

# Construction Risk Modelling and Assessment: Insights from a Literature Review

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## **Abstract**

Although risk assessment is probably the most difficult component of the Risk Management process, it is potentially the most useful. A critical review of the literature published on the topic over the last 27 years has revealed significant results, summarized as follows. Variants of Probability-Impact modeling are predominant; while traditionally the focus was on objective probability gradually subjective probability has become dominant. Risk analysis of project duration or cost is prevalent; the analysis of project performance risk is hardly mentioned in literature. Further, no risk assessment approach was discovered that deploys a common scale to simultaneously assess the alternative impacts of a risk on the various project objectives. Most of the existing approaches provide a risk rating; very few actually quantify risk. The limitations of the existing theories and tools indicate the need for improved alternatives. We conclude that the use of 'risk cost' as a common scale within a belief-based decision making framework would be an innovative solution, overcoming current shortcomings and generally improving construction risk assessment.

*Keywords:* risk assessment, risk modelling, risk cost, Dempster-Shafer Theory of Evidence, literature review.

## **Introduction**

"No construction project is risk free. Risk can be managed, minimized, shared, transferred or accepted. It can not be ignored" (Latham 1994). Moreover, construction, it is held, is exposed to more risk and uncertainty than perhaps any other industry sector (Flanagan and Norman 1993). It involves numerous stakeholders, long production durations and an open production system, entailing significant interaction between internal and external environments (BS 6079-4:2006). Such organizational and technological complexity generates enormous risks (Zou et al. 2007).

It appears that risk assessment is a controversial issue (Baloi and Price 2003); however, it is frequently considered to be the most useful part of the risk management (RM) process (Smith et al. 2006). Traditionally the focus has been on quantitative risk analysis (Tah and Carr 2001) despite the difficulties encountered in obtaining objective probabilities in the construction industry, where projects are very often one-off enterprises (Flanagan and Norman 1993). As a result, project managers are obliged to rely on the elicitation of subjective probabilities (Winch 2003). Therefore, as a probabilistic approach cannot be utilized to quantify risks, individual knowledge, experience, intuitive judgment and rules of thumb should be structured to facilitate risk assessment (Dikmen et al. 2007b).

This paper reviews the existing literature on construction risk modelling and assessment. Its aims being to highlight developments in these areas, discover their drawbacks and limitations, and evaluate the potential for further research. We have undertaken a comprehensive review of the risk assessment and modelling literature

published in the project management and construction management domains. Essentially, a chronological discussion of these publications is presented with an overview and commentary provided for each paper. A full analysis and discussion is provided, the paper culminating in a results and conclusions section.

## **Literature review**

### **The 1980's**

Although the number of the published papers during this period of time is relatively limited, they epitomize the different approaches (schools) for dealing with construction risk. For example, Chapman and Cooper (1983) outline one of the earliest attempts to consider the need for structuring project risks and systematically identifying their sources. They present the 'risk engineering' approach, which integrates different tools and techniques, including PERT, decision trees and probability distributions. The main focus of the paper is on combining risk events and the production of joint probability distributions for activity durations and subsequent project duration. Risk is modeled as a variation distribution of duration. In a subsequent paper, Cooper et al. (1985), they present a method for analyzing project cost risk: risks being structured as 'risk breakdown structures' (RBS) where the top of the hierarchy represents project cost risk. Risk is modeled as a variation distribution of base estimate of cost.

In one of the very few papers to highlight the need to consider the impact of risk on different project objectives, Franke (1987) advocates assessing risk impact in monetary terms. It proposes the use of 'risk cost' as a common scale: risk is modeled as the probability of occurrence and consequence. Although this paper adopts a pioneering approach to a comprehensive assessment of risk impact, overall project risk is treated in rather a simple way: as the sum of the individual risk costs, ignoring any interdependencies between these risks.

Kangari and Riggs (1989) illustrate the use of Fuzzy Sets Theory (FST) as a risk assessment tool; the earliest attempt to use FST to handle subjectivity issues in construction risk assessment. The paper presents an objective evaluation of the merits and shortcomings of FST.

### **The 1990's**

During the 1990's construction risk assessment and modelling gained momentum and became a 'hot topic' for research. Researchers, building upon previous work, primarily cantered around two main schools: Probability Theory and FST; although, they were open for other tools, techniques and approaches. For example, Hull (1990) introduces different models, based on Monte Carlo Simulation (MSC) and PERT, to assess proposal risk from cost and duration points of view, while Yeo (1990) presents a 'contingency engineering' method, using both a range estimates method and the PERT technique, to assess cost risk and estimating contingency.

