

FUZZY SET-BASED CONTINGENCY ESTIMATING AND MANAGEMENT

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A Thesis

in

The Dept. of Building, Civil and Environmental Engineering

Presented in Partial Fulfillment of the Requirements for
Master of Applied Science at Concordia University
Montreal, Quebec, Canada

April 2012

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CONCORDIA UNIVERSITY
School of Graduate Studies

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Entitled: FUZZY-SET BASED METHODOLOGY FOR CONTINGENCY
ESTIMATING AND MANAGEMENT

and submitted in partial fulfillment of the requirements for the degree of

Master of Applied Science (Building Engineering)

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ABSTRACT

FUZZY SET-BASED CONTINGENCY ESTIMATING AND MANAGEMENT

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Contingency estimating and management are critical and necessary functions for successful delivery of construction projects. Considering such importance, academics and industry professionals proposed a wide range of methods for risk quantification and accordingly for contingency estimating. Considerably less work was directed to contingency management including its depletion to mitigate risk over project durations. Generally, there are two types of risks; 1) known risks which can be identified, evaluated, planned and budgeted for and 2) unknown risks which may occurred. These two categories of risks required a cost and time contingency, even if they weren't planned for, in order to mitigate their impact in an orderly manner. In this respect, the importance of contingency management become critical in view of increasing project complexity and difficulty of estimating and/or allocating sufficient contingencies to mitigate risks encountered during project execution. This thesis focuses on the contingency management from two perspectives; estimating and depletion of contingency over project durations. A new method is developed using fuzzy sets theory, along with a set of measures, indices, and ratios to model the uncertainty inherent in this process and estimate cost contingencies. The uncertainties are expressed in the developed model

using a set of measures and indicators including possibility measure, agreement index, fuzziness measure, ambiguity measure, quality fuzzy number index, fuzziness expected value ratio, and ambiguity expected value ratio. These measures, indices, and ratios provide not only the possibility of having adequate contingency but also address issues of precision and vagueness associated with the uncertainty involved in a generic computational platform. The thesis, also, presents a comparison between fuzzy existing methods, Monte Carlo Simulation, PERT, and a proposed direct fuzzy set-based method. As to depletion, the thesis presents a management procedure focusing on depletion of the contingency. The developed procedure makes use of policies and procedures followed by leading construction organizations and owners of major constructed facilities. The developed method and its computational platform were coded using VB.net Programming. Two project examples drawn from the literature are analyzed to demonstrate the use of developed method and to illustrate its capabilities beyond those of traditional Methods.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and sincere appreciation to my supervisor Dr. Osama Moselhi for his keen support, guidance, encouragement, and valuable advices which helped me to sharpen my knowledge and personality during my research.

I would like to extend my deepest thanks to Natural Sciences and Engineering Research Council of Canada (NSERC), and Dr. Osama Moselhi for the financial support of this research.

I would like also to thank all Concordia staff, my Concordia friends, and colleagues for their support not only technically and scientifically but also, socially and psychologically.

I dedicate my thesis to my parents, sisters, and brothers for their support patience and confidence all the time, especially my youngest sister Waed.

Finally, I would like to express my deep thanks to the person who has always stood by my side day and night, and provided me continuous understanding and support, my lovely fiancée Lola Sahmarany.

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NOMENCLATURE

PERT = Program Evaluation and Review Technique

MCS = Monte Carlo Simulation

VB = Visual Basic

CFSS = Contingency Fuzzy System Software

PMI = Project Management Institute

PMBOk = Project Management Body of Knowledge

R = risk value

C = risk consequence or impact

P = probability of occurrence

RBS = Risk Breakdown Structure

RMP = Risk Management Plan

NCSX = National Compact Stellarator Experiment

FNQI = Fuzzy Number Quality Index

ANOVA = Analysis of Variance

JCL-PC = Joint Confidence Level – Probabilistic Calculator

WBS = Work Breakdown Structure

Pm = cost percentile

EV = Expected Value

CC = Cost Contingency

α = maximum risk level

Cov = Co-variance

m = deterministic duration of an activity

D = total duration of an activity

TTA = Total Time Allowance

ATA = Activity Time Allowance

D_{pi} = Duration Percentile of activity “i”

T_{di} = Target Durations of activity “i”

PDF = Probability Distribution Function

f_a, μ_a = membership function of fuzzy number “a”

COA = Center Of Area

y* = fuzzy number defuzzified value

Var = variance

A_i = fuzzy evaluation of an activity “i”

A_{ij} = jth fuzzy estimation of an activity “i”

P_k = fuzzy evaluation of package “k”

C = fuzzy evaluation of project

F (A) = Fuzziness measure of a fuzzy number “A”

AG (A) = Ambiguity measure of a fuzzy number “A”

P (A) = Possibility measure of a fuzzy number “A”

N (A) = Necessity measure of a fuzzy number “A”

μ_A (x) = value of membership of a fuzzy number “A” at a given “x”

m_λ = combined measure of possibility and necessity measures for given “ λ ”

FER (A) = Expected Value Fuzziness Ratio of a fuzzy number “A”

AER (A) = Expected Value Ambiguity Ratio of a fuzzy number “A”

AI (A, B) = Agreement Index between two fuzzy numbers “A” and “B”

DOE = Department of Energy

CE_{ij} = Estimated Contingency for activity “i” over period “ d_j ”

CD_{ij} = Depleted Contingency for activity “i” over period “ d_j ”

GUI = Graphical User Interface

DLL= Dynamic Link Library

W_F = weight of fuzziness

W_{AG} = Weight of Ambiguity

Err = Error ratio

TC = Total Contingency

NEST = North Edmonton Sanitary Trunk

UHCOC = Urban Highway Construction of California

MPLCC = Mitchell Park Library Community Administration

O.C.P.S. = Orange County Public Schools

FHWA = Federal Highway Association

IEEE = Institute of Electrical and Electronic Engineers

NASA = National Aeronautics and Space

$AC_i(T)$ = Actual Contingency for risk R_i during period T

$AC(T)$ = Actual Contingency for all risks during period T

$PC_i(T)$ = Planned Contingency for risk R_i during period T

$PC(T)$ = Planned Contingency for all risks during period T

RC = Reserve Contingency

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CHAPTER ONE

INTRODUCTION

1.1 Overview

Construction industries have been developing and growing in many ways, and the number and scale of construction projects has been increasing in tandem. A risk management plan plays an ever-increasingly important role in any project's success. An adequate risk management plan makes it possible for a project to deal with risks (threats/opportunities); to make appropriate and timely responses which minimize the losses or increase the benefits associated with those risks.

Risk management has therefore been attractive area to researchers, who focus on risk identification, evaluation, response, monitoring, and control. The risks associated with a project require contingency resources to be mitigated. Several contingency estimation and contingency allocation methods can be found in the literature, based on experience (percentage of the total project cost), PERT, Monte Carlo simulation, and other methods. Compared to the number of studies directed towards contingency estimation and allocation subjects, it was noted that considerably less work has been focused on contingency management, including its depletion over project durations.

Consequently, this research focuses on contingency, from two perspectives: 1) its estimation, using the fuzzy set theory, and 2) its management, using practitioners' methodologies.

1.2 Current Practices and their Limitations

Several methods have been developed to estimate, allocate and manage contingency. The majority of these methods are based on two classic approaches; deterministic and probabilistic. In addition, researchers have recently introduced the use of fuzzy set theory. Both the deterministic and probabilistic approaches still have several drawbacks and limiting assumptions, such as: the subjectivity of estimators, the availability of historical data, and a probability distribution's function shape (i.e. normal, beta, logarithmic or exponential).

In addition, the contingency management procedures and guidelines followed by construction industries have several differences and discrepancies. The meaning of contingency management differs from one organization to another. Each organization therefore generates its own contingency management methodology, enveloped by its own experience in similar projects and its policies. The different policies and their variances have made it impossible to document or implement a general methodology for contingency management or depletion per current practice. This situation clearly shows the need to create a unified and systematic methodology for contingency management.

Moreover, project managers use different strategies to deal with contingency depletion, strategies that are widely spread between optimistic, also called aggressive strategy, and pessimistic, or passive strategy. Contingency depletion is affected by several factors, many of which are not usually considered in a contingency management plan.

1.3 Research Scope and Objectives

This research addresses contingency management with a focus on its estimation and depletion over the project durations. This objective was set to be achieved by first studying the risk management environment and risk quantification methods. Current industries practices in contingency estimating and in contingency depletion were analyzed, and a new methodology utilizing linguistic expressions, normally used by practitioners, was developed to model the uncertainty associated with the project's contingency. The developed method for contingency depletion makes use of the current practices of leading owners and managers of constructed facilities. The sub-objectives of this research are:

1. To study and analyze the advantages and limitations of contingency estimating methods in literature.
2. To study and analyze contingency management and depletion current practice based on: literature examples, project under-construction reports, construction companies' procedures, and government policies.
3. To study and analyze the factors affecting contingency management and propose a procedure to assist companies in selecting appropriate contingency depletion curves based on these factors.
4. To develop a contingency estimating methodology based on fuzzy set theory in order to overcome the aforementioned limitations.
5. To develop a new methodology for contingency management and depletion
6. To design and code user- friendly computer software to support the application of the proposed contingency estimating methodology using VB.net.

1.4 Thesis Layout

Chapter 2 presents a literature review on risk management, contingency estimating, contingency management, fuzzy set theory, existing methods, depletion curves, current practices and policies. The proposed contingency estimation methodology based on fuzzy set theory is presented in chapter 3, including the factors that affect the different types of depletion curves,. The chapter also describes and shows the development of a new methodology for contingency management based on depletion curves, introducing a procedure for depletion curve selection based on an IF-AND-THEN approach. Chapter 4 shows the development of Contingency Fuzzy System Software (CFSS) using VB.net, including a detailed description of its capabilities, characteristics, and a detailed user-guide. The contingency estimating methodology and the CFSS results are validated by their application on two case studies extracted from the literature, as described in chapter 5 The contingency management methodology and depletion curve selection procedure is also validated in chapter 5, based on two case studies drawn from current practice. Chapter 6 presents a discussion of the proposed methodologies of contingency estimating and management based on case study results and in comparison to current methods and procedures. Chapter 7 presents the thesis conclusions, contributions and recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Several methods commonly used to estimate, allocate and manage construction project contingency are available in the literature. This chapter focuses on the most popular methods, highlighting their respective advantages, limitations, and disadvantages, as well as, their application domains.

Researchers have mainly concentrated their efforts on contingency estimating, even more so than on allocation, while considerably less work has been directed toward contingency management. Contingency management is, however very important to successfully manage contingency resources over a project's duration, made possible by implementing one of the depletion methods. The selection of a contingency depletion curve for a specific project depends on various factors; factors which are prioritized differently for each company. During project execution, the contingency manager asked two questions: 1- how to manage this contingency? , 2- how to deplete it?

The exhausting of contingency prior to project completion is considered a serious and grave condition (Diekmann et al., 1988). At the same time, excess contingency at project completion is not necessarily a sign of risk management plan success or of the effectiveness of contingency depletion as many of project managers believe (Ford, 2002).

The contingency managers (i.e. project manager) use common practice to manage contingency based on their experience and judgement (Ford, 2002). The lack of contingency management standards, documented methods and tools in the literature has thus led us to direct our research to contingency methods, tools and practice.

Contingency amounts are used to mitigate the risks associated with a project over its life cycle. The literature includes numerous definitions; the risk definition given by Project Management Institute (PMI) in the Project Management Body Of Knowledge (PMBOK) is “risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on project’s objectives” (PMI, 2003).

Raymond Madachy (2002) asserts that “The risk is the possibility of an undesirable outcome: excess budget, schedule overrun, and deliver unsuitable product” (Raymond Madachy, 2002).

The risk value depends on the probability of occurrence “P” and the corresponding consequence or impact “C” (Zhou, ASCE and Zhang, 2010).

$$R = P \times C \quad (2.1)$$

Where,

P is the probability of occurrence of a risky event during the project’s life cycle, and C is the consequence of a risky event.

The events list below should NOT be considered as risks (White, 2006):

Event 1: if the event will never occur under any circumstances (P=0 → R=0)

Event 2: if the event is certain and it will occur in any case ($P=1 \rightarrow R = C$)

Event 3: if the event does not have any impact if does or does not occur ($C=0 \rightarrow R=0$)

Any event where $0 < P < 1$ and $C \neq 0$ will be considered, evaluated, planned, mitigated and controlled for over the project duration. Risks with a positive value of C are called opportunities and those with negative impacts (negative C value) are known as threats. In the thesis we deal with risk regardless of its status as an opportunity or a threat.

There are two types of risk associated with projects:

- Known risks, also called “predictable risks”: these risks can be identified, evaluated, planned for, monitored and controlled; and
- Unknown risks also called “un-predictable risks” or “unknowable unknowns”: these risks cannot be identified, planned, monitored or controlled for since they become known when they occur.

2.2 Risk Management

Risk management is the current elaboration or new implementation of the classic project management procedure “plan -> do -> check -> act”; the current practice is to develop a plan for risk management by carrying out risk identification, risk evaluation, risk response plan, risk monitoring and risk control (KWAN and LEUNG, 2010). Stackpole (2010) summarized risk management; dividing it into three major components or outputs: a risk breakdown structure (RBS), a risk template, and a probability and impact matrix (Stackpole, 2010). The traditional project management procedure can be re-formed into a modern risk management procedure as shown in (**Error! Reference source not found.**).

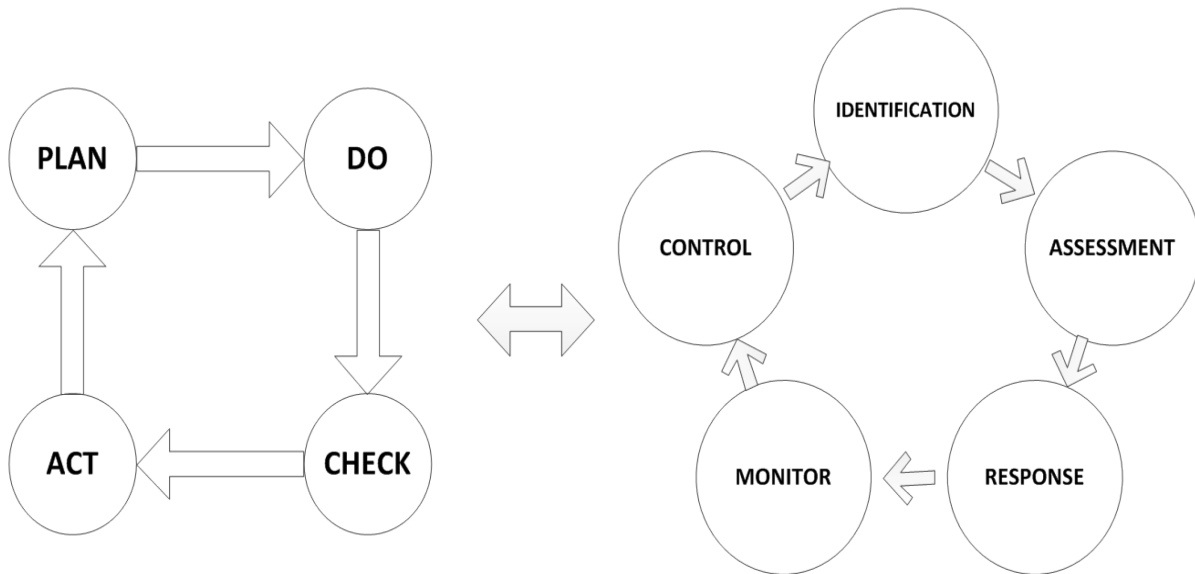


Fig. 2. 1 Risk Management Procedure: Classic (left) and Modern (right)

2.2.1 Risk Identification

The risk identification process generates a risk register or list of risks associated with a project. The stakeholders (i.e. owners, managers, end-users, neighbors etc...) are major contributors in this process. Currently, common practice for identifying the risks associated with a project is by examining the major areas of a project, collecting input from experts or from a database of lessons learned in previous experiences, and by applying analytical tools and techniques (PMI, 2008). Several tools and techniques are used in the risk identification process, such as Documentation Reviews (Witkin and Altschuld, 1995) Information Gathering (Hoffer et al., 2002), Expert Judgment (Colville, 2008), Diagramming Techniques (Tworek, 2010), Constraints and Assumption Analysis (Hillson, 2002), SWOT Analysis (Tworek, 2010), and Checklist Analysis (Khan and Abbasi, 1998).

2.2.2 Risk Evaluation

The risk evaluation process includes the analysis and evaluation of risks, both quantitatively and qualitatively. This process is considered as a screening process for the risk register since risks with low risk value (low probability and low impact) that fall below the range of risk tolerance of a project will be disregarded.

Several methods can be used in qualitative risk evaluation as well as in quantitative evaluation. The most commonly used methods or techniques are: risk matrix (Abdel GAWAD et al., 2008), Monte Carlo simulation (Seppala, 2008), decision trees (Thompson and Perry, 1992) and regression analysis. The output of a risk evaluation process will be input of its corresponding risk response plan.

2.2.3 Risk Response Plan

A risk response plan is a list of risk mitigation actions/options that can be taken to minimize the effects of a threat (negative impact) or maximize the benefits of an opportunity (positive effect). The threat responses are: avoid, transfer, mitigate and accept, while the opportunity responses are: exploit, share, enhance and accept (Stackpole, 2010).

Risk management plan (RMP) or risk response plan (RRP) incorporate responses to all risks associated with activities, packages, or projects listed in a risk register, including those with a low impact (acceptable risk based on a project's risk tolerance). The risk mitigation, by applying on of the action listed in the risk response plan, will deplete

project resources such as: time and cost. These resources are known as “project contingencies” in risk management.

There are several commonly used methods and techniques to formulate risk response plan such as: 1) a planning decision flowchart, 2) problem solving planning, 3) an action item list, and 4) risk information sheets. Since the recommended responses are not “solutions”, they should be monitored and controlled throughout the life cycle of the project.

2.2.4 Risk Monitoring and Control

Risk monitoring is an on-going process throughout the project’s life cycle (PMI, 2008). This valuable process is necessary to evaluate the performance and effectiveness of a risk response plan. The methods used to monitor risks over a project’s duration include, but not limited to: 1) bar graphs, 2) time graphs, 3) risk information sheets, 4) time correlation charts.

Any response failure that occurs during the monitoring process will trigger the control process. The risk control process will also be triggered when decision makers, based on available data from monitoring process, decide to re-assess risk or to update the risk responses in order to increase the manageability and controllability of risk occurrence and impact (Kwan and Leung, 2010). Some of the commonly used methods in risk control are: closing risk, cause and effect analysis, cost / benefits analysis, and problem solving analysis. The output of the risk control process is used to evaluate the risk management plan’s performance.

2.3 Contingency Modeling

Contingency has several definitions in the literature. The Project Management Institute defines contingency as “The amount of funds, budget or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization” (PMI, 2004). The American Association of Civil Engineers (AACE) 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” (AACE, 2007).

Contingency has an important role in risk management and project success because it increases the ability to mitigate risks associated with project cost overrun and/or project delay. Therefore, it is important to estimate project contingency properly so that it can play its designate role. In addition, contingency should be accurately estimated, reasonably allocated, and wisely managed over project durations (Barraza et al. 2007).

Without project contingency, a risk responses plan is useless, risk management has little or no function, the probability of a project suffering from cost overrun is high, and the project may reach an endpoint. For example, the National Compact Stellarator Experiment (NCSX) project had started in 2004 with a baseline contingency (cost =28%, time =10% = 5 months) to support its risk management plan. During 2004-2007, a reform risk management was implemented in order to reduce additional cost and delays. Even though, a reformed of risk management plan enhances a project’s performance, in this project, unfortunately, its effects were not sufficient to allow it to continue. As a result, NCSX’s project was cancelled in 2008 because of the estimated cost increases at

completion (>70%) and because the forecasted completion date was pushed back by 4 years (Neilson et al., 2010). This example reflects the importance of contingency estimating, allocation and management for any project.

A variety of different approaches can be found for estimating, allocating, and managing contingency, such as the deterministic, probabilistic, and fuzzy approaches. It is important to categorize the existing methods into three main functional categories: estimating, allocation, and management. Furthermore, these categories could be sub-categorized based on the contingency being studied: cost or time.

2.3.1 Contingency Estimating

Contingency estimating has been the main focus of several studies and a number of researchers, and can be performed utilizing an unlimited number of methods. These can be clustered in three main groups: deterministic methods, probabilistic methods, and fuzzy set-based methods. Contingency estimating is important for:

- Risk management plan applicability: if there are not enough contingency funds, the risk management plan in place is useless (Ruskin, 1981).
- Project success: if contingency is estimated accurately, there is a low probability of project cost overrun and delay (Baccarini, 2006).

