Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 85 (2014) 52 – 60

Procedia Engineering

www.elsevier.com/locate/procedia

Creative Construction Conference 2014, CC2014

An overview of budget contingency calculation methods in construction industry

Payam Bakhshi[a]*, Ali Touran[b]

[a]Assistant Professor, Wentworth Institute of Technology, 550 Huntington Ave., Boston, MA 02115, USA
[b]Professor, Northeastern University, 360 Huntington Ave., Boston, MA 02115, USA

Abstract

Due to risks and uncertainties associated with construction projects, owner agencies usually add a reserve amount to the estimated project cost. This reserve amount, known as contingency, is to absorb the monetary impact of the risks/uncertainties and to prevent cost overrun. Over the past two decades, many contingency calculation methods for construction projects have been introduced by practitioners and researchers. These methods can be ranged from simply considering a percentage of the project base cost to complex mathematical methods. Each of these methods suggests an approach for calculating contingency using different assumptions. The question is which one of these methods should be applied to a certain project at a specific phase. Knowing the advantages and disadvantages of each method can help practitioners in construction industry select the best method based upon their project characteristics, budget, and time. This paper compiles almost all contingency calculations methods and divides them into three main categories of: (1) deterministic methods, (2) probabilistic methods, and (3) modern mathematical methods. Each of these categories are then divided into more subcategories and discussed in detail.

Keywords: Contingency; Budget; Risk; Deterministic; Probabilistic; Monte Carlo Simulation.

1. Introduction

Owners usually need to have an accurate early cost estimate for their projects in order to provide sufficient budget for projects. Risks and uncertainties associated with a project are impediments to reach an accurate cost

* Corresponding author. Tel.: +1-617-989-4635; Fax: +1-617-989-4172.
E-mail address: bakhship@wit.edu

doi:10.1016/j.proeng.2014.10.528

estimate. For instance, nearly 50% of the large active transportation projects in the United States overran their initial budgets [30]. To overcome the cost overrun issue, identifying project risk factors and cost escalation factors have been the subject of much research [32]. To absorb the cost impact of these risk factors, a contingency budget is added to the total project budget. This means that a total cost of project is broken down to: (1) base cost, and (2) contingency cost. Base cost is the cost of project which is not including contingency [35]. These are certain cost items of a project with a given scope necessary to physically deliver the project. Contingency is defined as a reserve budget for coping with risks and uncertainties and to help keep the projects on budget. Contingency is traditionally estimated as a predetermined percentage of project base cost depending on the project phase. In recent years, some agencies have started conducting formal probabilistic risk assessment to estimate contingency budget rather than deterministic approach [34]. However, to establish the contingency budget, an agency must make all efforts to set aside a budget which is optimized. This becomes more important when an agency is dealing with a portfolio of projects. Allocation of an excess budget for a project will use up the money that can be spent on other projects. For instance the current approach used by the U.S. Federal Transit Administration (FTA) to estimate the contingency budget in transit projects called Top-down Model is based upon a probabilistic method using lognormal distributions for different cost categories in the project. However, the way that cost categories are ranged is very conservative resulting in a contingency budget far larger than what might be indeed needed [7]. In this paper, first several contingency definitions given by different agencies are presented. Then an exhaustive list of available methods for estimating contingency budget in construction industry is compiled and discussed.

2. Contingency Definitions

The Association for the Advancement of Cost Engineering [1] defines contingency as: “An amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs. Typically estimated using statistical analysis or judgment based on past asset or project experience.” Moreover, it declares that contingency does not include costs caused by: (1) Major scope changes; (2) Extraordinary events such as major strikes and catastrophes; (3) Management reserves which is an amount added to an estimate to allow for discretionary management purposes outside of the defined scope of the project; and (4) Escalation and currency effects. Construction Industry Research & Information Association [13] describes contingency as three basic types in construction projects: (1) Tolerance in the specification; (2) Float in the schedule; (3) Money in the budget. Also, Schneck et al. [31] categorizes contingency in construction projects in: (1) Schedule contingency; and (2) Cost contingency. Therefore, there is unanimity that contingency is considered in project management for managing risks and uncertainty associated with cost and schedule of a project. It should be noted that our focus in this paper is only on cost contingency. Thus, hereafter contingency refers to cost contingency unless otherwise stated. Since contingency is part of a project budget, this reveals the importance of estimating it as accurately as possible in the early stage of a project life. As the project progresses and the design details are decided, uncertainty associated with the project diminishes which means less contingency is required. Also, a close attention should be paid that project allowances are different from contingencies. Project allowances are estimates or plug numbers that estimator uses to account for project components that are hard to estimate either because the design is not complete or because based on available information an accurate estimate is not feasible [35]. These allowances are undoubtedly part of project scope and must be incorporated in the base cost.