Pioneering its application in construction, Mustafa and Al-Bahar (1991) adopt the Analytic Hierarchy Process (AHP) to assess construction project risk. Becoming one of the most cited papers in the literature; it applied the concept of value and weight to assess risk probability and impact. The paper also evaluates the suitability of using AHP to assess construction project risk, delineating its limitations for such applications. Likewise, Dey et al. (1994) present a risk assessment methodology, based on AHP, which combined objective and subjective assessments; risk was also modeled as Probability-Impact (P-I). Riggs et al. (1994) propose an approach for quantifying and integrating technical, cost, and schedule risks as utility functions. AHP was used to assign probabilities to a decision tree: the option with the maximum utility was to be chosen. The proposed model, however, could not be used to assess risk; it could only be used to assess the utilities of different 'risk scenarios'. AHP was also used by Zhi (1995) to assess the risk levels of overseas construction projects; the P-I model was

adopted and AHP deployed with minor modification. The impact assessments fell within [0-1] instead of the AHP's formal 1-9 ordinal scale.

Similarly, Diekmann (1992) discusses, from a theoretical and practical perspective, the issue of applicability and the shortcomings of risk analysis techniques based upon probability theory. He concludes that the methods utilized at that time were either too simplistic or too complicated to be used by practitioners.

Paek et al. (1993) proposes a risk-pricing algorithm, using FST, to assist contractors when determining the bid price of a construction project. Wirba et al. (1996) also presents a FST-based RM approach, which identifies risks, checks for dependence amongst them and assesses risk likelihood of occurrence by using linguistic variables. While this paper is widely cited, concern has been raised over the use of interdependence coefficients for dealing with risk interdependencies. Coefficients are computed by using the fuzzy weighted mean method, which is a point of weakness in FST, as it only calculates the weighted average.

A critical literature review (Williams, 1995) concludes that limited research had been undertaken on 'quality risk' and, likewise, there was a lack of research into the impact of risk on different project objectives. He postulates that 'risk cost' could be used as a common scale for assessing the total impact of risk. Elsewhere, Williams (1996) discusses the limitations of P-I risk models, while advocating a three dimensional risk model: Probability-Impact-Predictability, as recommended by Charette (1989).

A stochastic model, which combines the randomness of the cost and the duration of a project activity, was developed by Tavares et al. (1998). Project risk was modelled as the probability of not meeting project objectives, i.e. duration and cost; however, no other objectives were considered. Mulholland and Christian (1999) use the PERT technique to develop a distribution of project duration. The variance of the duration distribution of a project is used to measure schedule risk: the larger the variance, the greater the risk associated with project duration.

Again, the limitations of the P-I model are expounded by Ward (1999), who called for an improvement in risk assessment. Similarly, he advocates that the multiple impacts of a risk on project objectives should be considered, in order, to calculate the overall risk impact. Additionally, he criticizes the use of separate probability-impact grids for each type of risk impact and the summation of numerical scores to generate a single composite rating of a risk. As an alternative, he proposes the use of a weighted sum of alphabetical ratings. We consider that his approach may be not applicable, if the aim is to assess project risk; for example, a risk rating would be expressed, something like:  $3A+2C+5D$ . Such a rating can hardly be dealt with when aggregating the assessments; if there were many risks to be considered, a very complicated and unmanageable score would be generated.

## **Post 2000**

Since 2000, endeavours to model and assess construction risk have intensified, and have become more sophisticated, benefiting from the availability of high capacity PCs. As a result, risk assessment began to be dealt with within decision support systems (DSSs) and, despite their limitations, AHP and FST became the principal approaches for handling ill-defined problems with subjectivity, as they were considered to be the best available option.

Baccarini and Archer (2001) present a methodology, adopted by the Department of Contract and Management Services in Western Australia, which ranks projects based on risk. The methodology utilizes the P-I model, which calculates a risk score for project cost, time or quality. Like previous models, although it considers different impacts on project objectives, it is an over-simplistic approach, averaging the likelihoods and the

impacts of a risk on project cost, time and quality then multiplying them to generate a risk score. The final project risk score being the highest of the scores. The limitations of the various ways by which construction risk had previously been dealt with is discussed by Hillson (2002). He proposes assessing both threat and opportunity simultaneously within P-I models qualitatively and quantitatively.

Ward and Chapman (2003) criticize the use of Probability-Impact grid to size risk, arguing that it generated unnecessary uncertainty by over-simplifying estimates of impact and probability. As an alternative to probability-impact grid based approaches, they propose a six steps 'minimalist' approach for estimating uncertainty (Chapman and Ward, 2000).