Deterministic methods use point estimates which represent input parameters (i.e. cost, contingency percentages etc...). These estimates are usually based on average value, maximum value, expert judgement, and experience, and can result in underestimated or overestimated values (McGrew and Bilotta, 2000). Deterministic methods have a

relatively low degree of accuracy compared to probabilistic methods, but they are very useful when historical data is not available. Based on the details required for contingency estimating, two types of deterministic methods can be identified: overall estimated value and itemized evaluation method (Moselhi, 1997).

Probabilistic methods use, the contingency value and the likelihood that the contingency needs will not exceed this estimated value. If historical data is available, these methods can yield estimates that are more accurate than those of deterministic methods. The degree of a probabilistic method's accuracy is related to the available data volume. For example: when minimum data is available only low accuracy can be achieved.. This approach assumes that contingency items can be represented by a specific probability distribution function (Barraza and Bueno, 2007). Probabilistic methods may be clustered in two categories based on the estimator's assumptions: independent items, and correlated items (Sonmez et al., 2007). According to Moselhi (1997), each category can be applied with or without simulation (i.e. Monte Carlo Simulation).

Fuzzy set-based methods use experts' linguistic assessment of the risks involved. The fuzzy number may be represented by two ranges (i.e. the maximum range and the most probable range) which increase the accuracy of an expert's estimate (Paek et al., 2003). A fuzzy approach can be applied when contingency items follow any type of distribution (i.e. crisp, uniform, triangular, trapezoidal) and when there is no historical data available.

Several researchers focus on cost contingency estimating. Paek et al. (1993) proposed a method for pricing project risk and calculating contingency needed to mitigate risks associated with a project. The proposed method uses fuzzy set theory and the ranking

method proposed by Chen (1985) to calculate total project contingency (Paek et al, 1993; Chen, 1985). The advantages of this method are: 1) the use of fuzzy set theory, 2) the accommodation of expert subjectivity with a systematic estimation procedure. Its disadvantages are: 1) a dependency on project type, 2) its non-user-friendly algorithm application (there has been software developed to incorporate most of this algorithm, but validation of results is still not an easy task).

Osama Moselhi (1997) claims that the methods and techniques used for contingency estimation are primarily traditional algorithm methods and they range from crystal-ball (gut-feel method) to Monte Carlo Simulation (probabilistic method). Moselhi proposed a direct probabilistic method that considers the correlation that may exist between project cost items. The advantages of this method are: 1) simplicity, 2) it takes less time than other methods (i.e. Monte Carlo Simulation), and 3) it provides an acceptable contingency estimating range. The disadvantages are that it assumes that cost items are normally distributed, as well as the availability of historical data (Moselhi, 1997).

Touran (2003) proposes a method to estimate contingency for construction projects based on change orders which may arise throughout a project's duration. Touran's method depends on several variables, such as: 1) estimated rate of change (α), 2) project duration (T), 3) average cost per change order (μ_c), and 4) the variation's coefficient of change order's cost (f_c). The advantages of this method are: 1) simplicity, 2) less-parametric. The disadvantages or limitations are its assumption that change orders are Poisson distributed, and its application is limited to construction projects and only in the early stages (i.e. budgeting and planning) (Touran, 2003).

Cost contingency estimating attracted Barraza and Bueno's (2007) attention and led them to propose a method based on Monte Carlo simulation. They propose a total project contingency estimating method based on normal distribution with an assumed project probability of being under-run (i.e. 80%). The proposed method has a simple application and uses known parameters, but it assumes that activity costs are independent and normally distributed, which is not always the case (Barraza and Bueno , 2007).

Shaheen, Fayek and Aburizk (2007) propose a method for estimating project cost range using fuzzy set theory. The authors proposed a procedure using the Delphi method for experts' estimates, based on the deviation between the individual estimated value and the average estimated value of each cost item. The fuzziness measure, ambiguity measure and FNQI (fuzzy number quality index) can then be calculated. Their method calculates cost range, represented by a fuzzy number, and its expected value is most likely value of a project. The advantages of this approach are that it is faster and less-time consuming (only one iteration is needed). The disadvantages of this method are: 1) the proposed estimation process may take a long time to unify experts' input using Delphi method (iterate until two consecutive inputs average are quite similar); 2) formulas used to calculate the expected value are complicated and difficult to be verified, especially for trapezoidal fuzzy number (Shaheen et al., 2007) and 3) the selected measures (fuzziness, ambiguity, and FNQI) are not adequate to evaluate the quality of the results.

Given the current relative lack of research in estimating cost contingency, Thal, Cook, and White (2010) propose a model that starts with the identification of the factors impacting cost contingency based on ANalysis Of VAriance (ANOVA) procedure and a regression analysis. The model generates a contingency estimating formula using

combination of the significant factors thereby identified (which have significant impact on increasing cost contingency). The advantages of this model are that it: 1) reduces the contingency fund shortage; 2) tailors the contingency based on project-specific risks; and 3) generates reliable results in the earlier project stages (budgeting, planning, and contract award). This model has several limitations and disadvantages, such as: 1) the use of regression analysis, which depends upon a relevant data range; 2) assuming that the same factors which affected contingency in the past will do the same thing in the future; 3) it only deals with over-run; 4) it uses information that is available only up to contract awarding; and 5) it is limited to air-force projects (Thal et al., 2010)

Another method for cost contingency estimating was recently proposed by Idrus, Nuruddin and Rohman in 2010. Their proposed method uses risk analysis and a fuzzy expert system and can be described by seven stages: development of a conceptual model for cost contingency, determination of risk factors, development of a fuzzy expert system, model testing, tuning, and validation. The advantages of this proposed method are that it is flexible, rational, and it uses fuzzy expert system. This method's limitations are: 1) it is time-consuming; and 2) it relies on the availability of historical data for tuning purposes (Idrus et al., 2010).

Touran and Zhang (2011) propose a new method for contingency estimating based on the project completion percentage. Their proposed method is a modified version of the NASA JCL-PC (Joint Confidence Level – Probabilistic Calculator) method. The analysis gives results at 70%, 75% and 80% confidence levels. This method's advantages are: 1) the simplicity of its application, and 2) its ability to detect the possibility of a project's cost overrun at any milestone. The disadvantages are: 1) it assumes the availability of

historical data for similar projects; and 2) its application is limited to infrastructure projects (Touran and Zhang, 2011).

Other methods can be found in literature, such as: the crystal ball method, which considers a project cost's percentage as contingency (e.g. 10%), and which is arbitrary and difficult to defend (Baccarini, 2006), the Monte Carlo Simulation (Vose, 1996), the Artificial Neural Network method (Chen and Hartman, 2000), and the linear regression (Williams, 2003).

Most researchers in the contingency field have focused their work on cost contingency based on the assumption that “time is money”; considering that any required time contingency can be evaluated by its cost. Despite this overriding perspective, some researchers have focused on time contingency estimation as a separate subject using probabilistic methods (Barraza, 2011) and deterministic methods (Mohamed et al. 2009).

2.3.2 Contingency Allocation

The same approaches of contingency estimating, especially the deterministic and probabilistic approaches, are applicable to contingency allocation, except for the fuzzy approach, which is rarely used for contingency allocation. A project's contingency estimating cannot answer the questions usually asked by project managers: 1) Where (or when) should these contingencies be used?; and 2) How much contingency is allocated to each activity? Researchers have therefore extended contingency allocation from the project level (global contingency estimation) to the activity level (local contingency estimation) and can now provide a fair distribution between project activities based on their risk level (Barraza 2011).

Barraza (2011) proposed a heuristic approach using Monte Carlo Simulation (MCS) to assign project cost contingency to activities (depending upon the work breakdown structure details). The proposed method assumes that each activity has a probability distribution, an expected value (EV) and a cost percentile (Pm) or the budgeted cost calculated at the maximum risk level (α).

$$CC_i = Pm_i - EV_i \quad (2.2)$$

The maximum risk level is calculated where the cost of a project is equal to the budgeted cost. The main advantages of this method are that it increases the ability to control contingency, and it gives the project manager a fair allocation methodology for distributing the contingency fund among project activities based on Work Breakdown Structure (WBS). The main disadvantage of this method is that it assumes that all activities have same level of risk (needs contingency) which is not always the case (Barraza and Bueno, 2007).

Williams (1999) focused on time contingency allocation in the activity duration network by introducing a new measurement called the “Curciality”. The proposed method uses the PERT method with no uncertainty to calculate the deterministic length of each activity (m), its mean value, and covariance (Cov) calculated from simulation results. Then, by using a trial and error method, the maximum risk level (α) could be calculated in order to allocate the contingency of each activity ($\alpha \times Cov$). The total duration of the activity is represented as:

$$D = m + \alpha Cov \quad (2.3)$$

This method distinguishes between the contingency and float allowance of each activity and identifies the most crucial activity (the one actually causing the risk). The disadvantages of this method are that it: 1) eliminates the uncertainty of activities' durations, 2) time consuming (using trial and error method), and 3) is difficult to use in complex projects (Williams, 1999).

Consequently, Barraza (2011) has devoted considerable attention to the allocation of time contingency, since it is as important as cost allocation. He proposed a new method to allocate the corresponding time contingency of each activity. In other words, he distributes total time contingency of a project among its activities, represented as:

$$TTA = \sum_{i=1}^{i=n} ATA_i \quad (2.4)$$

Where, activity time allowance (ATA_i) is calculated by the difference of maximum duration percentile (Dp_i) and the target duration (Td_i). The advantage of this proposed method is the equitable distribution of time contingency among project activities. But unfortunately, as with cost contingency allocation, it assumes that all activities have the same risk level and that the probability distribution function (PDF) shape of each activity is known (Barraza, 2011).

Researchers use other methods for time contingency allocation based on conventional lump-sum multiplying the activity duration by same percentage of total project time contingency (e.g. 10%) also called crystal ball method (Moselhi, 1997; Baccarini 2006), by using probabilistic itemized allocation (called also Pareto's Law), PERT, Monte Carlo Simulation (Kwak and Ingall, 2007), Artificial Neural Network (Chen and Hartman, 2000), and by using fuzzy set theory (Jin and Doloi, 2009).

The procedures followed by practitioners for contingency allocation are slightly different. For example: the States of Jersey has a policy of contingency allocation based on three types of expenditures (Appendix A):

- Permanent and Non-Repayable: expenditures due to a change in circumstances or service requirements;
- Short Term and Repayable: Expenditures arising from departmental opportunities for “Invest-to-Save” initiatives; and
- Variation in Expenditure that have a “Net-Nil” impact: expenditures that may require variation between expenditure headings with no overall impact on the contingency balance.

Based on these three types a request for allocation of expenditures should be sent to the approval authority. The approval request includes: 1) the description, 2) the justification, 3) the recommendations, and 4) the amount. If the request is not approved, the allocation request will be returned to the originating department. Otherwise, the request is approved, distributed, and an equal amount of contingency is allocated to mitigate the risk(s) interpreted in this request (States of Jersey, 2012).

2.3.3 Contingency Management

Compared to contingency estimating and allocation, researchers have directed considerably less work towards contingency management research. Several studies began by targeting contingency management but have unfortunately being focused on either contingency estimating or allocation. For example, Yeo (1990) paid a considerable work

on contingency research and proposed a method to estimate, allocate, and monitor contingency but which unfortunately does not address how to manage it.

Ford (2002) found that contingency management practices are not as well-defined or organized as other managerial activities. He therefore made an effective effort toward contingency management by proposing a model based on project manager practices. The model represents the common practices of a contingency manager (i.e. Project Managers) from different companies and formulates the gut-feel management procedure followed by the project managers interviewed. The proposed model contains four accounts: emergency (or cost), schedule, improvement (quality), and excess. All the accounts start with 25% of the project contingency. Two types of transfer are then possible among these accounts: 1) Re-allocate to the left: transfer contingency from the current account to the account on left, and 2) Re-allocate to the right: transfer contingency from the current account to the account on right. Each account has two inputs: 1) to receive left re-allocations, and 2) to receive right re-allocations, and three outputs: 1) to mitigate risk, 2) to re-allocation “to the right”, 3) to re-allocation “to the left”. The reallocation between different accounts is well implemented by a series of 30 formulas (Ford, 2002).

Ford’s model introduces two type of management strategy: passive and aggressive (active). The passive and active strategies have five characteristics: 1) evolution of the contingency reallocation speed, 2) evolution of the schedule perception, 3) speed adjustment, 4) evolution of the willingness to use contingency to control a schedule, and 5) the escrow fraction used for improvement. The application of a strategy depends on the management skills of project manager, who is usually encouraged: 1) not to spend contingency too early in order to assure timely project completion, or 2) to spend at an

early stage when it can add value to the project (quality), or 3) to have an excess of project contingency at completion. The author found that a passive strategy performs better in emergency situations and for better schedule control, while an aggressive strategy performs better at absorbing changes in project conditions (Ford, 2002). The advantages of this model are that it: 1) gives current practice a formal procedure, 2) generalizes the decision making processes used in contingency management, and 3) establishes an interested contribution in contingency management. The disadvantages of this model include: 1) it is a subjective method because it depends on a project manager skills and his/her preferred contingency management strategy (aggressive or passive), 2) it only deals with cost contingency and omits the time contingency (i.e. time is money), and 3) it depends on a project manager having either an optimistic (aggressive strategy) or pessimistic (passive strategy) personality.

Barraza (2007) proposes a method to manage cost contingency using a simple heuristic method and Monte Carlo simulation. The proposed method controls project contingency by comparing the activities' allocated contingency versus the contingency used. The individual comparison evaluates the contingency performance (status) at a cost item level and the cumulative contingency evaluates the contingency performance (status) at the project level. Based on the required contingency the activity's (or project's) status varies between A (Positive), B (negative but less than the allocated contingency) and C (negative and greater than the allocated contingency). This method provides the ability to monitor cost contingency over the project durations, it allows more efficient management and thus can process corrective action implementation, and it allows contingency performance to be monitored at both the activity and project levels. The disadvantages of

this method are: 1) while easy to use in simple projects, it is not at all easy in complex projects, 2) it gives the ability to monitor without the capability to control or manage, and 3) it assumed that all of the activities' durations are normally distributed and that they have the same risk level (Barraza and Bueno, 2007).

Barraza (2011) proposes a new method for time contingency management using the allocation of time contingency at the activity level. In this method, the project manager is requested to control the activity's targeted contingency and to manage it so that it is equal to or less than the activity's allocated contingency. The advantages of Barraza's method are: 1) its simplicity; and 2) the easy implementation using commercial software like Excel and Crystal Ball. The disadvantages of this method are: 1) it is a subjective method, and 2) it depends on the project manager's skills and strategy. In addition, it does not take into account the unknown risks and the risks at project level (Barraza 2011).

The literature does not reflect the actual practices of contingency management. Therefore, this research focuses on the practical application of contingency management extracted from several sources in the construction industry including: 1) government projects (i.e. Department of Transportation, Energy, and Defense), 2) private companies procedures (i.e. OCPS), and 3) municipalities policies (i.e. States of Jersey and City of Palo Alto). These practices follow different methodologies which consider several assumptions, and reference important factors based on the organization's subjectivity in decision making. The contingency is managed by studying each risk separately and controlling it based on the contingency required for mitigation. If the required contingency is higher than the planned contingency, an approval of additional contingency use would need to be requested. The approval procedure depends on the

organization's policies and experience (Appendix A). Each organization follows its own practice in contingency management. Some examples of the practices considered in this research are:

- The policy of contingency management followed by Naval Special Warfare Command indicates an approval procedure for using contingency. The procedure includes an approval hierarchy based on responsibilities and delegations, ruled by the following criterion (Naval Special Warfare Command, 2008):
 - If the additional contingency fund required is less than or equal to \$25,000 it could be approved by the NSWC facility engineer. Otherwise, it should be approved by the NSWC program manager.
- A project's can be estimated based on a fixed percentage of project cost (i.e. 5%) and this percentage could be increased based on experience, project type, lessons learned and company experience in similar projects (Appendix A). A study on the Trail Projects awarded by the City of San Jose between 2002-2009 shows that 40% (6 of 15) of project with contingency less than 5% suffered from cost overrun, and same situation occurred for projects with a contingency of 5 to 10%. Only 20% of the projects with contingencies greater than 10% suffered from cost overrun. Therefore, San Jose decided to increase the planned contingency for future Trail Projects from 5% to 10% (City of San Jose, 2009).
- A procedure which includes a request to use the contingency that depends upon a project and contract types. It considers that each contract/project type could have different types of request forms (i.e. GMP). Requests should include the following information: risk description, risk total cost or amount required, justification,

responsible or risk owner, amount balance, and the reason(s) for approval or disapproval (Appendix A).

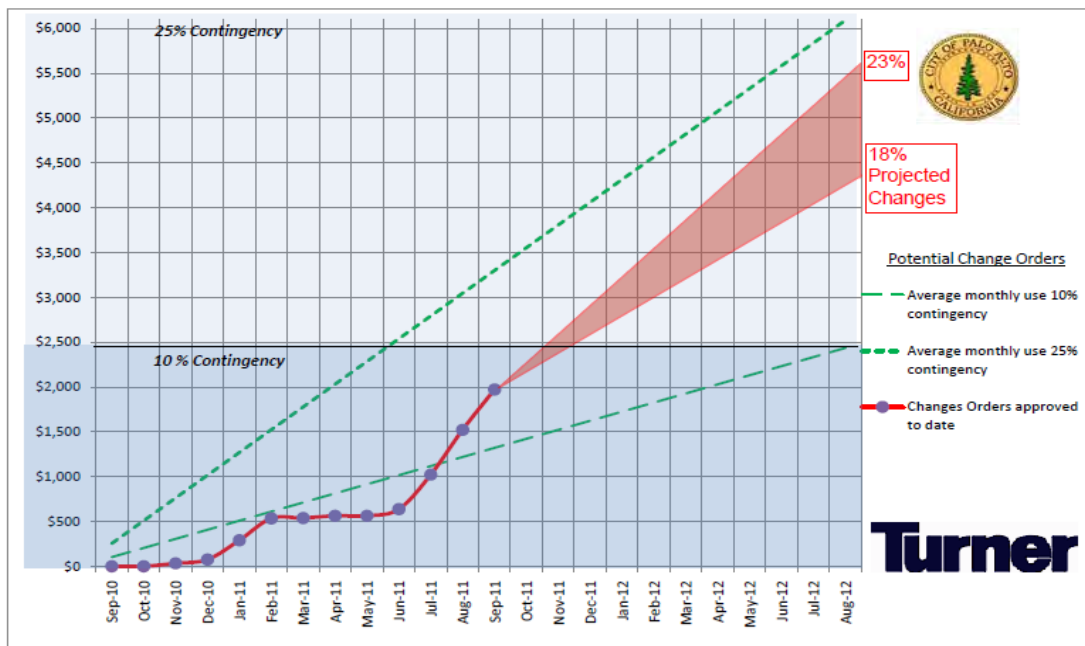
- A procedure that can be generated by mixing several procedures, including: 1) approval procedures, 2) delegations of responsibility between different management levels, and 3) contingency limitation to 5%, 10% or an amount of \$200,000 (Appendix A). The Federal Highway Association (FHWA) and the department of transportation of Canada consider that contingency depletion should be based on: 1) the amount, 2) the justification, 3) the approval authority, and 4) the funding sources.

Several rules are involved in this process, such as:

- Occurred risk has an allocated contingency or not;
 - Funding source is federal or non-federal; and
 - Contingency depletion requested is less or greater than specified amount (i.e. \$200,000).
- Some companies, based on their experience, build a typical drawdown plan for contingency management and depletion (Appendix A). According to the “Managing Major Projects” (MMP) website, the drawdown procedure should follow a specific depletion plan over project durations based on the company’s experience in similar projects. MMP considers that the contingency depletion of each activity is a weighted percentage of total contingency (Appendix A).

Further to the contingency management literature reviewed above, two case studies are examined in depth and later utilized in the developed contingency management method. Each is described below.

The first case study is “Mitchell Park Library Community Center” project for City of Palo Alto – California – USA was awarded to TURNER Construction in 2011. The projected cost is \$ 41 M and the budgeted cost is \$49 M. The project started with a contingency of 10% (\$2.44 M) of the \$ 24.4 M total construction cost. In September 2011, the project’s contingency was increased by an additional 15% (\$3.65 M). The reason of this increase is the unforeseen risks (i.e. existence of PG & E High Pressure Gas Line) and the unknown risks: 1) withdraw of steel structure sub-contractor, and 2) the exterior cladding was changed in order to meet the performance required in the project’s specification. In this project, Linear Depletion Curve was selected by Turner as the contingency depletion baseline for post and pre-extension of contingency as shown in **Error! Reference source not found..**



Mitchell Park Library Community Center
 Flintco Construction General Contract
 Contingency Analysis
 August 2011

Fig. 2.2 MPLCC Project Contingency Analysis Report Adopted with Turner(2011)

However, the actual contingency depletion curve could have a different and unpredictable shape based on the risks encountered (unknowns, unforeseen, and under-evaluated) and the approved “change orders”. The dashed line represents actual approved change orders on monthly basis while the shaded area represents the area bounded by minimum projected change orders (18%) and maximum projected change orders (23%).