3. Contingency Calculation Methods

The Association for the Advancement of Cost Engineering [4] categorizes the methods to estimate risk cost and establish contingency in four major groups: (1) Expert judgment; (2) Predetermined guidelines; (3) Simulation analysis including range estimating and expected value; and (4) Parametric modeling. Aforementioned methods will be explained in more detail in the following sections. Schneck et al. [31] groups the methods of contingency calculation into two main groups: (1) Deterministic methods; and (2) Probabilistic methods. Baccarini [6] describes the traditional percentage as the most commonly used method in practice. He also mentions Monte Carlo simulation, regression analysis, and artificial neural networks as the methods that have gained prominence in recent times. In this paper, as it is depicted in Fig. 1, the common methods for establishing contingency budget are divided into three main groups: (1) Deterministic methods; (2) Probabilistic methods, and (3) Modern mathematical methods. All other common methods will be explained as the subcategories of these three in the following sections.

3.1. Deterministic Methods

Deterministic methods are considered to be the simplest and most common methods used to establish contingency budget [4, 6]. These are used by owners when they do not want to apply a formal risk assessment on a project due to lack of time, size of project, or insufficient budget. The term deterministic implies that these methods offer a point estimate for contingency budget. Deterministic approaches cannot effectively address the risks specific to a project and consider the unique effects of project complexity, market condition, and location [24]. Therefore, deterministic methods can be summarized in two main categories as follows:

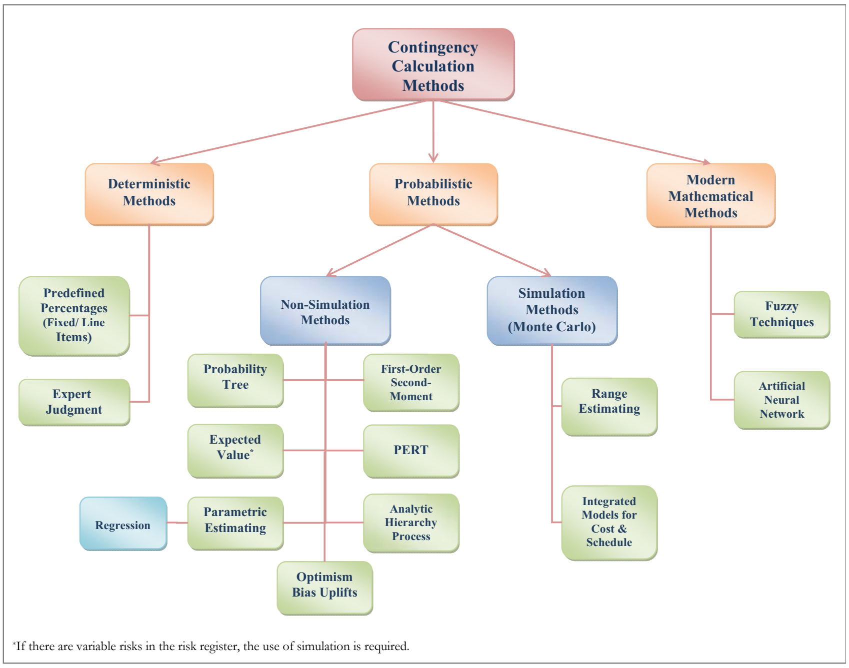

Fig. 1. Contingency Calculation Methods

<u>*Predefined Percentages (Fixed/Line Items)*</u>: This approach is the simplest method of contingency allocation. In this method, either an across-the-board predetermined (fixed) percentage of total project base cost or various percentages of line items will be added to the project budget as contingency. When contingency is added separately for each line item (allocated contingency), it can be an overall contingency as unallocated contingency added to the project budget on top of the allocated contingency. Each agency has its own set of guideline for contingency percentages. The suggested percentages are given for different key phases of a certain type of project and may be a single value or a range of values.