Jannadi and Almishari (2003) attempt to assess risks associated with various construction project activities, defining risk as the potential damage that may affect personnel or property. They model risk by probability, severity of impact and 'exposure' to all hazards of an activity and provide software to generate risk scores. However, they do not provide a methodology for aggregating risk ratings. Similarly, Cagno et al. (2007) adopt the P-I model and quantify the 'risk load' allocated to each project element by identifying sources of uncertainty, activities affected, and risk owners. Risk impact is assessed in monetary terms but collectively as a single figure. They attempt to improve risk modelling by introducing the concept of 'controllability' as a ratio between the expected risk impacts before and after applying mitigation actions. Controllability is dealt with as a tool for justifying mitigation actions economically.

Zhang (2007) illustrates the limitations of the P-I risk model claiming that it neglects the mediating influence of project systems. He introduces 'project vulnerability' arguing that once a risk event occurs, a project system will have interactions with the event, which determine the risk consequences that are ultimately experienced. A three dimensional risk model: Significance-Probability-Impact is presented by Han et al. (2008). They define 'risk significance' as the degree to which a practical expert feels risk intuitively, this includes a general recognition of risk, the difficulty of gaining information and implementing management skills, the degree of indirect or potential loss, and the relationship between project profitability and attitude toward risk. The output of a risk assessment task is a risk rating score related to a specific risk path, source-event, or project scenario, however they fail to mention any mechanism for assessing project risk level. Recently, Cioffi and Khamooshi (2009) presented a method for combining risk impacts and estimating the overall impact, at a given confidence level, leading to an appropriate contingency budget. They utilize probability theory and risk was also modeled as P-I.

Hastak and Shaked (2000) deploy AHP within a framework for assessing international construction projects, with risk modeled as P-I. Although the model provides an assessment of project risk level, we believe that the assessment methodology is rather simplistic. Additionally, the combined assessment of risk probability and impact using a score on a predetermined scale of 0–100 is a concern. A DSS for managing risk in the early stages of a construction project is proposed by Dey (2001) based on AHP and decision trees. It seeks to identify the best strategy, project scenario, for managing construction project risk through the expected monetary value (EMV) of each risk response strategy. The approach, however, does not quantify the impact of any risk; its output is the identification of the risk response scenario with the lowest expected extra cost.

Dikmen and Birgonul (2006) use AHP within a multi-criteria decision making (MCDM) framework for risk and opportunity assessment of international construction projects. They calculate the overall risk level of each project by multiplying the relative impact with the relative probability for each risk and then adding the scores up. The simplistic way of generating the project risk level is questionable. Moreover, the model cannot be used to quantify or assess project risk; it only compares the risk of one project with other projects and provides a relative risk score. AHP and Utility Theory are used by Hsueh et al. (2007) to develop a multi-criteria risk assessment model for construction Joint-Ventures. This paper, however, does not provide a project risk assessment tool. It merely proposes that decision makers are able to make judgments: the higher the expected utility value, the

lower the overall project risk. Finally, Zayed et al. (2008) use AHP to assign weights to risks before calculating project risk level, which is defined as the sum of the weighted risk effects of risk factors. However, the method of generating the project risk level, which neglects the interdependencies between risks, and the way of eliciting risk effect as a single figure based on expert opinion, raises some concern.

Using the well established FST to assess construction risk Tah and Carr (2000) develop a qualitative risk assessment model, which incorporates linguistic variables to assess risk likelihood and impact, and the interdependencies between different risks. However, they acknowledge the limitations of FST in such an application. Subsequently, Tah and Carr (2001) try to overcome the limitation of FST in aggregating different assessments by introducing a new combination rule based on the maximum assessment of a predominant risk factor. However, they admit that this method needs more investigation. We believe that there is a concern about the proposed aggregation rule. What if there is more than one predominant risk factor for instance?

Baloi and Price (2003) compare different theories used for dealing with uncertainty within the construction industry and recommend FST as a vital solution for assessing construction uncertainty. Shang et al. (2005) develop a DSS to facilitate construction risk assessment at design and conceptual stages. The DSS allows different project members to access the support tool via the WWW and to express their assessments. These assessments are then weighted and synthesized. FST is utilized and linguistic variables used to assess risk probability and impact.