The contingency depletion baseline, shown in **Error! Reference source not found.** is a linear curve starting from 0% at project start-up to 10% at project completion. But after contingency amendment, Turner assumes that the project contingency will be depleted linearly. This indicates the linear depletion curve used by Turner in the current practice. It should be noted that Turner continues to use a linear contingency depletion curve (i.e. using linear contingency depletion curve before and after the extension of the project’s contingency).

The second case involves is the installation of transmission lines, which includes several projects as described in **Error! Reference source not found.**

Table 2. 1 Projects Budgets (Adopted with City of Jonesboro Doc # 04-046-U)

Project	Baseline Estimate	Recommended Contingency	Recommended Budget
TS0994 Independence 161KV switchyard	\$395,999	\$19,063	\$415,062
TS0995 Newport 161 KV Substation	\$431,753	\$22,724	\$454,477
TL0536 Harrisburg Tap 161 KV Substation	\$22,267	\$0	\$22,267
TS0998 Marked Tree 161 KV Substation	\$185,955	\$0	\$185,955
TS0997 Paragouid 161 KV Substation	\$120,850	\$940	\$121,790
TS9077 Jonesboro: Replace Jumpers	\$51,542	\$589	\$52,131
TS9123 Searcy Price Relay Work	\$58,684	\$5,868	\$64,552

TL0536 Harrisburg – Marked Tree Tline	\$796,110	\$47,480	\$843,590
TL0537 Paragouild- AECC Paragouild S Tline	\$2,341,017	\$26,440	\$2,367,457
TL0538 Jonesboro – Jonesboro SPA Tline	\$528,827	\$29,982	\$558,809
TL9006 ISES – Newport New Tline	\$4,354,978	\$476,615	\$4,831,593
Total	\$9,287,982	\$629,701	\$9,917,683

The recommended contingency depletion curve shown in **Error! Reference source not found.** could be considered as S-curve. The drawdown curve is representative of all projects combined which could be supported by individual project contingency depletion curves to increase ability to control contingency totally and individually as stated the agreement (City Of Jonesboro, 2004).

Contingency Drawdown

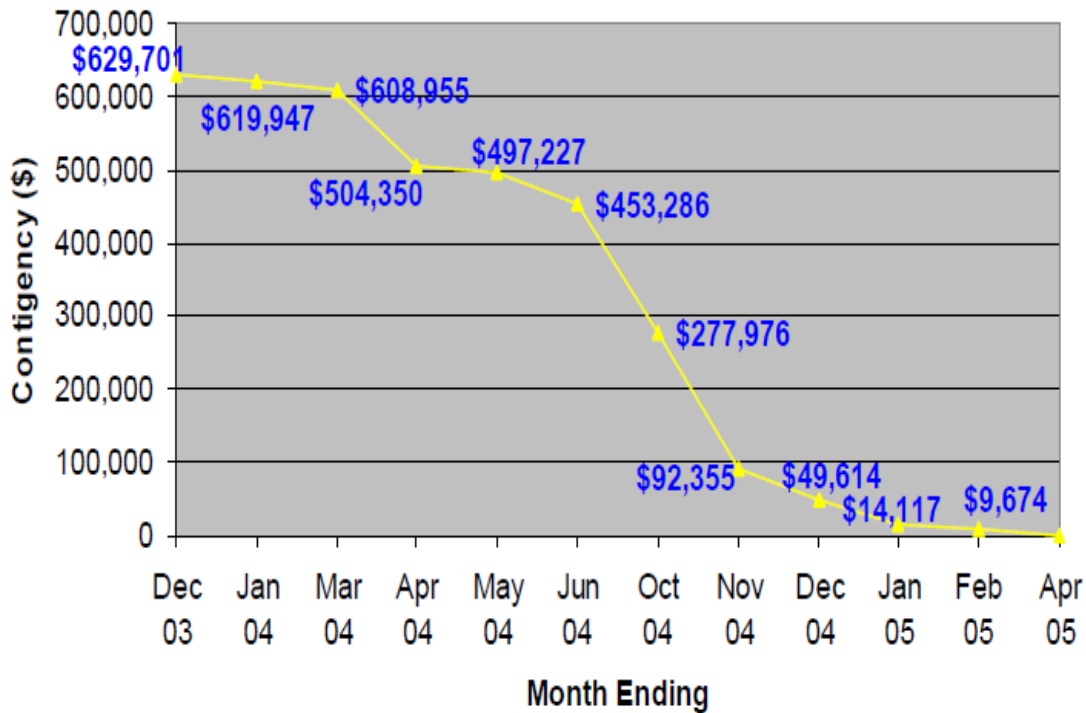


Fig. 2. 3Recommended Contingency Drawdown Curve (Noor et al., 2004; Appendix G)

The above example shows that the contingency management’s proposed method could be combined to multiple projects and individual project which expands the applicability domain of the proposed method.

Moreover, the example of managing major projects (MMP) presented in the Appendix A describes an actual drawdown contingency curve and a planned depletion curve which prove the importance of the comparison between the actual and planned drawdown contingency curves. This comparison increases the project manager’s ability to monitor and control the project contingency depletion. In addition, another perspective of

contingency depletion was introduced which uses the percentage of total contingency for each activity based on risks associated with it (MMP). Finally, a monitoring method was introduced based on depleted and balance as shown in Fig. A- 3.

2.4 Fuzzy Set Theory

Fuzzy sets were first introduced by Zadeh in 1965 to represent data and information composed of non-statistical uncertainties (i.e. linguistic representation). A fuzzy set is characterized by a membership function (Zadeh, 1965).

$$f_a: X \rightarrow \{0, 1\} \quad (2.5)$$

Fuzzy subset “a” of set X can be defined as a set of ordered pairs the first element from X and the second from the interval [0, 1], so that

$$\mu_a: X \rightarrow \{0, 1\} \quad (2.6)$$

The membership value of X is $f_a(X)$, which represents “if X belongs to fuzzy number “a” or not”: $f_a(X) = 1$ means X fully belongs to fuzzy number “a”, $f_a(X) = 0$ means X does not belong to “a”.

2.4.1 Fuzzy Numbers

Several years have passed since the introduction of fuzzy set theory, and researchers are paying considerable attention to this theory in a number of industries undergoing rapid development. The fuzzy number becomes so popular because it provides the user a linguistic representation which cannot be provided by other theories (e.g. probabilistic theory). The fuzzy number “A” can be represented by an ascending order quadruple $[a_1,$

$a_2, a_3, a_4]$. Based on the fuzzy number quadruple's values, four types of fuzzy numbers can be identified:

1. A Crisp Fuzzy Number: when all quadruple values are equal [$a_1=a_2=a_3=a_4$]. Also called a singleton.
2. A Uniform Fuzzy Number: when the first and second values are equal and third and fourth values are equal ($a_1=a_2$ and $a_3=a_4$).
3. A Triangular Fuzzy Number: when two or three consecutive values of the fuzzy number's quadruple are equal ($a_2=a_3$, $a_1=a_2=a_3$, $a_2=a_3=a_4$).
4. A Trapezoidal Fuzzy Number: the general form of a fuzzy number, when all the quadruple's values are in ascending order ($a_1 < a_2 < a_3 < a_4$).

Each fuzzy number is defined by its characteristic membership function. In general the membership function is represented by μ_A (Zadeh, 1965):

$$\mu_A(t) = \begin{cases} 1 & \text{when, } a_2 < t < a_3 \\ 0 < \text{value} < 1 & \text{when, } \begin{cases} a_1 < t < a_2 \\ \text{or} \\ a_3 < t < a_4 \end{cases} \\ 0 & \text{Otherwise} \end{cases} \quad (2.7)$$

Classical set theory can be extended to fuzzy set theory. Suppose A [a_1, a_2, a_3, a_4] and B [b_1, b_2, b_3, b_4] are two fuzzy numbers. The application of the classical set operations (Fig. 2.2) could be then expressed as:

Intersection

$$\mu_{A \cap B}(t) = \min [\mu_A(t), \mu_B(t)] \quad (2.8)$$

Union

$$\mu_{A \cup B}(t) = \min \{ \mu_A(t), \mu_B(t) \}. \quad (2.9)$$

and Inverse

$$\mu_{\neg A}(t) = 1 - \mu_A(t). \quad (2.10)$$

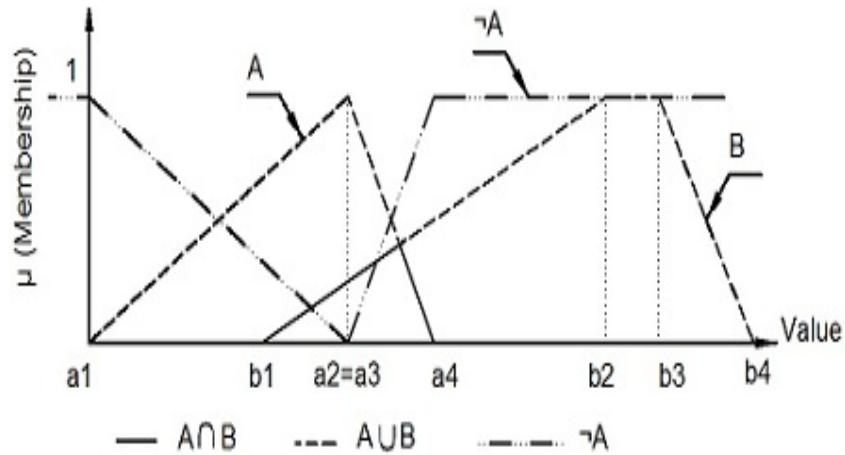


Fig. 2.2 The Fuzzy-Set operations

The relation between $A \cap B$ and $A \cup B$ should satisfy equation (2.11):

$$\mu_{A \cup B} = \mu_A + \mu_B - \mu_{A \cap B} \quad (2.11)$$

Furthermore, fuzzy arithmetic operations (i.e. addition, subtraction, multiplication, and division) may be represented as (Carlsson et al. 2004):

$$A + B = [a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4] \quad (2.12.a)$$

$$A - B = [a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1] \quad (2.12.b)$$

$$A \cdot B = [a_1 \cdot b_1, a_2 \cdot b_2, a_3 \cdot b_3, a_4 \cdot b_4] \quad (2.12.c)$$

$$A / B = [a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1] \quad (2.12.d)$$

In addition, the multiplication of a fuzzy number with a real number λ could be represented as (Carlsson et al. 2004):

$$\begin{cases} \lambda \cdot A = [\lambda \cdot a_1, \lambda \cdot a_2, \lambda \cdot a_3, \lambda \cdot a_4] & \text{if } \lambda \geq 0 \\ \text{or} \\ \lambda \cdot A = [\lambda \cdot a_4, \lambda \cdot a_3, \lambda \cdot a_2, \lambda \cdot a_1] & \text{if } \lambda < 0 \end{cases} \quad (2.13)$$

2.4.2 Defuzzification

A fuzzy number can be represented by a crisp value after defuzzification. The defuzzified value represents the expected value of a fuzzy number. There are several methods for the defuzzification of a fuzzy number:

- Center of gravity, also called the center of area (COA): the centroid distance of a fuzzy number, calculated by different methods as follows:

$$y^* = \frac{\int x\mu_i(x_i)}{\int \mu_i(x_i)} \quad (2.14.a)$$

- Center of gravity weighted by area: this method it is the same of the above method but it can be calculated to defuzzify multiple fuzzy numbers by using a modified formula (Amaya , 2009)

$$COA = \frac{\sum_{i=1}^n COA_i \times Area_i}{\sum_{i=1}^n Area_i} \quad (2.14.b)$$

- Center of gravity weighted by height or membership: this method is very similar to COA weighted by area except it use height weighting instead of area weighting:

$$COA = \frac{\sum_{i=1}^{i=n} COA_i \times \mu_i}{\sum_{i=1}^n \mu_i} \quad (2.14.c)$$

- Points of maximum criterion weighted by area: uses the point of maximum in a fuzzy set and weights it with the area of the same set as follows:

$$X = \frac{\sum_{i=1}^n x_i \times Area_i}{\sum_{i=1}^n Area_i} \quad (2.14.d)$$

Where, X is the defuzzified value and x(i) and area(i) are the value at the maximum point (or maximum membership) and the area of fuzzy number I, respectively.

- Points of maximum criterion weighted by height: same as the above methods but uses the height for weighting instead of the area:

$$X = \frac{\sum_{i=1}^n x_i \times \mu_i}{\sum_{i=1}^n \mu_i} \quad (2.14.e)$$

- Average of centers: is the average of the centers of gravity of each fuzzy number:

$$X = \frac{\sum_{i=1}^n COA_i}{n} \quad (2.14.f)$$

The most commonly used method is the center of area (COA) which calculates the fuzzy number expected value as the centroidal distance of the area. This value is also called a fuzzy number's defuzzified value.

$$y^* = \frac{\int x\mu_i(x_i)}{\int \mu_i(x_i)} \quad (2.15)$$

Where, y^* = defuzzified value; $\mu(x)$ = the aggregated membership function; and x = the output variable.

2.4.3 Expected Value and Variance Calculations

In probability theory: mean value and variance are centroid distance and centroid moment of inertia respectively. Several researchers have focused on the expected value and variance of fuzzy number calculation, such as Wang and Tian, 2010; Shaheen et al, 2007; Liu and Liu, 2002; Dorp and Kotz, 2003; Li et al., 2010; and Carlsson et al., 2004. These researchers have all calculated fuzzy number expected value as the centroid distance of a fuzzy number but not all of them came out with same formula (i.e. Shaheen et al.(2007); Wand and Tian.(2010)). In this research, the expected value will be calculated using fuzzy set theory and the basic mathematics of integration theory.

Let A [a, b, c, d] be a general fuzzy variable with membership function. Assuming this is increased on] $-\infty, x_0$] and decreased on $[x_0, +\infty$ [then, the expected value of “A” can be calculated as follows:

$$EV = x_0 - \frac{1}{2} \int_{-\infty}^{x_0} \mu(x). dx + \frac{1}{2} \int_{x_0}^{+\infty} \mu(x). dx \quad (2.16)$$

Where, x_0 represents when $\mu(x)$ changes its sign from an increasing function to a decreasing function. Based on equation (2.15) and trapezoidal fuzzy number shape, equation (2.16) could be re-written as follows:

- If we suppose that $\mu(x)$ is increased up to b and then decreased,

$$EV = c - \frac{1}{2} \int_a^b \mu(x). dx + \frac{1}{2} \int_b^c 1. dx + \frac{1}{2} \int_c^d \mu(x). dx \quad (2.16.a)$$

- If we suppose that $\mu(x)$ increased up to c and then decreased,

$$EV = c - \frac{1}{2} \int_a^b \mu(x). dx - \frac{1}{2} \int_b^c 1. dx + \frac{1}{2} \int_c^d \mu(x). dx \quad (2.16.b)$$

Accordingly, the variance of a fuzzy number could be calculated using the general formula of variance:

$$\text{Var}(X) = EV(X^2) - (EV(X))^2 \quad (2.17)$$

By considering the, trapezoidal fuzzy number as the general form of a fuzzy number while: triangular, uniform and crisp are special cases, then the expected value and variance calculations for all types of fuzzy numbers will be as follows (Wang and Tian, 2010; Shaheen et al, 2007; Liu and Liu, 2002; Dorp and Kotz, 2003; Li et al., 2010; carlsson et al., 2004):

- Trapezoidal [a, b, c, d]:

$$EV = \frac{a + b + c + d}{4} \quad (2.18.a)$$

$$\begin{aligned} \text{Var} = & \frac{(b - a)}{(d + c - b - a)} \left(\frac{1}{6} (a + b)^2 + \frac{1}{3} b^2 \right) + \frac{1}{(d + c - b - a)} \\ & \times \left(\frac{2}{3} (c^3 - b^3) \right) + \frac{1}{(d + c - b - a)} \left(\frac{2}{3} (c^3 - b^3) \right) \\ & + \frac{(d - c)}{(d + c - b - a)} \left(\frac{1}{3} c^2 + \frac{1}{6} (c + d)^2 \right) - EV^2 \end{aligned} \quad (2.18.b)$$

- Triangular [a, b, c]:

$$EV = \frac{a + b + b + c}{4} = \frac{a + 2.b + d}{4} \quad (2.19.a)$$

$$\text{Var} = \frac{a^2 + b^2 + c^2 - a.b - a.c - b.c}{18} \quad (2.19.b)$$

- Uniform [a, b]:

$$\text{EV} = \frac{a + a + b + d}{4} = \frac{a + b}{2} \quad (2.20.a)$$

$$\text{Var} = \frac{(b - a)^2}{12} \quad (2.20.b)$$

- Crisp [a]:

$$\text{EV} = \frac{a + a + a + a}{4} = a \quad (2.21.a)$$

$$\text{Var} = 0 \quad (2.21.b)$$

Based on the fuzzy theory advantages and the limitations of existing methods for contingency estimation fuzzy theory is selected for contingency estimating method development in this research. In addition, non-documented methods or procedures for contingency management represent an excellent motivation to propose a contingency management method which could overcome other methods' limitations. This research will produce 1) a new method for contingency estimation based on fuzzy system equations, 2) a new procedure for contingency management or depletion, and 3) a depletion curve selection procedure. The proposed contingency management methodology will be based on the practice procedures followed by project managers, government agencies, and private companies. The proposed methodologies for contingency estimating and management will be explicitly addressed in chapter 3.

CHAPTER THREE

DEVELOPED METHODOLOGY

3.1 Introduction

This chapter describe the developed method for contingency estimating using fuzzy set theory and the method developed for contingency management using different depletion curves applied in practice along with project managers' strategy, procedures and guidelines of government agencies and construction management companies. The research model can be represented as follows:

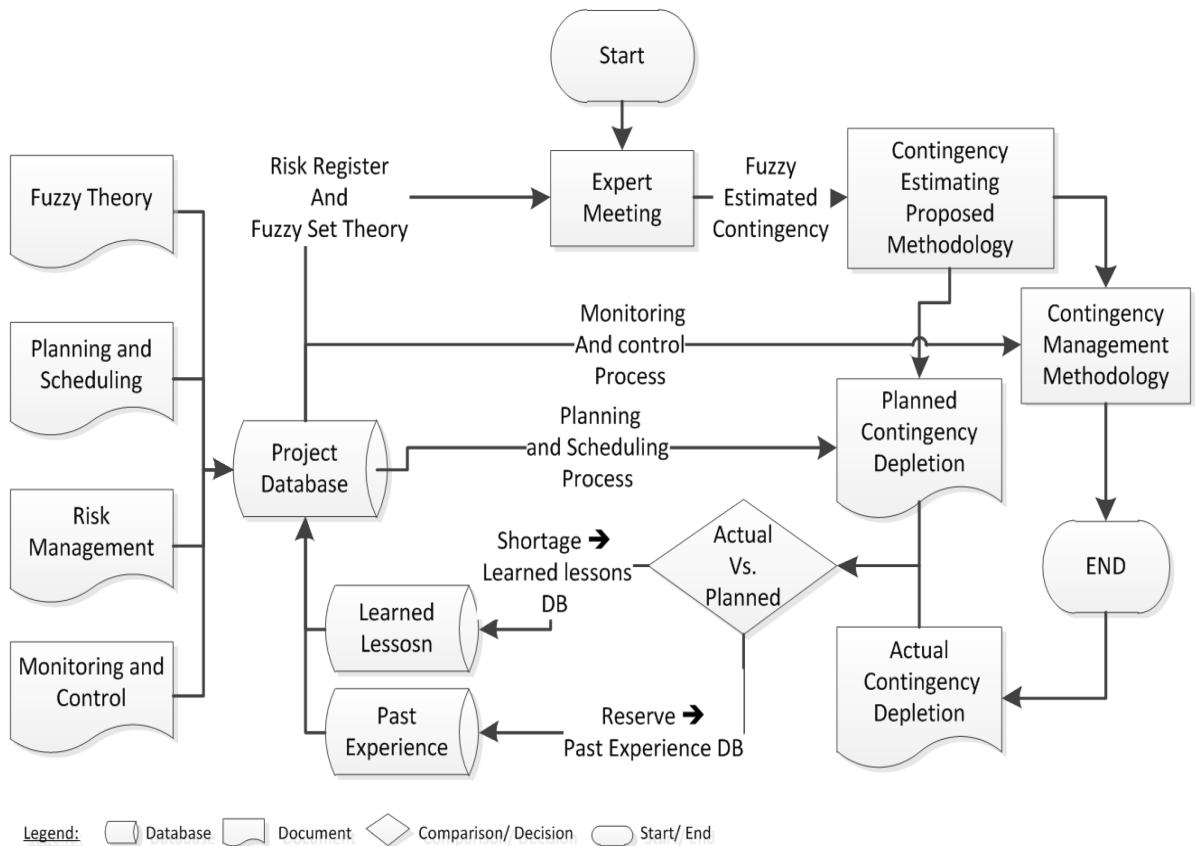


Fig. 3.1 Contingency Estimating and Management Model

The literature review justified the need for a new method for contingency estimating. To overcome the current methods' limitations this research offers a simple and direct contingency estimating method. Usually, project teams (i.e. project managers and estimators) try to avoid applying a new method for reasons such as: 1) complexity, especially if an experienced user is needed; and 2) anticipated low accuracy (not considerable) of a new method compared to the method currently used. Both these reasons have been eliminated by the proposed method, as well as others, as it is: 1) simple, 2) accurate, 3) direct, and 4) applicable without the need for historical data records.