<u>*Expert Judgment*</u>: The only difference of this method and predetermined percentage is that in this method there is not a set of predetermined percentages, but an expert or a group of experts with strong experience in risk management and risk analysis define(s) the percentage of contingency for the project under consideration. Even though this method can relatively considers the specific situation of each project by adding unique percentage for

each project but it does not go through a formal and comprehensive risk assessment. Therefore, the contingency budget cannot be estimated adequately. Furthermore, similar to predefined percentage method, it does not provide the confidence level for the sufficiency of the estimated contingency.

3.2. Probabilistic Methods

The main difference between probabilistic methods and deterministic methods is that in probabilistic methods, uncertainties are explicitly modeled using appropriate statistical distributions [35]. A cost estimate is considered as the prediction of the expected final cost of a project with a given scope and constructed during a certain time window [16]. This definition discloses the probabilistic nature of cost estimate. Due to all uncertainties and risks associated with construction projects from errors in calculation to catastrophes affecting the project, finding the exact cost of a project is near to impossible. That is why a distribution or range can be more a realistic representation of project cost item. Using a cost distribution, one can define the level of confidence against different values of project cost. According to Moselhi [21], contingency is an inverse function of risk that management accepts at an associated probability of cost overrun occurrence. The lower the taken risk of cost overrun occurrence is, the higher contingency budget will be required. In probabilistic models the uncertainties and risks are incorporated within the cost estimate. The necessary contingency budget is estimated based on a desired confidence level determined by sponsor agency. These types of models calculate a range of estimate rather than a point estimate. All mathematical operations such as addition, subtraction, multiplication, and other have to be performed on data ranges, and require the use of probability theory. Probabilistic models output which are distributions help the client understand the possible consequences of their decision where point estimate does not have this flexibility [5]. Probabilistic risk assessment may employ a set of tools such as fault tree, probability tree, decision analysis, and Monte Carlo simulation [35]. Probabilistic methods usually need more time and budget to conduct, and some agencies and most contractors are not willing to employ it on their normal projects. According to Smith and Bohn [33] only contractors engaged in procurement of highly complex projects invest in formal risk analysis.

3.2.1. Non-simulation Methods

This category includes the analytical methods in which risk assessment and contingency calculation are conducted without the use of simulation software packages. This is an advantage when an agency is not willing to invest on such software packages. However, these approaches are not suitable for large infrastructure projects where complex models are required. These models can be effective tools for the risk assessment of early phases of project developments such as conceptual or planning when project definition is not complete. With the advent of the low-cost, personal computer-based, and powerful simulation software, the justification for the use of non-simulation approaches is reduced. However, the main weaknesses of simulation approaches, such as lack of a closed-form solution and the possibility of non-convergence of results remain. Following are some examples of non-simulation methods.

Probability Tree: Probability trees provide a systematic method to transform individual risks each with a conditional expected value impact and probability of occurrence into an overall probability and expected value. This method is a diagrammatic representation of possible outcomes of consequence events. This model is not practical when the number of risks become large as the number of outcomes increases exponentially with the number of risks [26].

First-Order Second-Moment (FOSM): FOSM methods are approximate methods to calculate the mean and standard deviation of complex functions. They usually linearize the function first using methods such as Taylor series about an appropriate point (usually mean) and then its first and second moments are obtained.

Expected Value: In this method first all significant risks in the risk register are identified. Risk register is a list of all risks/opportunities along with their impacts on cost/schedule of the project which is the important product of risk identification process [35]. Then the risks need to be quantified by estimating the probability (likelihood) of risks' occurrence and impact of risks. The expected value of each risk is calculated by multiplying the probability of occurrence and its impact. If the all impacts are deterministic, the analysis can be done without simulation. However, most of the times it is not the case and the impact is uncertain and has a distribution. AACE [2] groups the risks that have deterministic impact as fixed (or deterministic) and those with uncertain impact as variable (or continuous). When the risks are variable or at least there is one, the use of Monte Carlo is required and this method should be considered as a simulation method. The correlation among the risks can be addressed while using Monte Carlo simulation. The contingency is considered to be the sum of all expected values and has a cumulative distribution function (CDF) when the impacts are uncertain. AACE [2] recommends that those risks that are being accepted by agency should be input to expected value analysis.