Zeng et al. (2007) attempt to combine the strength of FST and AHP to assess construction risk: FST is used to handle subjective assessments, while AHP is used to structure and prioritize diverse risk factors. Similarly, Zhang and Zou (2007) combine FST and AHP within what they call a 'Fuzzy-AHP' approach. However, the combination of the two approaches does not overcome the limitations of these separate tools.

Alternative methodologies include: the use of belief networks to derive a schedule risk model for estimating the pessimistic and optimistic values of an activity duration (Nasir et al. 2003). Also, Choi et al. (2004) design a Fuzzy-based uncertainty model which can consider uncertainty as objective probabilities and subjective judgments, probabilities or linguistic variables, according to the available amount of information. Oztas and Okmen (2004) use MCS to assess project cost and duration in risky environments. Although the tool considers the risks affecting project cost and duration, it is not a risk assessment tool; the output is an expected cost and duration but not risk size or rate. Likewise, Molenaar (2005) present a methodology based on MCS developed by the Washington State Department of Transportation (WSDOT) for estimating project cost by taking into account cost-related risk factors. Risk was modeled as P-I where the impact was the extra cost incurred.

Poh and Tah (2006) use an influence network to capture the interdependencies among factors affecting duration and cost of a construction activity. This methodology does not provide a tool for assessing cost and duration risk simultaneously; it can only be used to identify the interdependencies among parameters that determine the duration and cost of a construction activity. Thomas et al. (2006) use a Fault tree to model different risky scenarios, utilizing linguistic variables to assess risk probability and impact. They attempt to improve assessments by considering the opinions of different experts; they call this method Fuzzy-Delphi. The model does not assess project risk; instead it provides a tool for assessing the risk levels of pre-assumed and specific risk scenarios. Case-based Reasoning is used by Dikmen et al. (2007a) to estimate construction project mark-up. Project risk is represented by project contingency. Dikmen et al. (2007b) propose a fuzzy risk assessment methodology for assessing the risk of cost overrun of international construction projects. The significant contribution of this paper is the introduction of 'Controllability' or 'Manageability' concept. They argue that the ability of a company to manage risk should be considered during risk modeling. As a result, they consider the experience of the firm to be an influencing factor, which could mitigate project risk level. Dikmen et al. (2007c)

use the Analytic Network Process (ANP) for project appraisal and selection. Risk impact is assessed collectively as a score without any consideration of the different impacts of risk.

Having reviewed these different contributions, the next part of the paper will analyze and discuss them in attempt to draw informative conclusions and create an agenda for further research.

## **Analysis and discussion**

### **Risk modelling**

Despite the widespread adoption of the P-I model, many researchers have expressed concerns about its simplicity and limitations. The foregoing literature review highlights various attempts to improve construction risk modelling.

Researchers have considered this issue from different perspectives, for example: predictability: Charrete (1989) proposed adopting 'predictability' as a third dimension to be assessed for each risk; controllability: Cagno et al. (2007) considered 'risk controllability' as a ratio between the expected risk impacts before and after applying mitigation actions to justify them economically; manageability: Dikmen et al. (2007b) followed rather a different path by including 'risk manageability' as an influencing factor that could mitigate the overall project risk level; project vulnerability: Zhang (2007) advocated extending the project risk analysis process to incorporate 'vulnerability' factors; exposure to risk/risk significance: Han et al. (2008) proposed 'risk significance' and Jannadi and Almishari, (2003) the degree of exposure to risk as an integrated parameter of a risk model in addition to probability and impact.

Although each of these proposed improvements have been justified, we advocate the notion of extending the mathematical model of construction risk to incorporate additional explicit parameter(s) besides probability and impact. These parameters should reflect the practical experience and intuition of the analyst, the interdependencies between risks and the surrounding project environment, enabling the analyst to express his/her experience on each individual risks, thereby producing a more realistic risk assessment and project risk level.

### **Construction risk assessment**

When analyzing the existing construction risk assessment literature two levels of analysis are evident: risk assessment and project risk level.

#### **Risk assessment**

Different approaches have been adopted to assess the various types of risk. Researchers have used stochastic methods for dealing with duration risk or cost risk, while risk has been perceived as a synonym for variability of expected duration or estimated cost. Objective probability has been adopted as it suited such a perception. However, appropriate data for such approaches are rarely available.

Gradually, researchers have concluded that human factors, personal experience, intuition and judgment need to be considered. To reflect this, FST was introduced as a solution for handling subjective assessments. FST did not become popular as an approach for assessing construction risk until the late 1990's, however, by the beginning of the millennium it had become one of the most investigated approaches. AHP has been used for structuring potential risks in hierarchies, assessing their importance and generating scores. The adoption of this

methodology marked a change in the perception of risk from variability of an estimated value to a project attribute associated with each of its activities and phases.