The proposed contingency management method is needed to fill the gap between contingency estimating, allocation, and management. Since the subjectivity of decision makers in contingency management justifies the project managers' use of gut-feel decisions, these are normally based on the project managers' past experience in similar projects. In addition, the common practice considers contingency as an untapped fund and that it should be kept hidden from others (except for the person who has the authority to deplete it, i.e. the project manager) in order to avoid its misuse (Risner, 2010).

3.2 Contingency Estimating

The implementation of the proposed method for contingency estimating encompasses the execution of the following operations:

Fuzzification:

Cost items are represented by fuzzy numbers based on expert judgment. The outputs of fuzzification are the fuzzy estimates A_{ij} for each cost item A_i given by each expert E_j .

Where, $\left\{ \begin{array}{l} i = 1 \dots n, \text{ n is number of cost items} \\ j = 1 \dots m, \text{ m is number of experts participated} \\ \text{in estimating cost item } A_i \end{array} \right.$

Unifying Inputs:

The outputs of the fuzzification have been re-expressed as trapezoidal fuzzy numbers to satisfy the proposed method's input criteria. A unifying procedure generates the quadruples of the cost item's fuzzy estimates by expressing: 1) a crisp fuzzy number as $[a, a, a, a]$ instead of $[a]$, 2) a uniform fuzzy number as $[a, a, b, b]$ instead of $[a, b]$ and 3) a triangular fuzzy number as $[a, b, b, c]$ instead of $[a, b, c]$.

The fuzzy contingency estimating is carried out at the cost item, work package and project levels. At the cost item level, the fuzzy estimate is calculated as average of all the fuzzy estimates given by participating experts:

$$A_i = \sum_{j=0}^{j=m_i} A_{ij} \quad (3.1.a)$$

$$A_i = \frac{1}{m_i} \left[\sum_{j=0}^{j=m_i} a_{ij}, \sum_{j=0}^{j=m_i} b_{ij}, \sum_{j=0}^{j=m_i} c_{ij}, \sum_{j=0}^{j=m_i} d_{ij} \right] \quad (3.1.b)$$

$$A_i = \left[\frac{1}{m_i} \sum_{j=0}^{j=m_i} a_{ij}, \frac{1}{m_i} \sum_{j=0}^{j=m_i} b_{ij}, \frac{1}{m_i} \sum_{j=0}^{j=m_i} c_{ij}, \frac{1}{m_i} \sum_{j=0}^{j=m_i} d_{ij} \right] \quad (3.1.c)$$

At the package level, the fuzzy estimate of a package that contains n_i cost items A_i ($i= 1 \dots n_i$), may be calculated as the sum of all its cost items' fuzzy estimates:

$$P_k = \sum_{i=1}^{i=n_i} A_i^k \quad (3.2)$$

At the project level, the fuzzy estimate of a project that contains n_p packages P_k ($k= 1 \dots n$) in the project range cost estimate can be calculated as the sum of all its packages' fuzzy estimates:

$$C = \sum_{k=0}^{k=n_p} P_k \quad (3.3)$$

Where, A_i , P_k , and C are the fuzzy estimates of the activity, the package, and the project respectively.

Defuzzification

The fuzzy number's expected value and variance values are considered as the defuzzified values of the fuzzy number, similar to the probability theory. The expected value and variance formulas described in section 2.4.3 could be used to defuzzify the fuzzy estimates calculated in the previous step. The expected value can be calculated based on the estimating level (i.e. cost item, package, or project level) as follows:

- Cost Item Expected Value: two methods can be used to calculate the expected value of the cost item, either by: 1) using the expected value of the fuzzy cost item's estimate $[EV(A_i)]$, or 2) using the average of the expected values of the cost item's fuzzy estimates given by experts $[\frac{1}{n}EV(A_{ij})]$, where n is the number of experts participating in the cost item A_i estimation process.
- Package Expected Value: can be calculated as either: 1) the expected value of the package fuzzy estimates $[EV(P_k)]$, or 2) the sum of all the expected values of the cost items associated with this package $[\sum_{i=1}^{n_i} EV(A_i^k)]$, where n_i is the number of cost items included in the package.

- Project Expected Value: can be calculated: 1) as the expected value of the project's fuzzy estimate $[EV(C)]$, or 2) as the sum of the packages' expected value $[\sum_{k=1}^{n_p} EV(P_k)]$, where n_p is the number of packages included in the project.

The variance of a fuzzy number may be calculated based on the estimating level (i.e. cost item, package, or project level) and on the fuzzy number's type. The fuzzy number's variance can be calculated using the variances' formulas expressed in section 2.4.3.

Uncertainty Modeling

Uncertainty may be represented by introducing a number of measures, indices and ratios. In this thesis several measures extracted from the literature will be incorporated, such as: fuzziness (Klir and Fogler, 1988), ambiguity (Delgado et al., 1998), possibility (Dubois et al., 2004), necessity (Dubois et al., 2004), m_λ (Dubois et al., 2004), a fuzzy number quality index (FNQI) (Shaheen et al., 2007), and an agreement index (Sakawa and Mori, 1999). In addition, this research introduces two ratios: the fuzziness expected value ratio, and the ambiguity expected value ratio. These two units-less ratios improve the ability of the contingency estimator to check the results' quality (i.e. to what extent the results are fuzzy and ambiguous).

The extracted and proposed uncertainty measures will support decision making by providing reliable information about several expected scenarios. It also indicates the quality and reliability of such information. The contingency estimation model introduced in this thesis can be represented by three sub-models: 1) data gathering, 2) fuzzy estimating, and 3) defuzzification, which also includes the calculation of all the aforementioned uncertainty modeling (i.e. measures, indices and ratios) as shown Fig. 3.2.

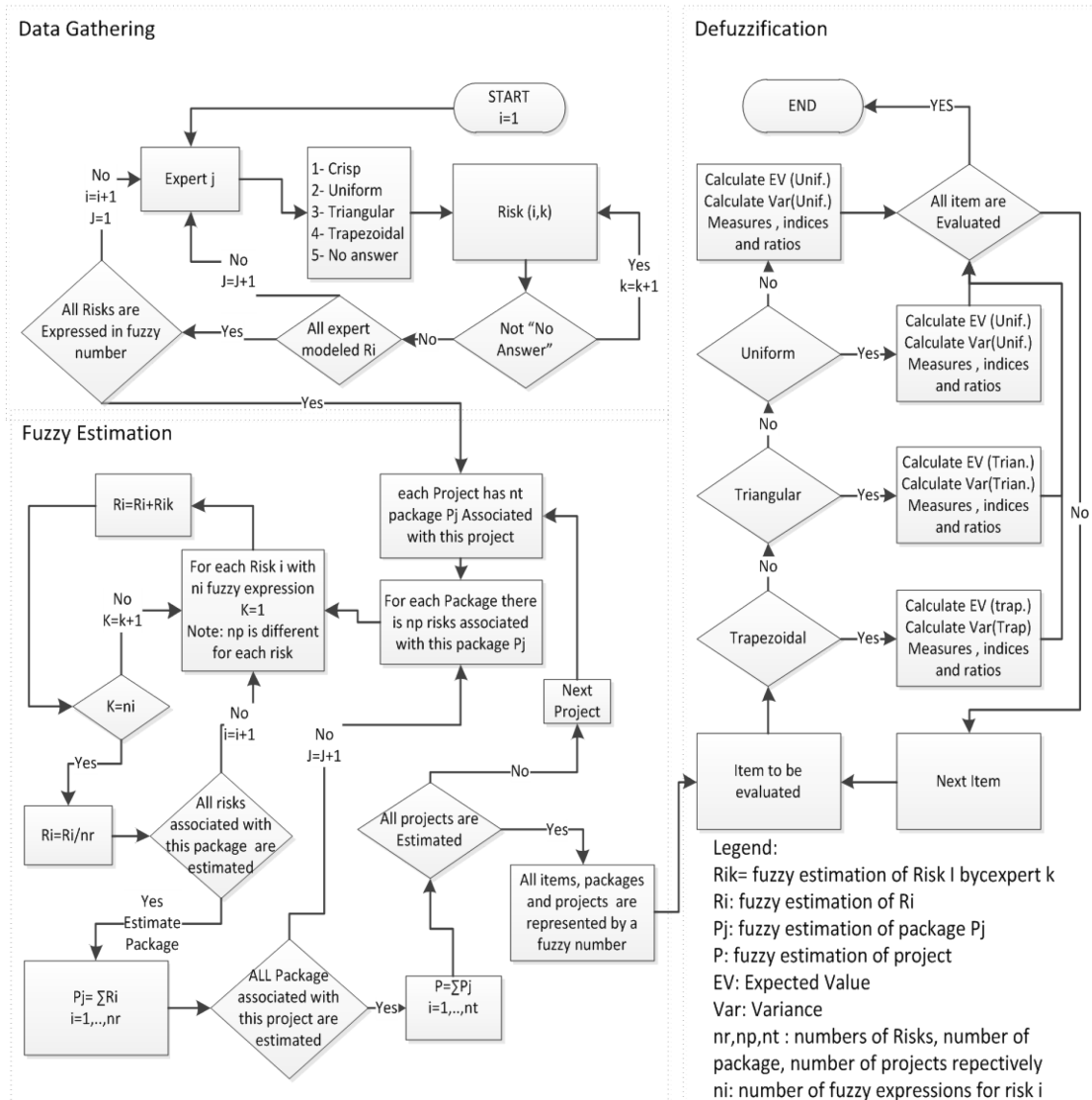


Fig. 3.2 Contingency Estimation Model

3.3 Uncertainty Quantification

3.3.1 Uncertainty Measures

The fuzziness measure was introduced by Klir and Fogler (1988); it can be considered as the degree of lack of distinction between the presentation of a fuzzy number and its complement. If it is difficult to distinguish between a fuzzy number and its complement then the maximum fuzziness is associated with that fuzzy number, otherwise, less

fuzziness is associated with it. This measure may reach “0” if the fuzzy number is crisp or uniform. The fuzziness measure can be calculated using the formula (Shaheen et al. 2007)

$$F(A) = \int_{-\infty}^{+\infty} (1 - |2\mu_A(x) - 1|) dx \quad (3.4)$$

The above integral can also be solved using integration by parts to simplify the calculation formula of the fuzzy number’s fuzziness measure as follows so that:

$$F(A) = \int_{-\infty}^{+\infty} dx - \int_{-\infty}^{+\infty} |2\mu_A(x) - 1| dx$$

$$F(A) = \int_{-\infty}^{+\infty} dx - \int_{-\infty}^a |2\mu_A(x) - 1| dx - \int_a^b |2\mu_A(x) - 1| dx - \int_b^c |2\mu_A(x) - 1| dx$$

$$+ \int_c^d |2\mu_A(x) - 1| dx + \int_d^{+\infty} |2\mu_A(x) - 1| dx$$

$$\text{Since, } \begin{cases} \mu_A(x) = 0 & \text{when } x < a \\ \mu_A(x) = \frac{x-a}{b-a} & \text{when } a < x < b \\ \mu_A(x) = 1 & \text{when } b < x < c \\ \mu_A(x) = \frac{x-d}{c-d} & \text{when } c < x < d \\ \mu_A(x) = 0 & \text{when } x > d \end{cases} \rightarrow \begin{cases} \int_{-\infty}^a (1 - |2\mu_A(x) - 1|) dx = 0 \\ \text{and} \\ \int_d^{+\infty} (1 - |2\mu_A(x) - 1|) dx = 0 \\ \text{and} \\ \int_{-\infty}^{+\infty} dx = \int_a^b dx + \int_b^c dx + \int_c^d dx \end{cases}$$

While,

$$\int_{-\infty}^{+\infty} dx = \int_a^b dx + \int_b^c dx + \int_c^d dx = b - a + c - b + d - c = d - a$$

Then F (A) can be re-written as follows:

$$F(A) = d - a - \int_a^b |2\mu_A(x) - 1| dx - \int_b^c |2\mu_A(x) - 1| dx - \int_c^d |2\mu_A(x) - 1| dx$$

Solving each integral separately:

$$\int_a^b |2\mu_A(x) - 1| dx = \int_a^{\frac{a+b}{2}} (2\mu_A(x) - 1) dx + \int_{\frac{a+b}{2}}^b (1 - 2\mu_A(x)) dx$$

$$\int_a^b |2\mu_A(x) - 1| dx = \int_a^{\frac{a+b}{2}} \left(2 \times \frac{x-a}{b-a} - 1\right) dx + \int_{\frac{a+b}{2}}^b \left(1 - 2 \times \frac{x-a}{b-a}\right) dx$$

$$\int_a^b |2\mu_A(x) - 1| dx = \int_a^{\frac{a+b}{2}} \left(\frac{2x}{b-a} - \frac{b+a}{b-a}\right) dx + \int_{\frac{a+b}{2}}^b \left(\frac{b+a}{b-a} - \frac{2x}{b-a}\right) dx$$

$$\int_a^b |2\mu_A(x) - 1| dx = \left[\frac{x^2}{b-a} - \frac{b+a}{b-a}x\right]_a^{\frac{a+b}{2}} + \left[\frac{b+a}{b-a}x - \frac{x^2}{b-a}\right]_{\frac{a+b}{2}}^b$$

$$\int_a^b |2\mu_A(x) - 1| dx = \frac{b-a}{4} + \frac{b-a}{4} = \frac{b-a}{2}$$

Similarly, for the interval [c, d]

$$\int_c^d |2\mu_A(x) - 1| dx = \frac{d-c}{2}$$

Moreover, the membership $\mu_A(x) = 1$ when $x \in [b, c] \rightarrow 2\mu_A(x) - 1 = 1$

$$\int_b^c |2\mu_A(x) - 1| dx = \int_b^c 1 dx = x \Big|_b^c = c - b$$

Equation (3.4) can therefore be updated as follows:

$$F(A) = d - a + \frac{a-b}{2} + b - c + \frac{c-d}{2}$$

By simplifying, the general formula of the fuzziness measure can be expressed as:

$$F(A) = \frac{(b-a) + (d-c)}{2} \tag{3.4.a}$$

The ambiguity measure was introduced by Delgado et al. (1998 a), and can be calculated using the following formula (Delgado et al. 1998a):

$$AG(A) = \int_0^1 r[R(r) - L(r)] dr \tag{3.5}$$

However, the general formula for the fuzzy number's ambiguity measure can also be generated using the integration theory. By definition, $R(r)$ and $L(r)$ are the left and right

functions of a fuzzy number with LR-type representation (another fuzzy number representation) which can be described as follows (Carlsson et al., 2004):

$$A(t) = \begin{cases} L\left(\frac{b-t}{b-a}\right), & t \in [a, b] \\ 1, & t \in [b, c] \\ R\left(\frac{t-c}{d-c}\right), & t \in [c, d] \\ 0, & \text{otherwise} \end{cases} \quad (3.6)$$

Where, $L(r)$ and $R(r)$ represent the r -cut representation of μ_A . Let us assume A is a trapezoidal fuzzy number which means $L(r)$ and $R(r)$ could be represented as follows:

$$L(r) = [b - r(b - a)] \quad (3.7)$$

$$R(r) = [r(d - c) + c] \quad (3.8)$$

Equation (3.5) could thus be re-written as follows:

$$\begin{aligned} AG(A) &= \int_0^1 r[(r(d - c) + c) - (b - r(b - a))] dr \\ AG(A) &= \int_0^1 (r^2(d - c) + cr) dr - \int_0^1 (br - r^2(b - a)) dr \\ AG(A) &= \left[\frac{r^3}{3}(d - c) + \frac{cr^2}{2} \right]_0^1 - \left[\frac{r^3}{3}(b - a) + \frac{br^2}{2} \right]_0^1 \\ AG(A) &= \left[\frac{(d - c)}{3} + \frac{c}{2} \right] - \left[\frac{(b - a)}{3} + \frac{b}{2} \right] \end{aligned}$$

By simplifying, a general formula for the trapezoidal fuzzy number's ambiguity measure could be generated as shown below:

$$AG(A) = \frac{d + 2c - 2b - a}{6} \quad (3.9)$$

Based on equations “3.4.a” and “3.9”, the fuzziness and ambiguity measures for most common fuzzy numbers can be calculated using the formulas presented in Table 3.1:

Table 3.1 Fuzziness and Ambiguity Measures Calculations

Fuzzy Number Type	Fuzziness Measure	Ambiguity Measure
Crisp [a]	0	0
Uniform [a, b]	0	$\frac{b - a}{2}$
Triangular [a, b, c]	$\frac{c - a}{2}$	$\frac{c - a}{6}$
Trapezoidal [a, b, c, d]	$\frac{(b - a) + (d - c)}{2}$	$\frac{d + 2c - 2b - a}{6}$

The possibility measure was introduced by Zadeh (1965). It has since been used by many other researchers. By definition, it measures how likely a fuzzy number A will belong to a specific interval [m, n]. Let A be a fuzzy variable with membership function $\mu_A(x)$, and [m,n] an arbitrary interval in \mathbb{R} (real set). Then, the possibility measure of a fuzzy event $\{A \in [m, n]\}$ could be expressed as follows (Dubois et al., 2004; Yang and Iwamura, 2008):

$$Pos\{A \in [m, n]\} = \sup_{x \in [m, n]} (\mu_A(x)) \quad (3.10)$$

The necessity measure satisfies properties that are similar to the possibility measure with respect to set-intersection, and it can be calculated as the impossibility of opposite event. For example, let A be a fuzzy variable with membership function $\mu_A(x)$, and [m, n] an

arbitrary interval in \mathbb{R} (real set). The necessity measure will be expressed as follows (Dubois et al., 2004):

$$\text{Nec}\{A \in [m, n]\} = 1 - \sup_{x \notin [m, n]} (\mu_A(x)) \quad (3.11)$$

The possibility and necessity measures represent the optimistic and the pessimistic decision maker, respectively. Therefore, it is important to combine the both measures with a new measure (m_λ) which represents a normal decision maker. The combined measure m_λ could be represented as follows:

$$m_\lambda = \lambda \times \text{Pos}\{A\} + (1 - \lambda)\text{Nec}\{A\} \quad (3.12)$$

where λ is a number $\in [0, 1]$ that represents the optimism characteristic of the decision maker:

$$\text{if } \begin{cases} \lambda = 0, \rightarrow \text{pessimistic decision maker} \rightarrow m_\lambda = \text{Nec}(A) \\ \lambda = 1, \rightarrow \text{optimistic decision maker} \rightarrow m_\lambda = \text{Pos}(A) \\ 0 < \lambda < 1, \rightarrow \text{Otherwise} \rightarrow \text{Nec}(A) < m_\lambda < \text{Pos}(A) \end{cases} \quad (3.12.a)$$

For a neutral decision maker with $\lambda=0.5$ (neither optimistic nor pessimistic) the m_λ measure may be expressed as:

$$m_\lambda = \frac{\text{Nec}(A) + \text{Pos}(A)}{2} \quad (3.12.b)$$

3.3.2 Uncertainty Ratios

The fuzziness expected value ratio (FER) can be represented by the ratio of the fuzziness measure to the expected value of a fuzzy number “A”. This ratio could be expressed as:

$$\text{FER}(A) = \frac{F(A)}{EV(A)} \quad (3.13)$$

Similarly, the ambiguity expected value ratio (AER) is a ratio of the ambiguity measure of a fuzzy number “A” over its expected value. This ratio could be expressed as:

$$\text{AER}(A) = \frac{\text{AG}(A)}{\text{EV}(A)} \quad (3.14)$$

These ratios are unit-less and they represent the fuzziness and the ambiguity percentage of the fuzzy number’s expected value. These two ratios indicate the quality of the fuzzy number’s estimate more accurately than do the fuzziness and the ambiguity measures on their own.

3.3.3 Uncertainty Indices

This methodology includes two types of indices: (1) the fuzzy number quality index (FNQI), and (2) the agreement index (AI). Shaheen et al. (2007) introduced the FNQI to combine the effects of the fuzziness measure and the ambiguity measure. This index may be calculated as the weighted average of both measures (fuzziness and ambiguity) as follows (Shaheen et al. 2007):

$$\text{FNQI} = \frac{W_F \times F(A) + W_{AG} \times \text{AG}(A)}{W_F + W_{AG}} \quad (3.15)$$

Where, W_F and W_{AG} represent the weights of the fuzziness measure and the ambiguity measure respectively. This index helps to eliminate the non-reliable inputs, as they will have higher FNQI values than other inputs (Shaheen et al., 2007).