Program Evaluation and Review Technique (PERT): Program Evaluation and Review Technique (PERT) is a project management method developed in 1957 which works for both schedule and cost of projects using central limit theorem (CLM). This method assumes a Beta distribution for the cost of each item which is approximated with a three point estimate: optimistic cost (lowest), most likely (target), and pessimistic (highest). These three points can be either estimated quantitatively using data from previous projects or qualitatively using expert knowledge and experience [21]. Having the three-point estimate of each cost item, mean and variance of cost item distribution can be calculated based on some assumptions in the PERT method. However, Yeo [39] modifies the original variance equation according to a 5-95th percentile. PERT assumes that the cost items are independent of each other which is a drawback of this method. Moselhi and Dimitrov [22] suggested a probabilistic method similar to PERT which can accommodate the correlation among the project cost items. Even though the modified PERT model proposed by Moselhi and Dimitrov accommodates the correlation among cost items and have preference over traditional PERT model, this is still cannot be considered theoretically accurate since it assumes that total cost has a normal distribution. This assumption is not true when cost items are not independent and correlation among them is observed.

Parametric Estimating: This method creates a relationship between an output which can be the cost overrun and inputs which can be a set of risk factors. This relationship is developed using historical data and methods such as multivariate regression analysis, artificial neural network, or even trial and error. Even though this method is simple and quick to apply, precaution is needed to select the risk factors that have predictable relationship with the outcome. First, parameters of the model which are risk factors such as scope definition, level of complexity, and size of project must be identified [3]. It is recommended by AACE [3] that outcome is set as cost growth percentage relative to the base estimate excluding contingency. Data must be controlled to be free of any obvious and significant errors. After establishing all input and output parameters and collecting the necessary data, the relationship model can be constructed using either traditional multivariate regression analysis or more recent neural network methods. The neural network methods are classified as Modern Mathematical Methods and will be explained in Section 3.3.

Regression: This type of parametric estimating has been used since 1970s. This model is more effective for the early cost estimate when there is not enough detail about the project. Using a sophisticated model at the early stages of project requires adding assumptions that add more uncertainty to the analysis and runs against the parsimony principle of regression analysis. Ideally, the regression model must be simple and without using unnecessary parameters, it should provide the best fit for the data at hand [6]. Regression method is recommended where there is a linear relationship between dependent (*e.g.* cost growth) and independent variables (risk factors). While the assumption of linearity is not necessarily true, it is commonly made. As an instance of the regression method, Kim and Ellis [20] formed a model to estimate and predict cost contingency of transportation projects based on two factors: original contract amount, and estimated contingency amounts set by maximum funding limits.

Analytical Hierarchy Process (AHP): To assess the effect of risks on the projects, different methods have been proposed that utilize probability analysis and Monte Carlo simulation. However, there is not always quantitative detailed information available to us for developing such models. Therefore, the use of a subjective approach for project risk assessment sometimes becomes indispensable. The analytical Hierarchy Process (AHP) developed by Saaty [28] presents a flexible and simple way of project risks analysis. The linguistic terms used in AHP allows risk analyst to include subjectivity, experience, and knowledge in an intuitive and natural way. This was first applied in the risk analysis by Mustafa and Al-Bahar in 1991 for the risk assessment of a construction project [15]. In a method suggested by Dey et al. [15], first the whole project is classified according to the work breakdown structure (WBS). Risk analysis is performed separately for various work packages (WP). In each WP, risk factors and subfactors are identified and the overall risk of WP is calculated using the AHP. To allocate contingency budget they use two tiers. First, they implement the PERT approach suggested by Yeo [39] for each WP to estimate the total cost distribution. Then using the overall risk of WP estimated from AHP, they find the appropriate targeted cost from the total cost distribution. The required contingency is the difference of the targeted cost and base cost.

