeholders”. References to this category primarily focused on the lack of transparency to external participants. These stakeholder included clients, subcontractors, and other parties not directly part of the project delivery organization. As a result, this barrier does not relate to internal communication, as internal collaboration and communication is a perceived benefit derived from the use of probabilistic controls. Organizations that noted this as a barrier indicated the difficulties of showing the client a probabilistic analysis because (1) most clients did not understand probabilistic risk analysis, and 2) the organization was worried about showing a range of project cost. For example, one organization discussed how they continue to struggle for work in a tight market and by showing a range of costs, or bidding for a high confidence level, may lessen their chances of getting that job. Organizations noted that overcoming this barrier required increasing transparency and trust between the owner, contractor, and other stakeholders.

**DISCUSSION AND CONCLUSION**

This research identified potential barriers faced by organizations when employing probabilistic approaches for risk analysis. The five barriers identified are interconnected; therefore, addressing only one or two of the barriers may not be sufficient in order to implement probabilistic analysis. For example, in order to adequately adopt policy and procedures for risk analysis within an organization, there must be true acceptance of that policy (and further enforcement) by upper management in order for successful implementation.

Further, the research sought to assist organizations in determining strategies for overcoming these barriers. First, organizations need to obtain buy-in and support from employees. As noted in the case studies, it is typical for employees to resist culture changes within the organization – in this case, probabilistic approaches for risk management. However, by training employees over an extended period of time, including the benefits received through the use of probabilistic controls – employees are generally more open to adopting the new process. It is important to keep the risk management process simple and not overly time consuming. If done properly, this will help increase communication and knowledge of risks and mitigation efforts, enable a deeper understanding of cost and schedule estimates and certainty, and enable the organization to choose the best projects to pursue. Second, it is imperative that the organization adopts appropriate policy and procedures for risk management and probabilistic approaches to risk management, including obtaining the necessary approvals and ensuring that the appropriate parties are represented in the process. It is also important that these policies be enforced and used on all projects. Finally, it is important that the concept of risk management and probabilistic analysis be explained
more clearly and regularly to clients (and other project stakeholders). The case studies noted that by explaining the benefits and reasons for using a probabilistic approach, clients will be more open to using the process. These three tasks – employee buy-in, implementation of policy and procedures, and stakeholder communication – are only guidelines to implementing probabilistic controls and further research on the actual adoption process to probabilistic risk is warranted.

Finally, it is important to note that since this research was case-study based, in order to create more generalizable and validated findings, a large sample size via survey methods is recommended. The case-study approach, however, was extremely beneficial for this research, as it allowed the researchers to closely study twelve separate organizations in industry. By being able to interview key leaders within these organizations and study their risk management process, the researchers were able to better answer “how” and “why” the organizations adopted and were using probabilistic risk analysis, something that would be difficult through only quantitative research. This study shows the value that case study research can bring to the construction engineering and management industry.

As the design and construction industry grows, projects will continue to be overwhelmed with uncertainty. To better understand and mitigate the uncertainty inherent in projects, industry leaders and organizations must implement new practices that systematically address the impacts of risks on their projects. As noted in previous studies, tools for addressing this uncertainty exist; however, adoption of these tools in the industry is only beginning to gain momentum. Expanding this research to include a broader range of companies and validating these findings is recommended. However, the five key barriers identified in this research should help organizations begin to understand the barriers that will be faced when implementing a probabilistic approach to risk analysis.

REFERENCES