The agreement index (AI) represents the agreement percentage between two fuzzy numbers. It was calculated by Sakawa and Mori (1999) as the ratio of the intersection area of two fuzzy numbers’ memberships over the area of the first fuzzy number membership. This index can be expressed as follows (Sakawa and Mori, 1999):

$$AI(A, B) = \frac{\text{Area}(A \cap B)}{\text{Area} A} \quad (3.16)$$

The agreement index has a maximum value equal to 1 when $A \cap B = A$.

These measures, indices, and ratios were selected and incorporated in the proposed methodology. In general, uncertainty modeling (including all of these measures) maximizes the user's ability to control the inputs by providing useful information about the quality of the inputs (i.e. FNQI) and outputs (i.e. FER).

3.4 Contingency Management

The effort required to manage a project's contingency is related to the project's allocated contingency fund volume (Ruskin 1981). For example, if the allocated contingency fund volume is relatively high (i.e. 50% of a project's cost), the management effort required to manage the contingency varies from limited to negligible. In contrast, if the allocated contingency fund is relatively low (i.e. <5% of a project's cost) then, the management effort required would have to be considerably aggressive (Ruskin, 1981).

The proposed method for contingency management is based on a contingency depletion curve. It was noted that the selection of a contingency's depletion curve depends on several factors. Therefore, this research extracts all the factors that affect contingency depletion utilizing a range of sources including the literature, associations' policies, companies' practices, and project managers' applications.

3.4.1. Factors Affecting Contingency Depletion

Both the literature and practices show that there are several factors affecting contingency depletion. These factors are: 1) project type (U.S. DOE, 2006), 2) complexity (U.S. DOE,

2006), 3) risk impact and severity (Washington TRU Solutions LLC, 2008), 4) type of occurred risk (U.S. DOE, 2009), and 5) management strategy or approach (Ruskin, 1981).

Project Type

The project type is a very important factor since the contingency management of an infrastructure project could be very different from that of a tunneling or a building project. Project type is closely connected to contract type, since lump sum contracts are more risky than unit price contracts, cost plus contracts, and cost plus-plus contracts, especially for contractor. The availability of reliable information about a project and its associated difficulties increases the contingency manager's ability to deplete contingency as planned. Otherwise, the contingency manager is obliged to avoid the early depletion of contingency and especially be aware of the unforeseen risks which may occur over a project's duration. In addition, a contractor's experience in similar projects decreases the amount of unforeseen or unplanned risks and it can eliminate contingency depletion fuzziness. Therefore, the project's type is considered an important factor that affects the contingency depletion.

Complexity

The complexity factor seems to be related to a project's type, but complexity can be addressed from different perspectives such as: 1) a fast-track delivery system, 2) technical difficulties, and 3) the requirements of new technology. The project complexity should be considered by the contingency manager up to the point where the fuzziness associated with the project's complexity is eliminated.

Risk Impact (Severity)

The risk impact, called also cost-benefit tradeoff, is considered an important factor that affects contingency depletion. For example if the impact of an occurred risk has a very low effect, then, the use of contingency to mitigate this risk would be meaningless and actually have no value for the project. Likewise, if the allocated contingency for the mitigation of occurred risk not enough to compensate (project risk tolerance) and the mitigation's cost-benefit tradeoff (in monetary value) is less than the additional contingency that would be required, then, the use of contingency for this situation would not make economic sense and is not recommended.

Type of Risk Occurred

Different types of risk can be found in the literature including technical, scheduling, resources (labor, material, machinery, support services etc...), financial (rate change, interest, inflation etc...), technological, political, and country-based. Each type can be managed using different approaches especially when a risk would have a considerable impact and uncertain consequences (i.e. politics, technical difficulty, technology availability).

Management Skills and Strategy

The management skills of a project's manager and his/her depletion strategy (passive or aggressive) affect contingency depletion. According to Ford (2002), each strategy has its advantages and disadvantages. The project manager (contingency manager) usually makes a subjective decision about the selected strategy's advantages over other strategies (Ford 2002). The project manager's selection is difficult to defend since it does not

follow any systematic procedure. The selection of a project manager's strategy thus affects the contingency's depletion.

3.4.2 Proposed Depletion Curves

In the literature there are strategies, subjective procedures, and contingency depletion applications based on experience. The use of the depletion curve methodology is limited to the basic depletion curve (Noor and Tichacek, 2004) and the linear curve (Turner, 2011). The typical spending curve considers that contingency depletion should follow the shape of the project cost baseline (S-curve). The linear contingency depletion curve assumed that the contingency should be uniformly distributed over a project's duration (or contingency's milestones). This research identifies four types of contingency depletion curves (Fig. 3.3) from the literature and proposes a new depletion curve. *Linear Depletion Curve*

Basically, this is the ideal depletion curve. It distributes the contingency fund between project periods or milestones uniformly. Several companies prefer to establish a project with a linear depletion curve as its planned depletion curve. For example Turner (2011) used a linear depletion curve in Mitchell Park Library Community Center project for the City of Palo-Alto in the United States (Turner, 2011).

Basic Depletion Curve (S-curve)

This curve is also called the typical spending curve (Noor and Tichacek, 2004). It considers that the depletion of contingency should follow the project cost baseline since all the project's resources (i.e. man power, money, and material) are depleted accordingly.

Front-end Depletion Curve

This depletion curve is considered to be a complicated depletion curve. Its application requires more effort than the application of linear or basic depletion curves. It represents the project manager's aggressive strategy (Ford, 2002; Ruskin, 1981). The aggressive strategy considers that the project's start-up is fuzzier and risky, which rationalizes the earlier depletion of the project contingency (Nalewalk, 2009).

Back-end Depletion Curve

The back-end loading depletion curve is the opposite of the front-end loading depletion curve and it represents the project manager's passive strategy. This strategy encourages the project managers to avoid early depletion in order to mitigate unforeseen risks, and to assure project completion on time (Ford, 2002). This policy in turn justifies the late depletion of project contingency.

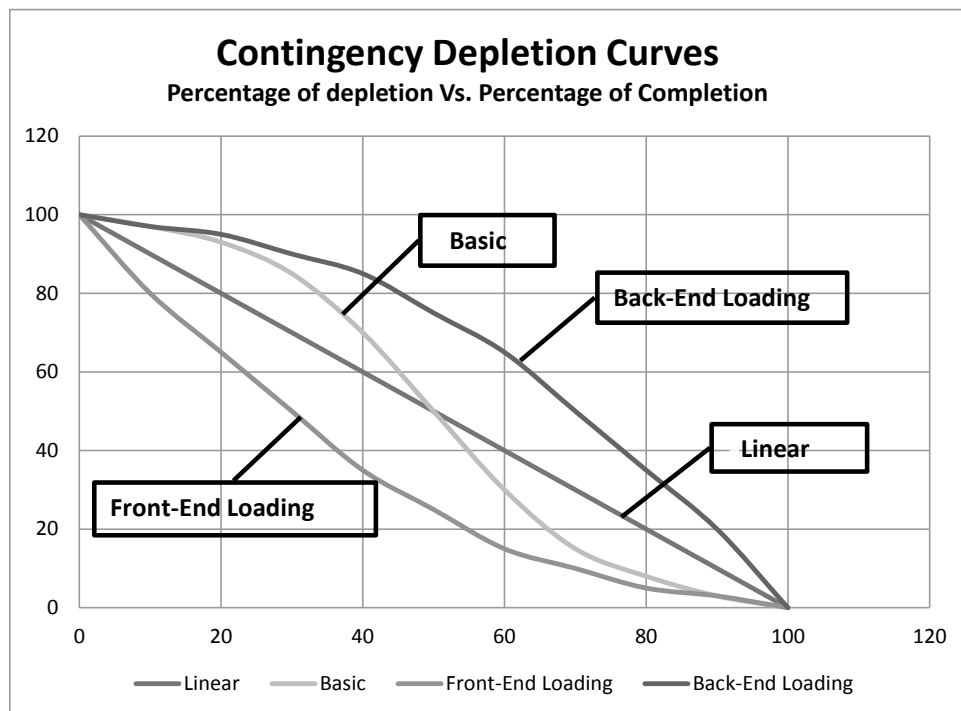


Fig. 3.3 Depletion Curve Types

Custom Depletion Curve

The proposed contingency depletion curve, the custom depletion could also be called the “tailored depletion curve”, since it is generated based on the periodically estimated contingency. This curve assumes that within any period the depleted contingency should be less or equal to the estimated contingency (assuming that all the risks associated with the project are identified). Let us consider that d_j is one of project milestones, CE_{ij} is the estimated contingency for activity “i” over the period d_j and CD_{ij} is its depleted contingency for the same period (Fig. 3.4 **Error! Reference source not found.**).

$$\sum_{i=1}^n CE_{ij} \geq \sum_{i=1}^n CD_{ij} \quad (3.17)$$

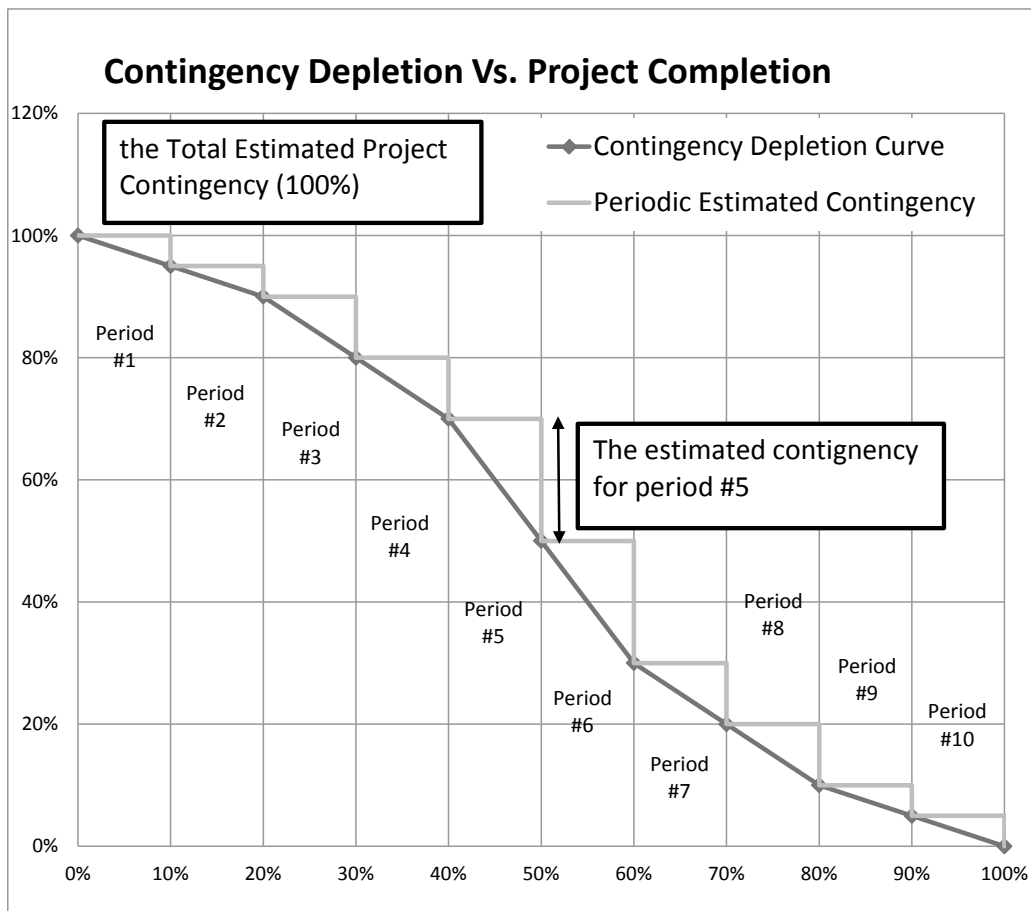


Fig. 3.4 Custom Contingency Depletion Curve

For a specific period or project milestone, the summation of depleted contingency should be less than or equal to the summation of estimated contingency for the same period. Assuming that during this specific period, m activities were implemented this means that:

$$\sum_{i=1}^m CD_i \leq \sum_{i=1}^m CE_i \quad (3.18)$$

As with contingency management, some of the planned risks may occur during a specific period T and this could generate an excess in the project's contingency. Therefore, a reserve contingency account (RC) should receive the entire excess contingency. This policy increases the contingency fund's controllability by eliminating the misuse and the over-exhaustion of contingency. The reserve contingency account could be increased or decreased based on the difference between planned contingency (PC) and the actual contingency (AC) during the specific period T as follows:

$$PC(T) \geq AC(T) \quad (3.19)$$

$$RC = RC + [PC(T) - AC(T)] \quad (3.20)$$

Where: $PC(T)$ is the estimated contingency during the period T , which could also be read from (Fig. 3.6). $AC(T)$ could be calculated as follows:

$$AC(T) = \sum_{i=1}^n AC_i(T) \quad (3.21)$$

Where, $AC_i(T)$ is the actual contingency used to mitigate risk R_i during the period T , and n is the number of risks planned during the period T .

In the cases where $PC(T) < AC(T)$, a shortage in contingency could be generated which means the use of the contingency reserve is required. A "use reserve contingency

request” would then be submitted to the contingency reserve account’s manager for approval. The contingency shortage should be covered by the use of the contingency reserve only when the request has been approved; otherwise, an extension of contingency (i.e. new contingency fund resource) is needed. In addition, the contingency reserve could be used to mitigate the unforeseen risks and the unknown risks if necessary. The contingency depletion performance could be evaluated by calculating the ratio between planned project contingency (PC) and actual depleted contingency (AC) as follows:

$$\left\{ \begin{array}{l} \frac{AC}{PC} > 1 \Rightarrow \textit{Contingency Shortage is generated} \\ \frac{AC}{PC} < 1 \Rightarrow \textit{Contingency Excess is generated} \\ \frac{AC}{PC} = 1 \Rightarrow \textit{No Contingency shortage or excess} \end{array} \right.$$

This procedure could be represented as follows (Fig. 3. 5):

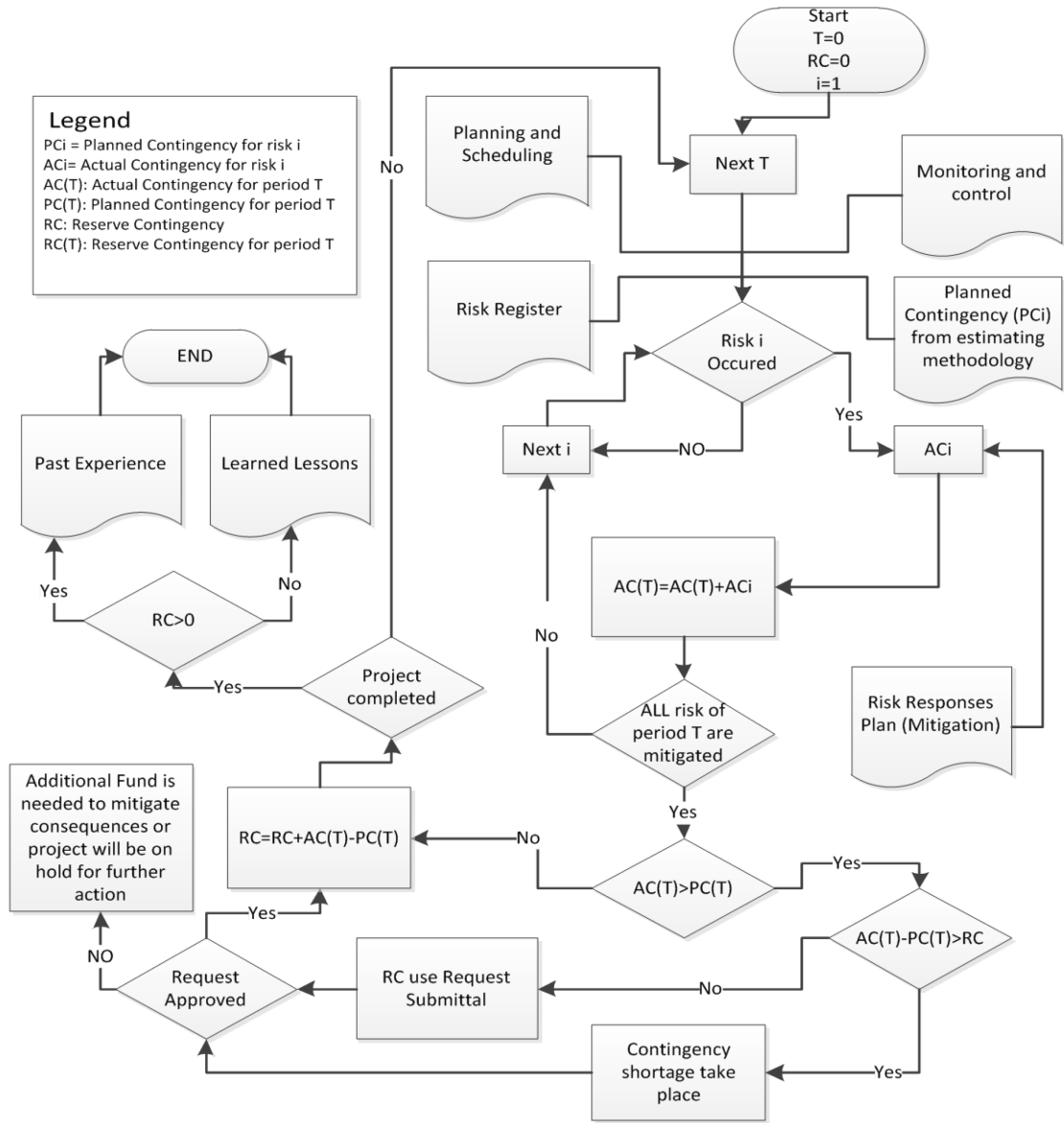


Fig. 3. 5 Contingency Management Model

The selection procedure of the contingency’s depletion curve as a “Project Planned Contingency Depletion Curve” should take into consideration the factors that can affect the selection (i.e. a company’s financial capacity).

The selection could be performed using the “IF-AND-THEN” approach which increases the probability to choosing the most suitable depletion curve for a specific project. This

approach is governed by several rules based on: 1) experience, 2) past project learned lessons, 3) management skills, and 4) applicability. These rules can be improved on project basis. There are several scenarios can be presented, such as the following five:

Scenario 1: IF the project is an infrastructure project (i.e. information about the project is not complete) AND the project manager prefers to use the aggressive strategy AND the company's financial capacity is good THEN the back-end loading depletion curve would be recommended, since it improves the ability to control the project manager's aggressive strategy and avoid the early depletion of the project contingency (i.e. until more information about the project becomes available).

Scenario 2: IF the project's delivery system is fast-track AND the project manager prefers the passive strategy AND the company's financial capacity is very good THEN the front-end loading depletion cure would be recommended, since it increases the ability to control a project manager's passiveness and encourages contingency depletion earlier in order to avoid any project delay.

Scenario 3: IF the project information is complete and reliable AND the associated risks with the project are well identified and evaluated AND the project financing has a uniform cash flow AND the company's past experience in similar projects is excellent THEN the linear depletion curve would be recommended, since it is simple to use, monitor and control. It could be the best-fit depletion curve in the case of uniform cash flow.

Scenario 4: IF the company has very good experience in similar projects AND the project financing follows the S-curve project cost baseline (i.e. same funding resources) THEN

the basic depletion curve would be recommended, since it follows the resources' availability (i.e. money, manpower, machinery, materials) over the project durations and addresses all the risks associated with them accordingly.

Scenario 5: IF the project type is conventional (i.e. Education Center) AND the company's financial capacity is average AND the company's experience in similar project is average AND the risks associated with the project are reliably evaluated THEN tailored depletion curve would be recommended, since it eliminates the late and the earlier depletion of contingency, and improves the ability to control contingency depletion periodically (i.e. at any project's milestone).

CHAPTER FOUR

DEVELOPED COMPUTER APPLICATION

4.1 Introduction

This chapter describes the implementation of the developed contingency estimating method described in Chapter 3. The software called “Contingency Fuzzy System Software” or CFSS was developed using object-oriented programming and NET framework version 4. It was coded using visual basic VB.NET 2010. CFSS is standalone software which can be used without the reliance on a 3rd party software or any other external component or dynamic libraries such as. Microsoft Excel, DLL files.