Optimism Bias Uplifts: Optimism Bias Uplifts method (also known as Reference Class Forecasting) is a non-simulation probabilistic method developed by Flyvbjerg and COWI [18] for the British Department for Transport (DfT) in effort to deal with optimism bias in capital project cost estimates. In this method, transportation projects have been divided into a number of distinct groups. These groups include road, rail, fixed links (such as tunnel or bridge), buildings, and IT projects and have been selected in order to have statistically similar risk of cost overrun based on the study of an international database of 260 transportation projects. For each category, the probability distribution for cost overrun as the share of projects with a given maximum cost overrun was created. Having established the empirical cumulative probability distribution, uplifts are set up as a function of the level of risk that the DfT is willing to accept regarding cost overrun. "Uplift" is the term used to show the amount that the original estimate needs to be increased to arrive at the project budget for a given level of certainty with respect to cost adequacy. In this approach, it is assumed that the projects in future will behave similar to the past projects from a budgeting point of view. Also, because the uplift values are based on a relatively small number of projects (for example, the database is comprised of only 46 rail projects), serious error can potentially occur in the calculated uplifts. In Bakhshi and Touran [7], the Optimism Bias Uplifts method using by the DfT in the U.K. is compared with a method practiced by the United States FTA for transit projects in the U.S.

3.2.2. Simulation Methods (Monte Carlo)

In this method usually expert judgment and an analytical method come together to reach a probabilistic output using a simulation routine [4]. In many cases where the closed form equations are not available or due to several mathematical operations of distributions, analytical models become more complicated, simulation can help analyst find the probabilistic output. Touran [36] declares that the use of simulation in most cases is indispensable because direct analytical approaches tend to be difficult and are sometimes infeasible. Monte Carlo is one of the most common simulation methods in the construction industry which is widely applied in risk analysis and contingency calculation. This method first was introduced by Stanislaw Ulam, a Polish mathematician. The outcome of simulation should be evaluated to ensure it is reasonable [12]. One of the most common methods that employ Monte Carlo simulation is Range Estimating.

Range Estimating: This term was first coined by Curran [14] and he even obtained a patent for the use of the term. In this method, first critical cost items are identified. The deterministic estimate of each critical cost item is considered as the most likely value. Next, the minimum and maxmum values of the critical items are defined by a project group. At the end, with the help of Monte Carlo simulation the total cost cumulative distribution function (CDF) is calculated. This CDF is used to estimate the required contingency to reach the desired confidence level that budget will not fall short. To identify the critical items, the Pareto's Law, the law of the significant few and the insignificant many, or what is known as 80/20 rule is employed [21]. It means 80% of the risks costs will be associated with 20% of cost items. In other words, 20% or fewer of the cost items are critical. AACE [5] explains the critical item as an item that its deviation from target can cause ±0.5% change (called critical variance) in the bottom line cost at the conceptual estimate or ±0.2% at the detailed estimate. Just those cost items identified as critical are ranged by a project team based on their knowledge and experience. Each critical item can have different probability density function (PDF) such as triangular, normal, lognormal, or Beta. The selection of appropriate PDF for each cost item depends on how it fits the available data or meets the project group's belief. There are numerous commercial software packages such as @Risk and Cristal Ball that can help analysts apply Monte Carlo simulation. By adding all cost items (ranged and fix) and running the model for sufficient iterations (say 500 to 5000), the total project cost which is now a distribution (CDF) rather than a deterministic value, is calculated. This CDF describes the probability that total project cost as a random variable will be found at a value less than or equal to a certain number. Based upon the level of risk that agency desires to accept (80% is a common confidence level), the total project cost is selected from the estimated CDF. The required contingency is the difference between the newly estimated cost and initially estimated cost before applying range estimating. The range estimating can be applied at any key phase of the project and even during the construction phase at any certain period of time to release unnecessary contingency budget. Recently all software packages are capable to accommodate correlation among cost items by the means of Spearman Rank correlation method. An example of this method is the technique used by the Federal Transit Administration [17] published in Project Guidance (PG)# 40 called Top-down model. This method is explained in more detail and compared with the method used by British Department for Transport in Bakhshi and Touran [7].