Remarkably, it is striking how neglected the analysis of project performance risk is in literature; the focus being on cost risk or duration cost. Moreover, the majority of the assessments were risk rating not risk quantification.

### **Project risk level**

Similarly, a variety of approaches were utilized to handle project risk level. Some researchers followed the objective probability school to assess project cost risk and duration risk. They used MCS and PERT to combine the probability distributions, which reflected the variability of an activities' duration and cost. These tools require specific and appropriate data, which is seldom available in the construction industry. Other researchers dealt with project risk as a project attribute, requiring estimates based on the scores of individual risks assessed under a hierarchical structure. Within this school of thinking, AHP and FST were mainly adopted to assess risk weight, probability and impact. The aggregation is usually conducted by means of the fuzzy aggregation rule of FST, despite its limitation of only being able to generate an average score, which is not realistic for risk analysis (Tah and Carr 2001). While this limitation was recognized and acknowledged by researchers, it was argued that this was the only available method for aggregating subjective assessments expressed by linguistic variables. Besides its relative outcomes, AHP has three main limitations: the number of required comparisons, the consistency of these comparisons and the lack of a representation for ignorance (Beynon et al. 2000). Utility theory has also been deployed within this school. Overall project utility being used as a metaphor for the attractiveness of or the risk level of a project, derived either by a simple or by a weighted sum of individual utilities. Such an approach has the limitation of being over-simplistic due to the assumption of independency between risk factors (Dikmen et al. 2004).

### **Results, Conclusions and Suggestions**

Our review of the literature reveals the following key results:

1. Construction risk modelling is a developing and ongoing process.
2. To date no satisfactory theory or tool for assessing construction risk has been developed or proposed.
3. The majority of existing risk assessment contributions have only delivered risk ratings.
4. There is a lack of a comprehensive framework that would enable the different impacts of a risk on specific project objectives, such as, time, cost and quality to be assessed.
5. Although many authors recommend the use of 'risk cost' as an assessment scale (c.f. Chan and Au, 2008; Franke, 1987; Paek et al. 1993; Sanchez, 2005; Williams, 1993; and Williams, 1995) and estimating contingency allowances being a well-established practice in the construction industry, pricing risk has never been used systematically to assess construction project risk.
6. No suitable assessment aggregation rule has been developed or proposed.

Based on the above results, we advocate the use of 'risk cost' as an assessment scale. Utilizing 'risk cost' within an appropriate approach for structuring and enabling the experience and intuition of practitioners to be incorporated will facilitate a realistic and usable assessment method. Risk cost is a common scale and a term

widely understood by all parties, making the risk assessment process more functional and acceptable to practitioners bearing in mind the lack of an accepted method for risk assessment in the construction industry (Mulholland and Christian 1999).

We propose to assess risk impact as a percentage of project net present value (NPV). NPV has been chosen because it is the most preferable economic project appraisal criterion and is in common use by practitioners (Cooper and Chapman 1987). Although one may argue against using risk cost as a scale for assessing intangible factors like quality risk, we believe that while its adoption may be problematical it is achievable. A decision maker, who is capable of prioritizing the importance of intangible attributes within the AHP framework, should be able to produce a percentage of NPV to reflect the impact of damage on an intangible objective arising from a risk. Moreover, practitioners who are able to size and price residual risks, the unknown unknowns, and provide a contingency allowance for them should be able to size and price the known unknowns: the risks.

We consider that a 'belief-based' decision making framework can be a suitable assessment framework and propose to adopt the Dempster-Shafer Theory (DST) of evidence. The advantage of DST over probability theory and FST is its ability to represent ignorance or lack of information, which is a typical problem in risk analysis in the construction industry. Moreover, it is more appropriate for domains with a hierarchical structure (Liu et al. 2003). The revised Dempster's combination rule of evidence (Yang (2001); Yang and Xu (2002)) will be appropriate for aggregating individual risk assessments in order to get project risk level.

Notably, DST has never been used in the construction risk assessment domain. The authors argue that researching the potential applications of DST in risk analysis and decision making in construction industry may be viable and original contribution to knowledge.

To conclude, the combination of using risk cost as an assessment scale within a belief-based decision making framework and the revised Dempster's rule of evidence combination will make an original contribution to the literature, addressing perceived shortcomings in construction risk assessment. This research is a part of a wider research project aimed building a new construction risk model and risk assessment framework.

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