CFSS includes four main modules: 1) input module, 2) fuzzy estimation module, 3) graphical representation module, and 4) analytical reporting module. The input module contains fuzzy contingency inputs (based on number of estimators/ experts) associated with each risk at the cost item level. The estimation module (number 2 noted above) includes five sub-modules: a) fuzzy estimation, b) measures, c) ratios, d) indices, e) defuzzification value, and f) estimation with certain possibility not exceeding a specific value. The graphical representation module (number 3 noted above) shows graphically the fuzzy estimate of cost items, packages and project(s). The analytical reporting module (number 4 noted above) considered the CFSS output, generates an analytical report for either one specific project or a group of projects. The report generated includes the information needed to monitor and control a specific cost item, package or project. The

CFSS model is flexible and easy to use. Project cost estimates follow detailed, risk breakdown structure (RBS), which can be described as shown in (Fig. 4.1)

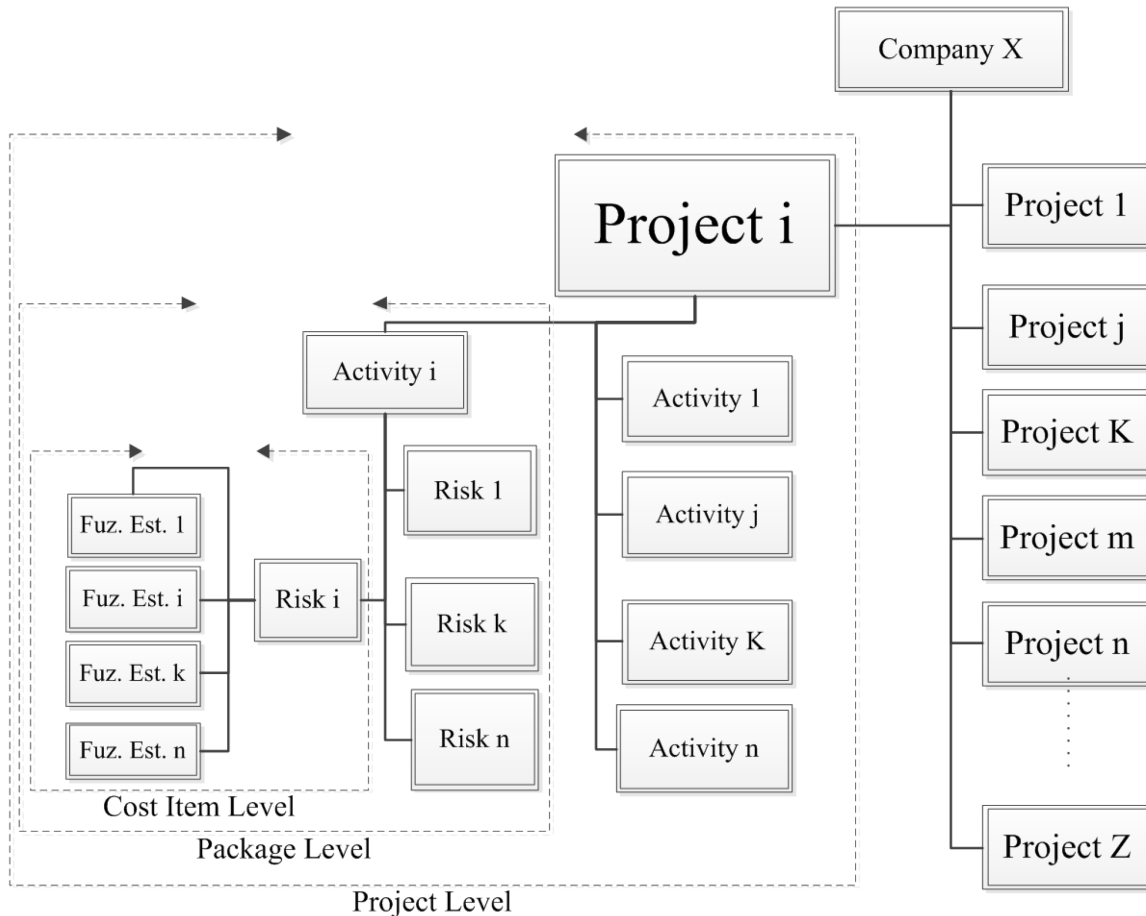


Fig. 4.1 Fuzzy Contingency Estimation Model

Each cost item (risk) can have a different number of fuzzy estimates based on the number of experts participating in the cost item's estimation process. The fuzzy estimate of each risk item is calculated as average of all estimates provided. The fuzzy estimate of each activity is calculated as $(\text{sum of fuzzy estimates of risks}) / (\text{cost of items associated with this activity})$. The fuzzy estimate of project is the sum of fuzzy estimates of all project activities.

4.2 Characteristics of the Developed Application

CFSS uses a Graphical User Interface (GUI); coded in VB.NET. The software allows users to input data with different methods: 1) New Data Entry, this method used when a new category is implemented and the majority of inputs can't be imported from an existed or saved data. 2) Loading an incomplete data: used to load incomplete data entry file in order to complete the same. 3) Importing Data from an existing Project: data will imported from an existing project with the ability to join the new and existing data at any phase. The software's main screen is shown in (Fig. 4. 2).

The software is user-friendly and it doesn't need any experience or training to use it. The interactive screens, between the software and the instructions, provided to user are capable of limiting the errors associated with input.

This software is limited to 3-level of details: cost item, package and project. However, it could be expanded to introduce more levels. The complicated calculations are hidden to limit the inexperienced user's confusion. Besides that, CFSS has a user-friendly output in a readable and well organized format. The software has a graphical representation in order to simplify the output.

Given that this is stand-alone software, the setup of the software can be done easily. The software works in a windows environment with a net framework installed on it.

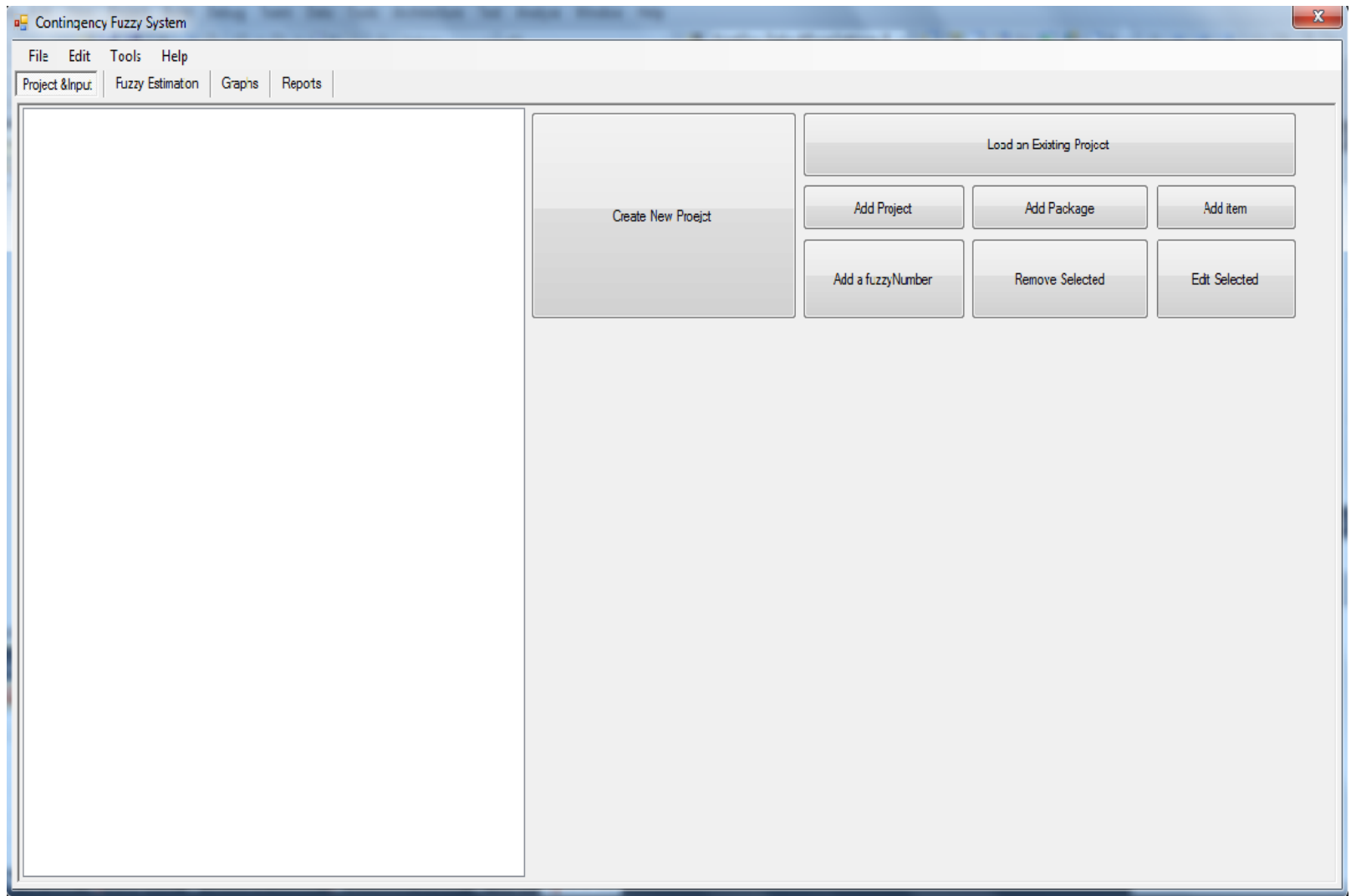


Fig. 4. 2 Contingency Fuzzy System

4.2.1 Working on a New Project

The software gives the user two options in order to create a new project: 1) by pressing “Create New Project” button on the main Screen, or 2) by Adding project using “Add Project” button once the file is empty. The create option will asked user to name the new project as shown in (Fig. 4. 3).

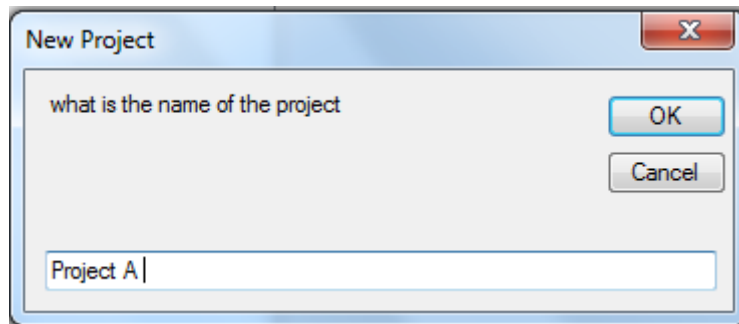


Fig. 4. 3 Creating a New Project

In this case, the user can name the project with any name (i.e. Montreal Community Library Center Project).

Adding a new component to project could be done by one of four options: (1) Add Project, (2) Add Package, (3) Add Item, and (4) Add a fuzzy number as shown in (Fig. 4.4). The “Add project” button adds a new project to an existing one.

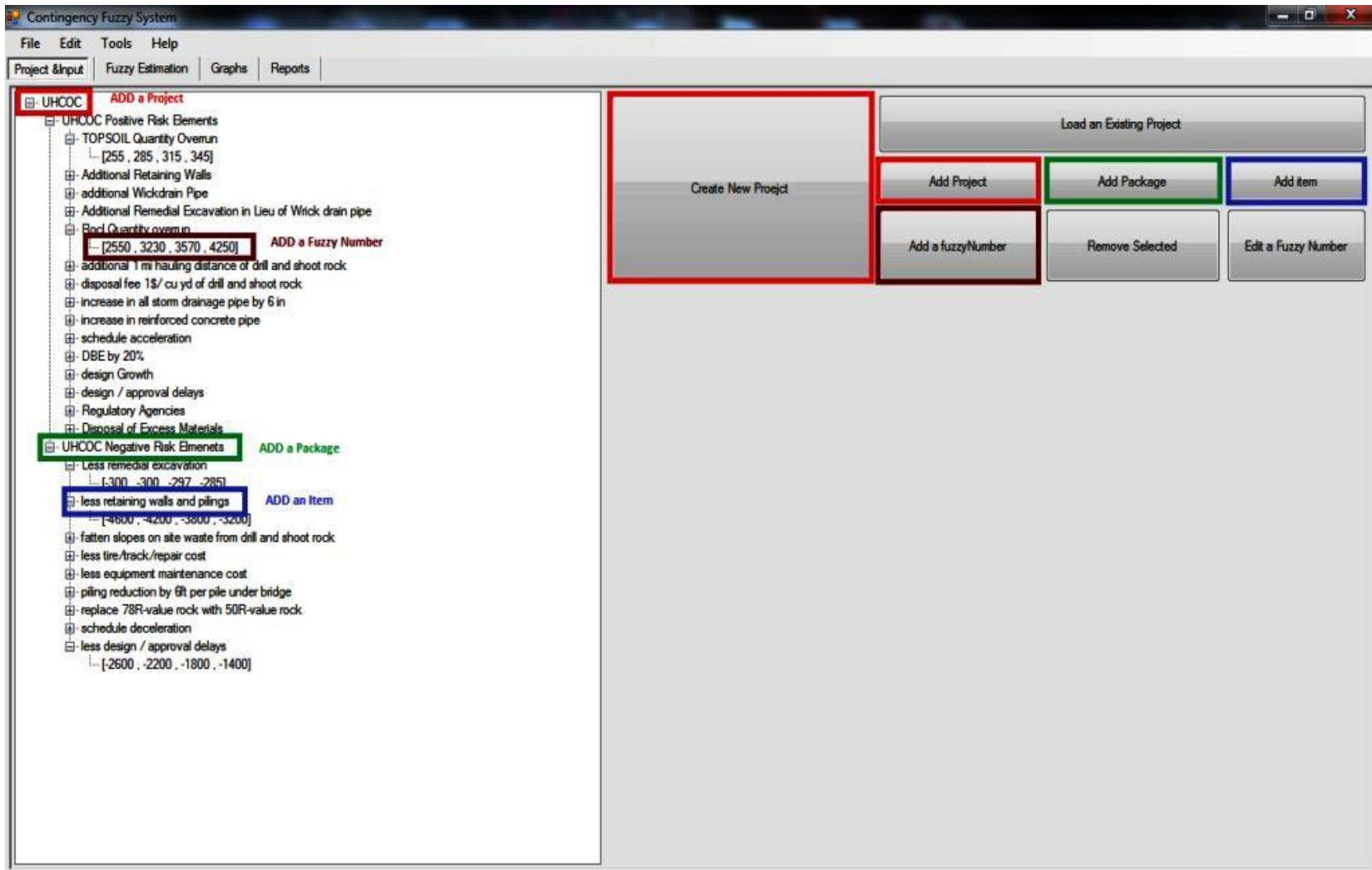


Fig. 4.4 Adding a New Component

The “Add package” button shows an interactive screen which asks the user to enter the package name as shown in (Fig. 4.5). There is one condition prior to add a package: 1) the user should select a project node, otherwise an interactive screen show up and asked him to select a project node first as shown in (Fig. 4.6).

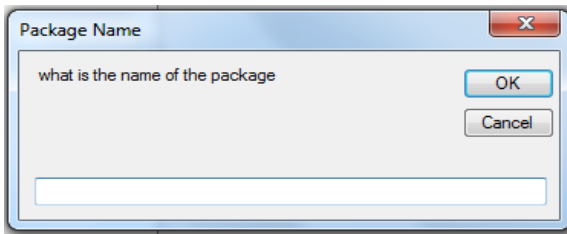


Fig. 4.5 Adding a Package

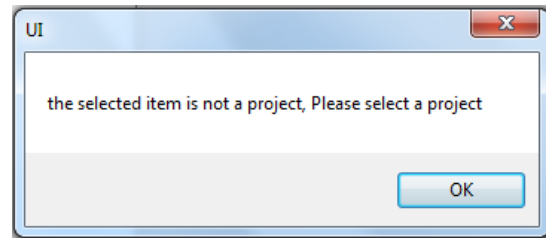


Fig. 4.6 Adding Package Error

The “Add Item” button (Fig. 4.4) asked the user to enter the cost item’s name as shown in (Fig. 4.7). There is one condition prior to add a cost item: 1) the user should select a package node, otherwise an interactive screen show up and asked him to select a package node first as shown in (Fig. 4.8).

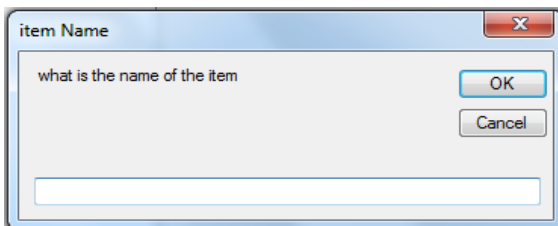


Fig. 4.7 Adding a Package

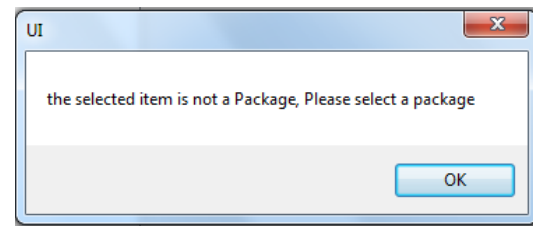


Fig. 4.8 Adding Item Error

The “Add Item” button (Fig. 4.4) asks the user to enter a cost item’s fuzzy estimate as shown in (Fig. 4.9). There is on one condition prior to add a fuzzy number: 1) the user should select a cost item node, otherwise one of two interactive screens, based on the error, will occur. There are two types of errors: 1) input error (Fig. 4.10) which indicates that the user didn’t follow the instructions and correct input as mentioned in (Fig. 4.9), 2)

selection error (Fig. 4.11) which indicates that the user didn't select a cost item node therefore an interactive screen will be shown and asked the user to select a cost item.

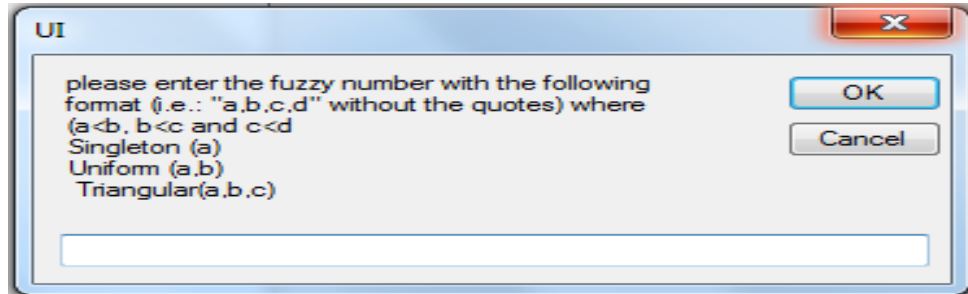


Fig. 4.9 Adding a Fuzzy Number

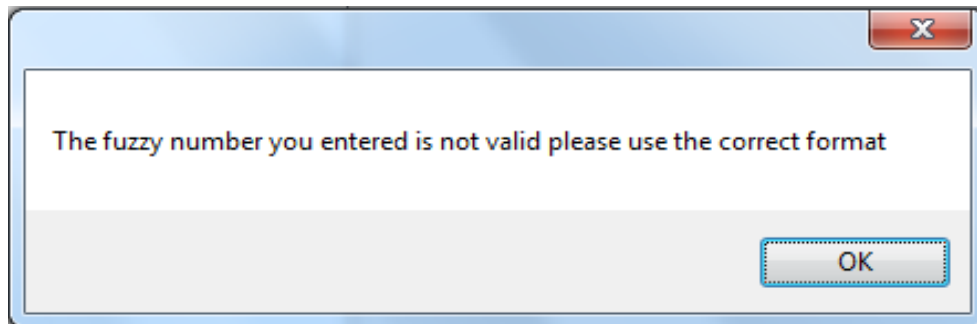


Fig. 4.10 Adding Fuzzy Number Input Error

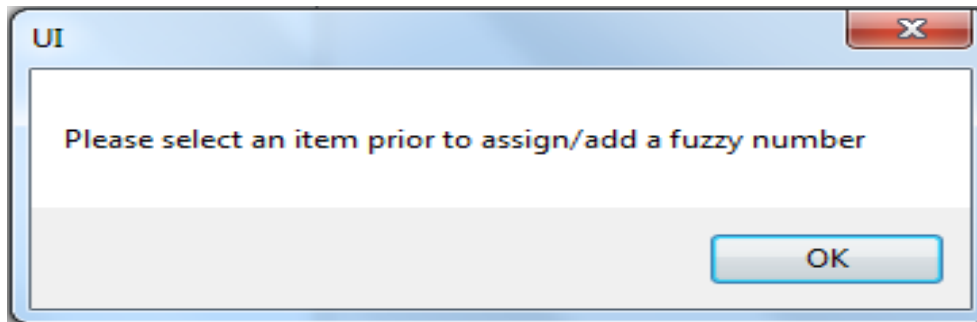


Fig. 4.11 Adding Fuzzy Number Selection Error

There are four types of accepted input of fuzzy numbers: 1) Trapezoidal Fuzzy Number, considered general format of a fuzzy number the input should be with the format of four numbers as follows "#, #, #, #" without quotes. 2) Triangular fuzzy number it is a simplified input comparing to trapezoidal since user needs to enter only three numbers as follows "#, #, #". 3) Uniform fuzzy number here it is enough to enter only the lower and

upper bound “#, #”, 4) Crisp fuzzy number it is the easiest since user is requested to enter only one number “#”.