Integrated Models for Cost and Schedule: Even though it is obvious that cost estimate and schedule of construction projects are somehow related, cost estimating and probabilistic scheduling are often separately and independently applied [19]. When there is no such a direct link between schedule and cost estimate of a project, the developed model cannot completely capture uncertainty and risk impacts associated with the project. Therefore, the calculated contingency budget may not be sufficient. A model called ABC-Sim (Activity Based Costing Simulation) was developed by Isidore and Edward Back [19] in which range estimating and probabilistic scheduling are applied simultaneously on an appropriately modelled construction project at the work breakdown structure (WBS) level. Roberds and McGrath [27] suggested an integrated cost and schedule risk assessment approach for infrastructure projects. They discussed that most commercial software packages developed for conducting risk analysis using Monte Carlo simulation are not capable of conducting true probabilistic, risk based, integrated cost and schedule modeling. They suggested the use of general-purpose Monte Carlo simulation software such as @Risk for developing tailor-made spreadsheet-based models. Touran and Bakhshi [37] introduced an integrated cost and schedule model for multi-year programs which considers uncertainties in cost, schedule, and escalation. This model uses Monte Carlo Simulation and considers Martingale series for modeling of escalation uncertainties.

3.3. Modern Mathematical Methods

Fuzzy Techniques: Fuzzy set theory is a branch of modern mathematics that was first introduced by Zadeh in 1965 for modeling vagueness intrinsic in human cognitive process [9]. This is a method for capturing vagueness, uncertainty, imprecision, embedded human knowledge, human behavior, and intuition, and fuzzy logic enables computing with words where words are used instead of numbers [29]. In the risk assessment process when there is no statistical data available, opinions of experts with years of experience become very important. Experts can provide qualitative assessment of the risks. The conversion of these qualitative statements to numbers for estimating the uncertainty is not always easy. Fuzzy set theory is a mathematical tool that can help analyst quantify these linguistic terms [11]. Due to conceptual differences between fuzzy logic and probabilistic logic, Fuzzy technique has not been categorized into probabilistic methods. Even though both have values ranging between 0 and 1, fuzzy logic corresponds to degree of truth and probabilistic logic corresponds to probability (likelihood) [8]. Sachs and Tiong [29] developed a method for quantifying qualitative information on risk called Quantitative Qualitative Information on Risks (QQIR). In this method, fuzzy sets are used for capturing expert opinions and fuzzy weighted average method is employed for aggregating that information. The outcome of their model is a probability density function. Moreover, Chan et al. [9] gives a review of fuzzy techniques in the field of construction management. It seems that the use of fuzzy sets and logics in the risk assessment and contingency calculation is becoming more widespread. As an example, Choi et al. [11] developed a risk assessment method for underground construction projects. The proposed model is comprised of four steps of identifying, analyzing, evaluating, and managing the risks inherent in construction projects and a risk analysis software is developed using uncertainty modeling based on fuzzy sets concept. Also, Paek et al. [25] presented a model for pricing construction risks using fuzzy sets as a tool for contractors to assist them in deciding the bidding price of a construction project.

Artificial Neural Network: Artificial Neural Network (ANN) is an information processing technique that simulates human brain and its biological process [10]. ANN uses a mechanism to learn from training examples and detect hidden relationships among data for generalizing solutions to future problems [6]. ANN is a better solution for modeling complex nonlinear relationships than conventional method such as nonlinear regression analysis [10]. ANN uses a set of observations (input and output) to find the pattern called training example. After training, a network has the capability to estimate outputs quickly for new cases when fed only with their associated inputs [22]. Two drawbacks of ANNs are: analyzing and explaining the relationship between inputs and outputs is hard to accomplish because ANNs are essentially black-box methods [10]; also selection of the consistence and unbiased inputs as the training data is really important because existence of bias in the training data is the major factor that limits the performance of an ANN [38]. As an example of this method, Chen and Hartman [10] used ANN on the oil and gas projects. They selected projects performed by one organization in order to have as much consistency in practices as possible. A commercial neural network development software package called NeuroShell 2 was used to implement training and develop the model.