All these instructions are incorporated to simplify the user’s input and decrease the time required for data input. The software will automatically identify the fuzzy number’s type and generate the equivalent quadruple of triangular, uniform and crisp. The important note which should be considered during fuzzy numbers input is: all the numbers should be in ascendant order otherwise the input error will show up and tell the user to follow the input’s instructions as shown in (Fig. 4.10)

There are two corrective buttons as shown in (Fig. 4.12): 1) Remove selected: this button will remove selected node with all its sub-nodes 2) Edit Selected: this will edit the selected fuzzy number’s value if a fuzzy number was selected and it changes the name otherwise.

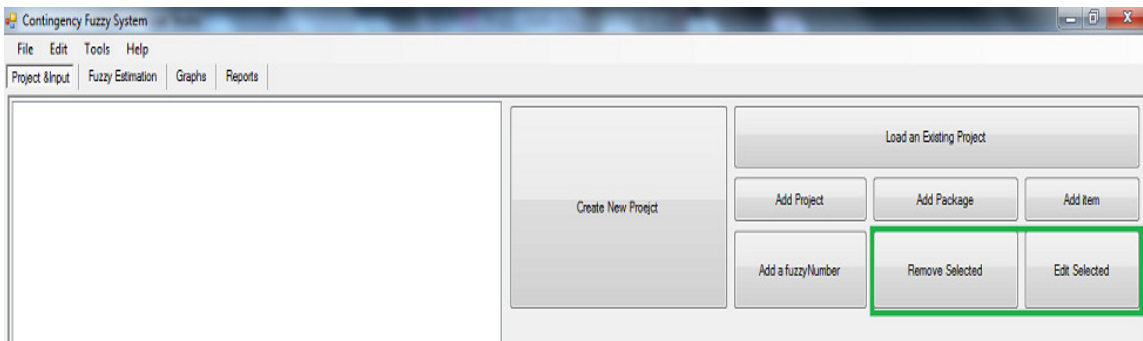


Fig. 4.12 Editing a Component

After the new project’s input are completed, then the estimation module, graphical module, and reporting module are ready to be used. Otherwise, the user could save the input by using file drop down menu: File → Save → then he could choose between “Save Project” or “save as new project” (Fig. 4.13).

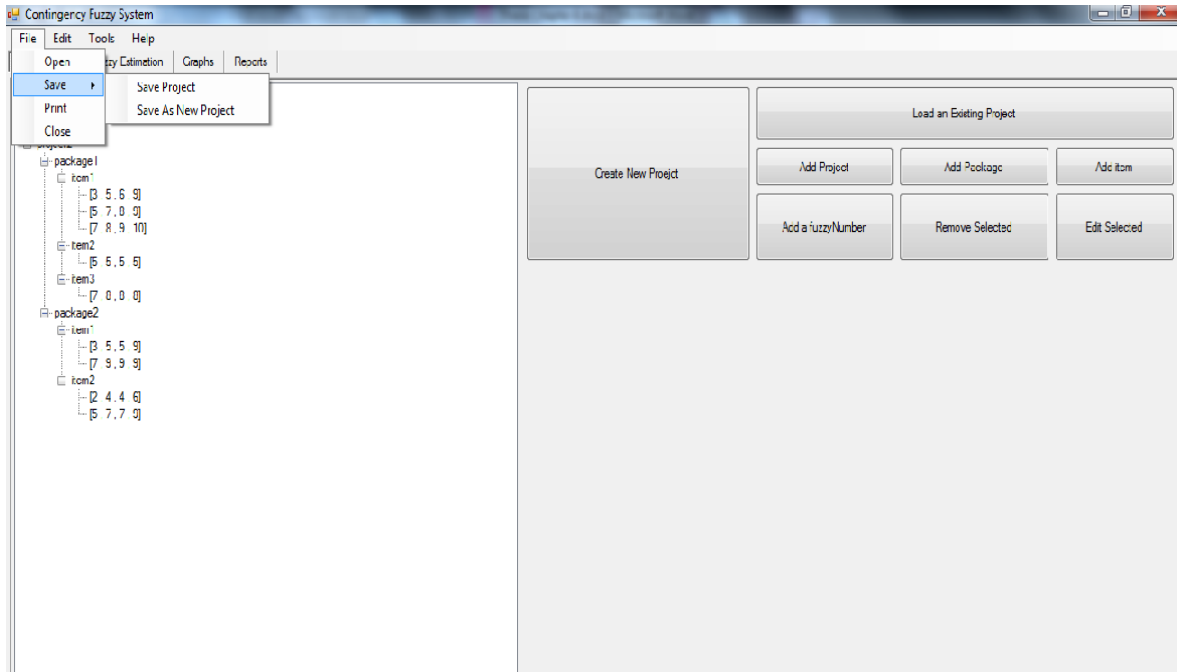


Fig. 4.13 Saving a Project

The file will be saved with “.dat” extension in order to be used when necessary. The saved file can be opened as an existing project or can be imported as an additional project.

4.2.2 Working on Existing Project

After the creation a new project and the saving the data in a file, the user can load the saved data by clicking “Load an Existing Project” button which will open a file-open-dialog which asked user to select the required file with “.dat” extension to be opened (Fig. 4.14). The open command can also be reached by using the drop down file menu and choosing the open command (File → open) (Fig. 4.15). Once the file is selected, a new interactive screen will pop-up asking user whether load selected file as a new project or add it to the current one (Fig. 4.16). Based on the user’s decision the file data will be loaded in the input in order to be used as shown in (Fig. 4.16).

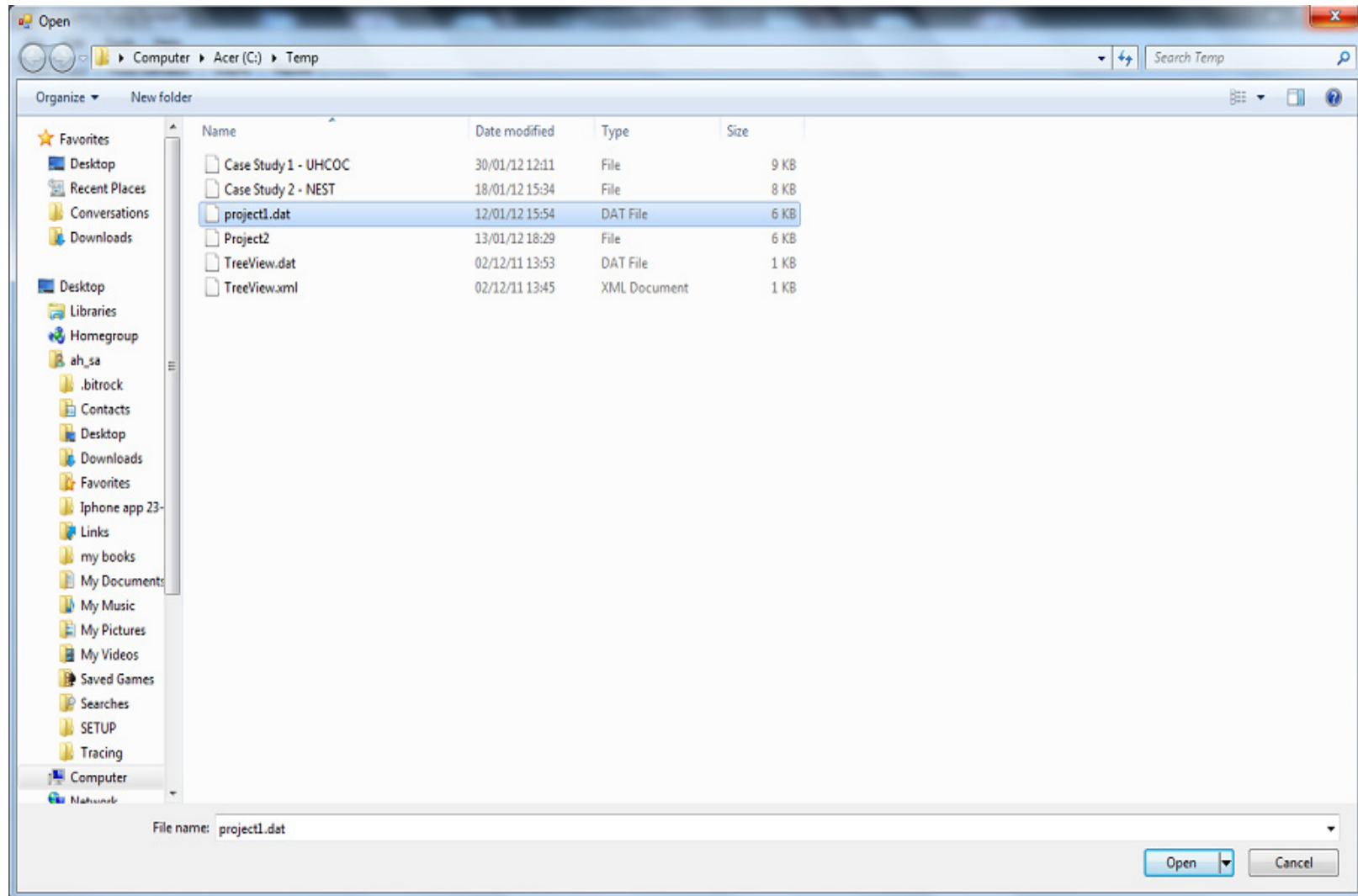


Fig. 4.14 Opening an Existing File

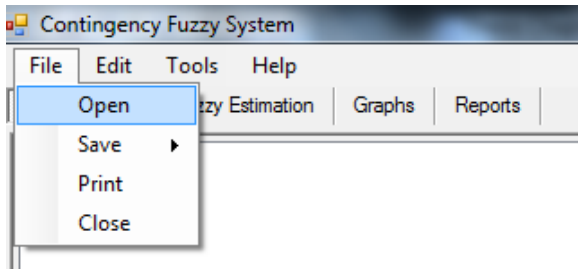


Fig. 4.15 Open Project from File Menu

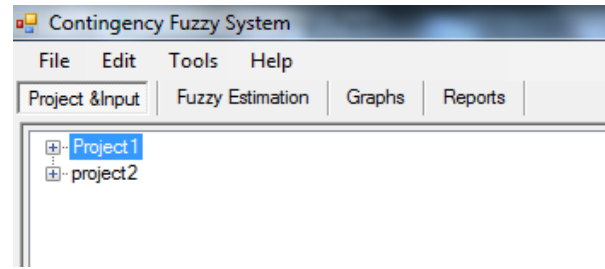


Fig. 4.16 Existing Project Loaded as Input

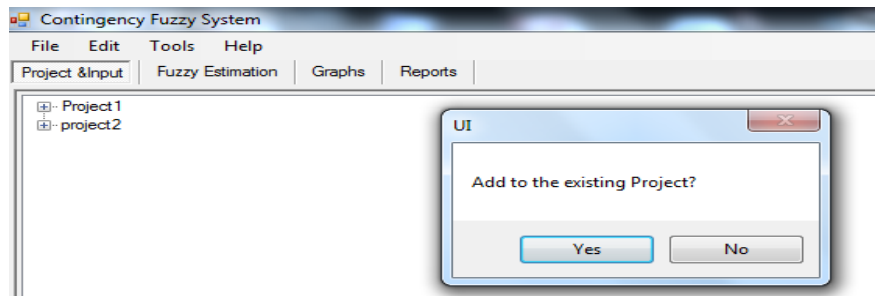


Fig. 4.17 Adding to Existing Project Interactive Screen

4.2.3 Estimation Module

As the inputs are completed all the project components are automatically loaded to a combo-box list existed in the estimation tab. The estimation tab main screen has four blocked sub-main category. The user is able to use sub-categories after the selection of a component from the project's components listed in the combo-box. Once a component is selected the four sub-categories are activated and ready to use.

Estimation sub-category

It contains: 1) fuzzy representation, 2) mean, 3) variance, and 4) area of the selected component. No additional input is needed all values will be calculated once the "estimate" button is clicked.

Measures Sub-Category

It includes: 1) ambiguity measure, 2) fuzziness measure, 3) fuzzy number quality index, 4) fuzziness expected value ratio, 5) ambiguity expected value ratio, and 6) agreement index. This category needs two additional inputs: 1) fuzziness weight (the ambiguity's weight will be calculated automatically), and 2) another component selection should be made in order to calculate the agreement index between the two components.

Possibility and necessity Measure Sub-Category

This calculates: 1) possibility, 2) necessity, and 3) m_λ measures for a specific interval [lower bound, upper bound]. The inputs of this sub-category are lower and upper bound of the interval and λ .

Degree of Membership Sub-category

This calculates the degree of membership for the selected component at any given X and it could, for a specific degree of membership value, calculate the left and right value of X. The additional inputs are X and μ .

The user is requested to follow two steps to get results without getting involved in the details of all the internal calculations procedures (Fig. 4.18): 1) Select Component, and 2) Press "Calculate / Estimate" button. Once, the "calculate" button is pressed the fuzzy estimation, expected value, variance and area of the selected component would be calculated.

Contingency Fuzzy System

File Edit Tools Help

Project & Input | Fuzzy Estimation | Graphs | Reports

Select an item from the list:

Project 1:Package 1:Item 1 STEP 1

Results
the selected item is: Project 1:Package 1:Item 1

Estimate

Fuzzy Representation / Estimation :	[1,5 , 2,5 , 4 , 7,5]	STEP 2 Calculate / Estimate	Possibility and Necessity		<input type="text" value="λ="/> <input type="button" value="Calculate"/>		
Mean Value:	3,875		Lower Bound	<input type="text"/>		Upper Bound	<input type="text"/>
Variance:	2,69271		Possibility Measure:	<input type="text"/>			
Area	3,75		Necessity Measure:	<input type="text"/>			
			mλ:	<input type="text"/>			

Measures

$\omega F =$ $\omega AG =$

Ambiguity Measure:

Fuzziness Measure:

FNQI:

Ambiguity Ratio: Fuzziness Ratio:

Select an Item:

Agreement Index:

Degree Of Membership

X= (enter the value of X)

$\mu (X) =$

$\mu (X) =$ (select a Membership)

X(Left)=

X(right)=

Fig. 4.18 Estimation of Selected Component

The measures sub category is used to calculate all the measures associated with selected component. The additional input is the fuzziness weight and the ambiguity weight which can be automatically generated. In case of non-acceptable input of the fuzziness weight (i.e. bigger than 1) an error interactive screen will show up (Fig. 4.19):

$$W_F = 1 - W_{AG} \quad (4.1)$$

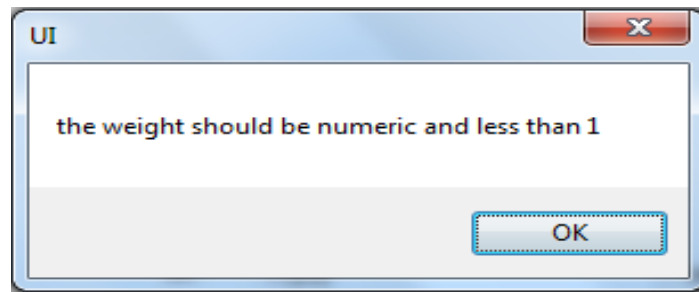


Fig. 4.19 Fuzziness Weight Input Error

The Ambiguity Measures (AG), Fuzziness Measures (F), Fuzziness Expected value Ratio (FER), Ambiguity Expected value Ratio (AEV), and Fuzzy Number Quality Index (FNQI) are calculated based on their equations. All the measures calculations can be done by following 5 simple steps (Fig. 4.20) : 1) select a component from the first list, 2) enter the fuzziness weight, 3) press the “Calculate Fuzzy Measures” button, 4) select another component from the second drop-down list in order to calculate its agreement index, and 5) press the “Calculate Agreement Index” button.

The result of each measure will be shown in the correspondent field. This calculator could be useful to check, monitor and control the contingency required for mitigating a specific risk at any project milestone.

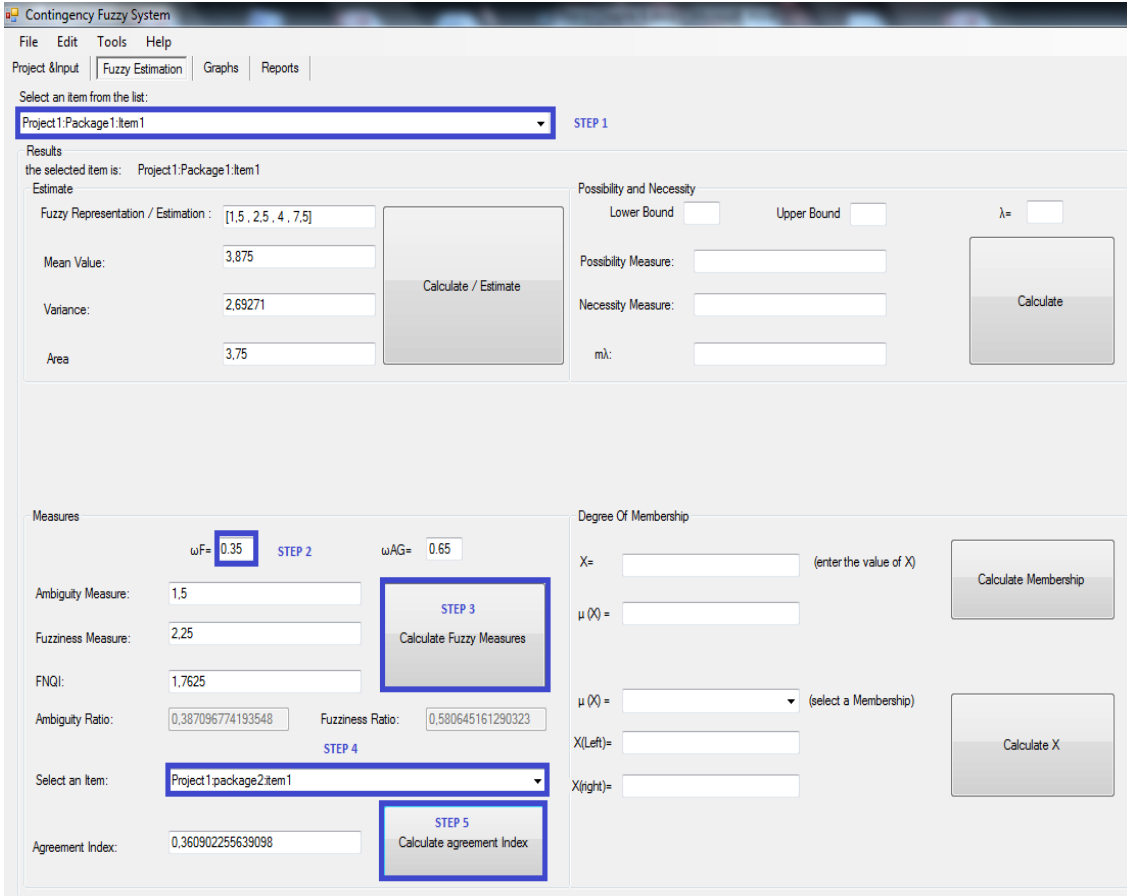


Fig. 4.20 Uncertainty Measures Calculations of a Selected Component

The possibility, necessity, and m_λ uncertainty measures could be calculated based on their equations 3.10, 3.11, and 3.12 respectively. The necessity, Possibility, and m_λ measures could be calculated by 5 steps (Fig. 4. 21): 1) select a component from the drop-down list, 2) enter the interval's lower bound value, 3) enter the interval's upper bound value, 4) enter the λ value, and 5) press the "Calculate" button.