4. Conclusion

According to the presented contingency definitions, there is consensus that cost contingency is a reserve budget for coping with monetary impacts of risks and uncertainties associated with a project. It should be noted that contingency budget is not intended to absorb the impacts of escalation, major scope changes, and extraordinary. Therefore, to keep a project within budget, calculation of adequate contingency is essential. To this end, it is imperative that an agency/owner be aware of different contingency calculation methods and select the most appropriate one based on the project characteristics. In this paper, the common cost contingency calculation methods were collected and classified into three main categories of: (1) deterministic, (2) probabilistic, and (3) modern mathematical methods. Then, probabilistic methods were further divided into two main categories: (1) non-simulation methods, and (2) simulation methods. Overall fourteen different methods were identified and discussed under these categories. This paper is a good resource for agencies/owners who are in budget development phase and want to allocate contingency budget for their projects.

References

[1] Association for the Advancement of Cost Engineering (AACE) International, "Cost Engineering Terminology," AACE Recommended Practice No. 10S-90, TCM Framework: General Reference, March 2010.
[2] Association for the Advancement of Cost Engineering (AACE) International, "Risk Analysis and Contingency Determination Using Expected Value," AACE Recommended Practice No. 44R-08, TCM Framework: 7.6- Risk Management, January 2009.
[3] Association for the Advancement of Cost Engineering (AACE) International, "Risk Analysis and Contingency Determination Using Parametric Estimating," AACE Recommended Practice No. 42R-08, TCM Framework: 7.6- Risk Management, January 2009.
[4] Association for the Advancement of Cost Engineering (AACE) International, "Contingency Estimating- General Principles," AACE Recommended Practice No. 40R-08, TCM Framework: 7.6, June 2008.
[5] Association for the Advancement of Cost Engineering (AACE) International, "Risk Analysis and Contingency Determination Using Range Estimating," AACE Recommended Practice No. 41R-08, TCM Framework: 7.6- Risk Management, October 2008.
[6] D. Baccarini, "The Maturing Concept of Estimating Project Cost Contingency- A Review," in *31st Australasian University Building Educators Association Conference (AUBEA)*, Australia, 2006.
[7] P. Bakhshi and A. Touran, "Comparison of Current Probabilistic Approaches for Budget Estimating for Transportation Projects," in *Proceedings of 7th International Probabilistic Workshop*, The Netherlands, November 2009.
[8] J. Buckley and E. Eslami, *An Introduction to Fuzzy Logic and Fuzzy Sets*, Physica-Verlag, Heidelberg, New York, 2002.
[9] A. Chan, D. Chan, and J. Yeung, "Overview of the Application of Fuzzy Techniques in Construction Management Research," *Journal of Construction Engineering and Management,* vol. 135, no. 11, pp.1241-1252, November 2009.
[10] D. Chen and F. T. Hartman, "A Neural Network Approach to Risk Assessment and Contingency Allocation," in *Association for the Advancement of Cost Engineering (AACE) International Transaction*, Risk.07, 2000.
[11] H. Choi, H. Cho, and J. Seo, "Risk Assessment Methodology for Underground Construction Projects," *Journal of Construction Engineering*

and Management, vol. 130, no. 2, pp. 258-272, April 2004.
[12] D. Clark, "Monte Carlo Analysis: Ten Years of Experience," *Cost Engineering Journal*, vol. 43, no. 6, pp. 40-45, June 2001.
[13] Construction Industry Research & Information Association (CIRIA), "Control of Risk: A Guide to the Systematic Management of Risk from Construction," Special Publication 125, U.K, 1996.
[14] M. Curran, "Range Estimating: Coping with Uncertainty," in *Association for the Advancement of Cost Engineering (AACE) International Transaction*, 1976.
[15] P. Dey, M. T. Tabucanon, and S. O. Ogunlana, "Planning for Project Control through Risk Analysis: a Petroleum Pipeline-Laying Project," *International Journal of Project Management*, vol. 12, no. 1, pp. 23-33, 1994.
[16] L. Dysert, "Is Estimate Accuracy an Oxymoron?" in *Association for the Advancement of Cost Engineering (AACE) International Transaction*, EST. 01, 2006.
[17] Federal Transit Administration (FTA), "Risk Management Products and Procedures," PG# 40, March 2007.
[18] B. Flyvbjerg and COWI, "Procedures for Dealing with Optimism Bias in Transport Planning," Guidance Document for the British Department for Transport, Report No. 58924, June 2004.
[19] L. Isidore, and W. Edward Back, "Multiple Simulation Analysis for Probabilistic Cost and Schedule Integration," *Journal of Construction Engineering and Management,* vol. 128, no. 3, pp. 211-219, June 2002.
[20] J. Kim and R. Ellis, "Accurate Cost Contingency Model for Transportation Construction Projects," in *Transportation Research Board Annual Meeting*, 2006.
[21] O. Moselhi, "Risk Assessment and Contingency Estimating," in *Association for the Advancement of Cost Engineering (AACE) International Transaction*, D&RM/A.06, 1997.
[22] O. Moselhi, and B. Dimitrov, "Discussion of Monte Carlo Technique with Correlated Random Variables by Touran and Wiser," *Journal of Construction Engineering and Management,* vol. 119, no. 3, pp. 658-660, 1993.
[23] O. Moselhi, T. Hegazy, and P. Fazio, "DBID: Analogy–Based DSS for Bidding in Construction," *Journal of Construction Engineering and Management,* vol. 119, no. 3, pp. 658-660, September 1993.
[24] A. Olumide, S. Anderson, and K. Molenaar, "Sliding Scale Contingency for the Project Development Process," *Journal of the Transportation Research Board*, no. 2151, pp. 21-27, August 2010.
[25] J. H. Paek, Y. W. Lee, and J. H. Ock, "Pricing Construction Risk: Fuzzy Set Application," *Journal of Construction Engineering and Management*, vol. 119, no. 4, pp. 743-756, December 1993.
[26] Parsons Inc., A. Touran, and Golder Association, "Risk Analysis Methodologies and Procedures," The Federal Transit Administration, Project No. DC-03-5649, 2004.
[27] W. Roberds and T. McGrath, "Quantitative Cost and Schedule Risk Assessment and Risk Management for Large Infrastructure Projects," in *PMI COS Conference Proceeding*, 2006.
[28] T. L. Saaty, *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, McGraw-Hill, 1980.
[29] T. Sachs and R. Tiong, "Quantifying Qualitative Information on Risks: Development of the QQIR Method," *Journal of Construction Engineering and Management,* vol. 135, no. 1, pp. 56-71, January 2009.
[30] J. Sinnette, "Accounting for Megaproject Dollars," *Public Roads*, vol. 68, no. 1, July/August 2004.
[31] D. Schneck, R. Laver, and M. O'Connor, "Cost Contingencies, Development Basis, and Project Application," *Journal of the Transportation Research Board*, no. 2111, pp. 109-124, December 2009.
[32] J. Shane, K. Molenaar, S. Anderson, and C. Schexnayder, "Construction Project Cost Escalation Factors," *Journal of Management in Engineering,* vol. 25, no. 4, pp. 221-229, October 2009.
[33] G. Smith and C. Bohn, "Small to Medium Contractor Contingency and Assumption of Risk," *Journal of Construction Engineering and Management,* vol. 125, no. 2, pp. 101-108, March/April 1999.
[34] A. Touran, "A Probabilistic Approach for Budgeting in a Portfolio of Projects," *Journal of Construction Engineering and Management,* vol. 136, no. 3, pp. 361-366, March 2010.
[35] A. Touran, "Owners Risk Reduction Techniques Using a CM," CMAA Research Report, Construction Management Association of America, October 2006.
[36] A. Touran, "Probabilistic Cost Estimating with Subjective Correlations," *Journal of Construction Engineering and Management,* vol. 119, no. 1, pp. 58-71, March 1993.
[37] A. Touran and P. Bakhshi, "Effect of Escalation on Large Construction Programs," in *Association for the Advancement of Cost Engineering (AACE) International Transactions*, Risk.14, 2010.
[38] A. Touran and R. Lopez, "Modeling Cost Escalation in Large Infrastructure Projects," *Journal of Construction Engineering and Management,* vol. 132, no. 8, pp. 853-860, August 2006.
[39] K. T. Yeo, "Risks, Classification of Estimates, and Contingency Management," *Journal of Management in Engineering,* vol. 6, no. 4, pp. 458-470, October 1990.