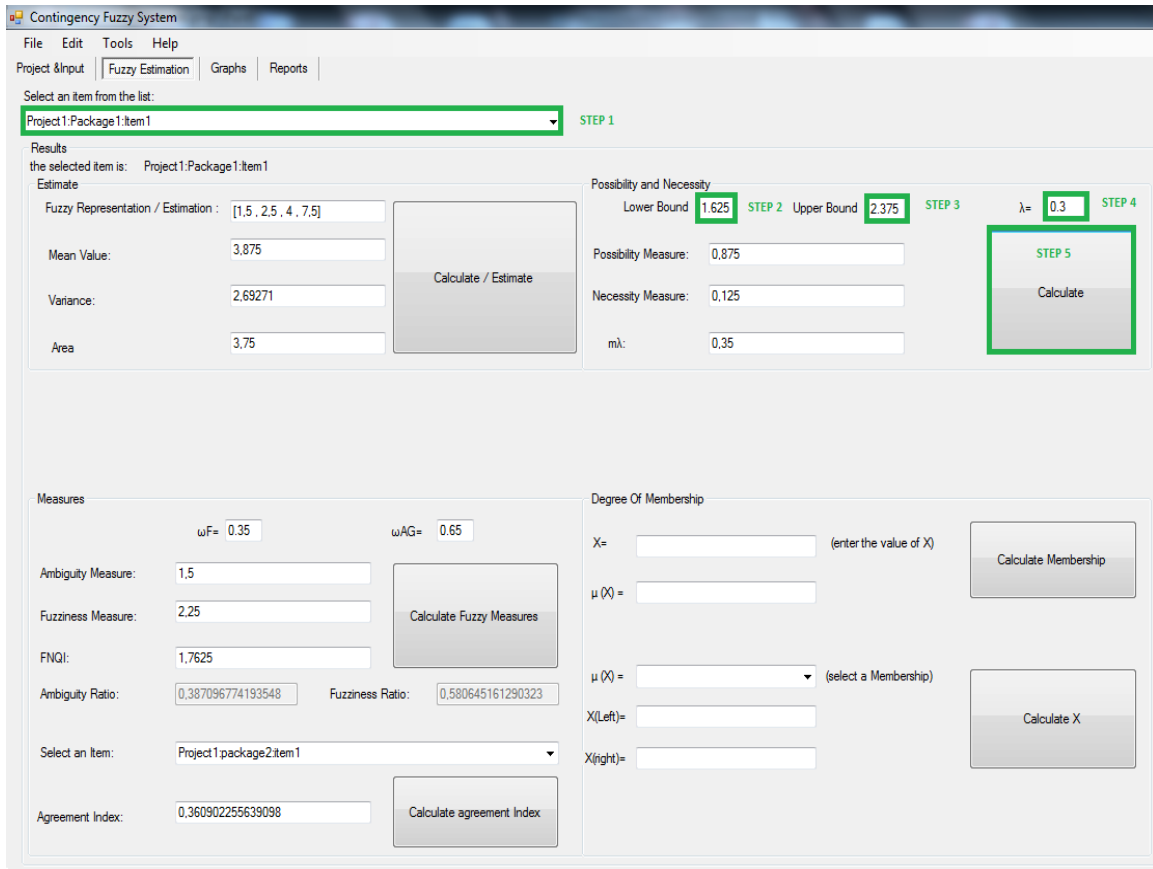


Fig. 4. 21 Possibility and Necessity Calculation of Selected Component

The Degree of Membership sub-category calculates the selected component's degree of membership for a given X and it calculates left and right value of X for a specific degree of membership (Fig. 4. 22). The degree of membership calculations could be done as follows: 1) select a component from the first list, 2) enter X value, 3) press "Calculate Membership" button to calculate $\mu(X)$, 4) select membership desired value from $\mu(X)$ drop-down list, and 5) press "Calculate X" button to calculate X (left) and X (right) values.

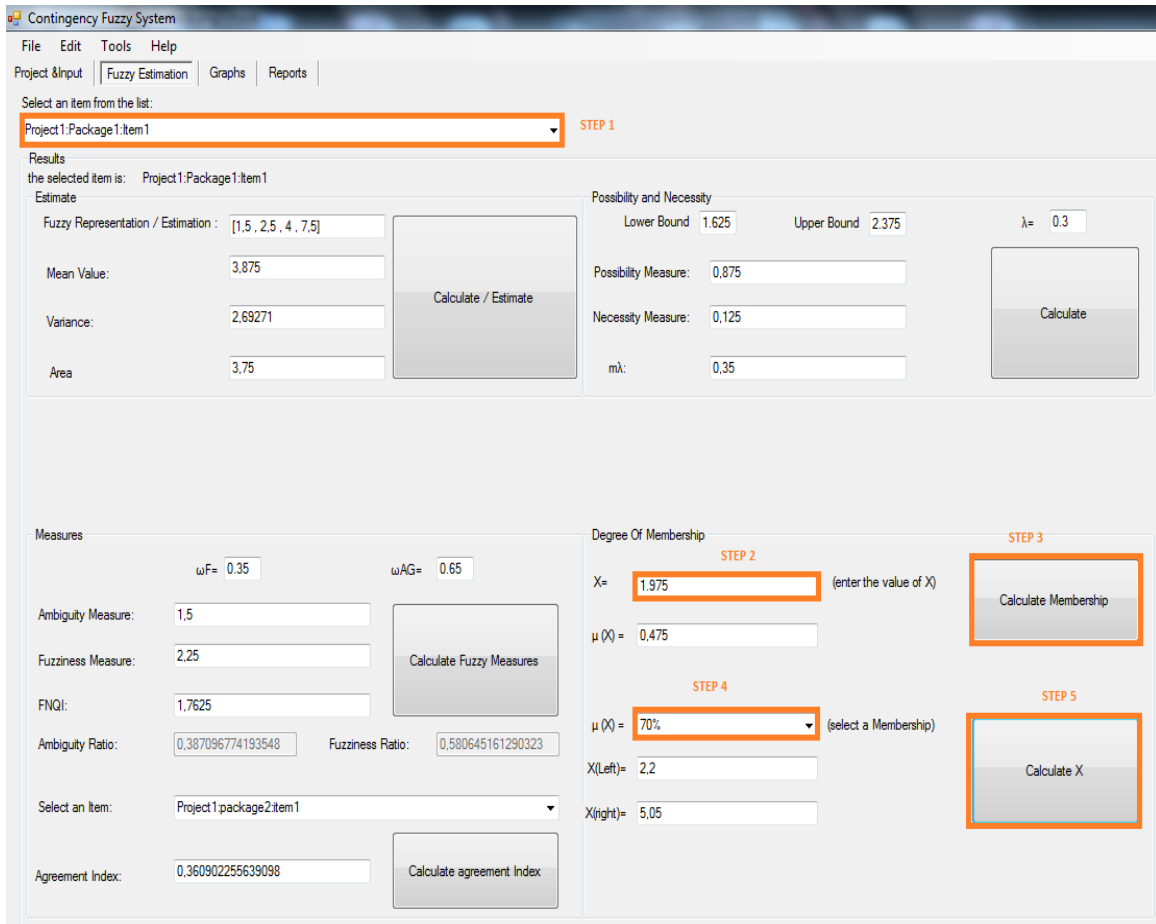


Fig. 4. 22 Degree of Membership Calculations of Selected Component

4.2.4 Graphical Module

The graphical module generates a graphical representation of any project components based on sub-components.

- Project could be represented by project, packages or by cost items.
- Package could be represented by package or cost items.
- Cost item could be represented by its fuzzy representation only.

The graphs can be drawn by three steps (Fig. 4. 23) as follows: 1) select component to be represented, 2) select the desired representation's option "By Project", "By Package", or "By item", and 3) press the "Plot" button

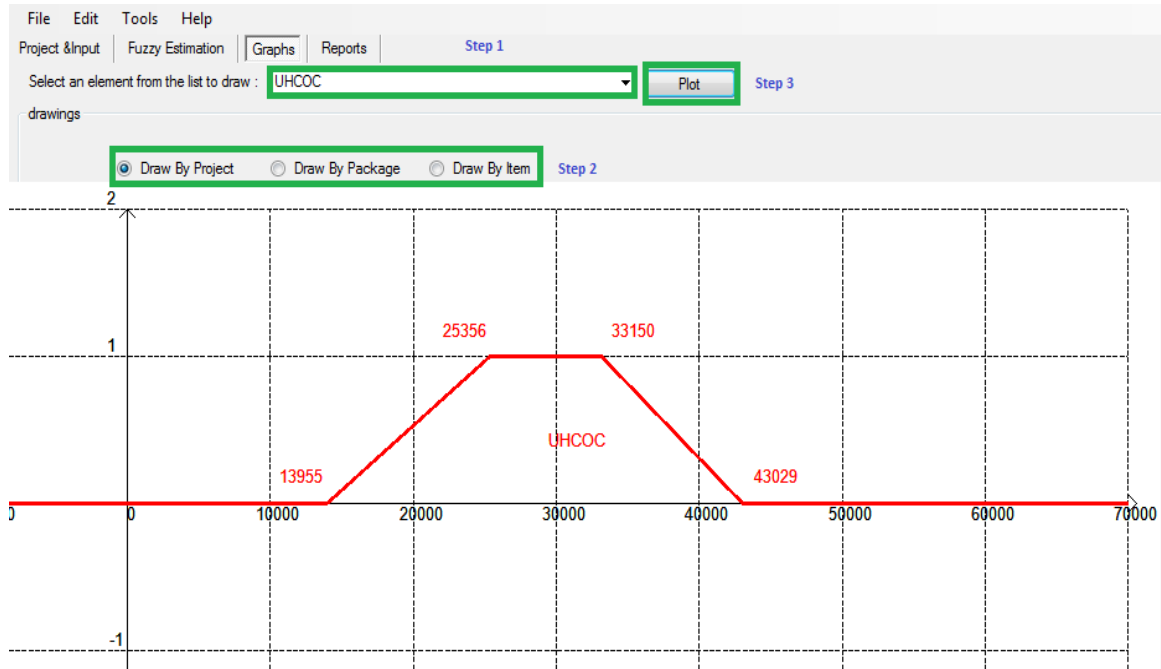


Fig. 4. 23 Graphical Representation of a Selected Component

4.2.5 Reporting Module

The reporting module is numerical output of CFSS organized in a table format. Each component of the project has its fuzzy estimation, expected value, variance, uncertainty measures, and contingency estimation. In addition to that, this report could be printed directly from the software without the need to be converted to any other format (i.e. Excel) with a print preview option as shown in (Fig. 4.24). The software output or project report can be generated by following three steps as follows: 1) select the project from the list, 2) press the "Generate Report" button, and 3) press the print / print preview report button.

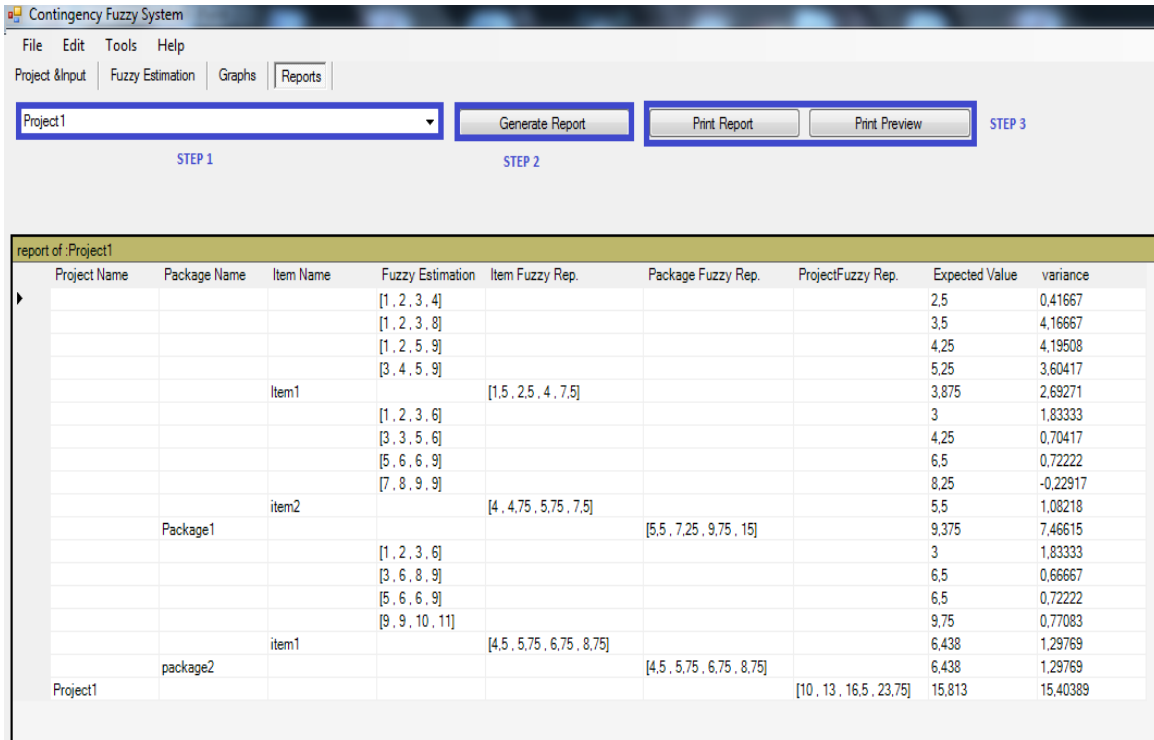


Fig. 4.24 Project Report

The report details can be modified to comply with the project or company requirements. The software is coded by 100% vb.net including database, reporting, graphical representation, fuzzy theory library, fuzzy operation and contingency estimation procedures which afford the user great flexibility and options to customize and increase the applicability to specific projects.

In Chapter 5 case studies and the data will be used to explicitly discuss and evaluate the software and the proposed contingency estimating method. CFSS will be applied to two real case studies extracted from literature in order to evaluate the software performance and the efficiency of proposed estimating method compared to the existing methods developed using fuzzy, MCS and PERT.

CHAPTER FIVE

APPLICATIONS AND VALIDATION

5.1 Introduction

The developed contingency estimation method was applied to two example projects; referred to later as cases. The two cases are of real projects and were drawn from literature to demonstrate the use of the developed method and its computer application and to validate it. The first case involved the preparation of range cost estimate of the North Edmonton Sanitary Trunk Project (NEST) constructed by City of Edmonton. The second case involved contingency estimating of the construction cost of Urban Highway Construction in California (UHCOC). In both cases fuzzy-set theory was used in addition to other traditional methods such as Program Evaluation and Review Technique (PERT) and Monte Carlo simulation. The two cases were analyzed and the results were compared to those generated using other methods.

In the first case, Shaheen et al. (2007) proposed a method based on fuzzy- set theory used NEST project as the case study to evaluate their method in comparison to Monte Carlo Simulation. In the second case, Paek et al. (1993) proposed a method also based on fuzzy-set theory and used the UHCOC project as the case study. The latter method was compared to PERT in a discussion raised by Moselhi (1993).

In this chapter, the contingency estimating developed method is applied to the two cases. The results obtained were compared to those generated using 1) the method proposed by

Paek et al. (1993), 2) the method proposed by Shaheen et al. (2007), 3) Monte Carlo Simulation and 4) Program Evaluation and Review Technique (PERT).

5.2 Contingency and Range Estimating

As stated earlier, the proposed method was applied to the two case studies: 1) the North Edmonton Sanitary Trunk (NEST) project (Shaheen et al., 2007), and 2) the UHCOC project (Paek et al., 1993).

5.2.1 Case Study 1

The NEST project is a tunnelling project for the City of Edmonton called “North Edmonton Sanitary Trunk”. The project had a maximum allocated budgeted of \$8.8 M and was estimated to cost \$6 M. The main cost packages and their subcategories are shown in Table 5. 1below.

Table 5. 1 Data of NEST Project Adopted with Shaheen et al. (2007)

Item #	Description	a	b	c	d
1.1.1	Mobilization	40000	70000	70000	100000
1.1.2	Power Installation	89000	89000	89000	89000
1.1.3	Power – 156 Str.	15000	15000	50000	50000
1.2	Excavate Work shaft	97600	122000	122000	146400
1.3	Excavate Undercut	200000	269000	269000	350000
1.4	Excavate Tail Tunnel to East	100000	123000	123000	150000
1.5	Form and Pour Undercut	80000	80000	80000	80000

Item #	Description	a	b	c	d
1.6	Form and Pour Tail Undercut	39000	39000	39000	39000
1.7	Form and Pour Shaft	100000	120000	120000	150000
2.1	Excavate Access Shaft	16000	16000	16000	16000
2.2	Backfill Shaft and Install Segments	44000	44000	44000	44000
3.1	Tunnel Install Segments (866 m) price per m = 2254 \$	1951964	2142484	2142484	2909760
3.2	Patch and Rub Tunnel Crown	80	134	134	140
3.3	Patch and Rub Tunnel Final Cleanup	161	188	188	215
3.4	Spoil Removal	5,4	8,1	8,1	9,7
4.1	Access Manhole Shaft	61000	61000	61000	61000
5.1	Tunnel and Install Segments (756 m) price per m = 2254 \$	1704024	1870344	1870344	2540160
5.2	Patch and Rub Tunnel Crown	80	134	134	140
5.3	Patch and Rub Tunnel Final Cleanup	161	188	188	215
5.4	Spoil Removal	5,4	8,1	8,1	9,7
6	Removal Shaft	101000	101000	101000	101000

The original data of each cost item was represented by a triangular fuzzy number that maps the optimistic, most likely, and pessimistic estimates listed in Table 5. 1.

Subsequently, a unifying procedure was performed to modify each triangular fuzzy number into a trapezoidal fuzzy number represented with quadruple (a, b, c, d). In addition, the PERT formula was slightly modified in order to deal with quadruple fuzzy number instead of its original triangular representation. The unified data is entered to the input module of the developed software (CFSS) as shown in (Fig. 5. 1).



Fig. 5. 1 Data Input for NEST Project Case Study

The expected value (EV) of each cost item was then calculated; i.e. defuzzified using Equation 5.1:

$$Cost\ item\ (R_i) = EV(R_i) \quad (5.1)$$

The fuzzy cost-estimate at the package level (e.g. that of the main work shaft), which contains several cost items was calculated as follows:

$$\text{fuzzy estimate of package}(P_j) = \sum_{i=1}^n \text{fuzzy estimate of cost item}(R_{ij}) \quad (5.2)$$

The expected value of each package was calculated as follows:

$$\text{Cost package } (P_j) = EV(P_j) \quad (5.3)$$

And the fuzzy cost estimate of the project was calculated, accordingly as follows:

$$TC = \sum_{j=1}^m P_j \quad (5.4)$$

Then; the project cost value was calculated by defuzzifying TC in Equation 5.4 above as:

$$\text{Estimated project Cost } (C) = EV(TC) \quad (5.5)$$

Once all the calculated estimates of cost items, packages, and project were completed, a full report was then generated as shown in (Fig. 5. 2). This report provides not only the expected value of project cost, but also a number of measures, indices and the depict the level of the uncertainty associated with project cost; representing the vagueness and imprecision implicit in the estimated cost.

- The fuzzy estimate calculated for the NEST project using the proposed method is: [4,639,030; 5,162,160; 5,197,160; 6,827,140].
- The above fuzzy estimate, being in the form of a trapezoidal fuzzy number, its expected value was calculated by defuzzifying it as described in Chapter 3. This yielded project expected cost value of \$ 5, 456, 373 M.

Project Name	Package Name	Item Name	Fuzzy Estimation	Item Fuzzy Rep.	Package Fuzzy Rep.	Project Fuzzy Rep.	Expected Value	variance
	Main Work Shaft		[16, 16, 16, 16]		[760.6, 927, 962, 1154.4]		951	9974,98879
		Excavate Access	[44, 44, 44, 44]	[16, 16, 16, 16]			16	0
		Backfill Shaft and l		[44, 44, 44, 44]			44	0
	Access Manhole		[1952, 2142.5, 2142.5, 2910]		[60, 60, 60, 60]		60	0
		Tunnel and Install		[1952, 2142.5, 2142.5, 2910]			2286,75	42864,18056
		Patch and Rub Tu	[0,08, 0,13, 0,13, 0,14]	[0,08, 0,13, 0,13, 0,14]			0,12	0,00017
		Patch and Rub Tu	[0,16, 0,19, 0,19, 0,22]	[0,16, 0,19, 0,19, 0,22]			0,19	0,00015
		Patch and Rub Tu	[0,01, 0,01, 0,01, 0,01]	[0,01, 0,01, 0,01, 0,01]			0,19	0,00015
		Spoil Removal		[0,01, 0,01, 0,01, 0,01]			0,01	0
	Tunneling (866m)		[61, 61, 61, 61]		[1952,25, 2142,83, 2142,83, 2910,37]		2287,07	42873,12007
		Access Manhole S		[61, 61, 61, 61]			61	0
	Access Manhole S		[1704, 1870, 1870, 2540]		[61, 61, 61, 61]		61	0
		Tunnel and Install		[1704, 1870, 1870, 2540]			1996	32648,66667
		Patch and Rub Tu	[0,01, 0,13, 0,13, 0,14]	[0,01, 0,13, 0,13, 0,14]			0,103	0,00087
		Patch and Rub Tu	[0,16, 0,19, 0,19, 0,22]	[0,16, 0,19, 0,19, 0,22]			0,103	0,00087
		Patch and Rub Tu	[0,01, 0,01, 0,01, 0,01]	[0,01, 0,01, 0,01, 0,01]			0,19	0,00015
		Spoil Removal		[0,01, 0,01, 0,01, 0,01]			0,01	0
	Tunneling (756m)		[101, 101, 101, 101]		[1704,18, 1870,33, 1870,33, 2540,37]		1996,303	32660,36501
		Removal Shaft		[101, 101, 101, 101]			101	0
	Removal Shaft				[101, 101, 101, 101]		101	0
NEST						[4638,03, 5162,16, 5197,16, 6827,14]	5456,373	1199931,7811

Fig. 5. 2 NEST Case Study Report

The output of the proposed method is shown in Fig. 5. 2. The results were compared to those generated by: 1) the method proposed by Shaheen et al. (2007), 2) Monte Carlo Simulation (Shaheen et al., 2007), and 3) PERT method as shown in the (Table 5.2).

Table 5.2 Comparison of Results

Method	Expected Value formula	Total Project Estimation
Proposed Method	$\frac{a + b + c + d}{4}$	\$ 5, 456, 373
Shaheen et al. (2007)	$a + \frac{1}{3(c - b + d - a)} \times [2(c - b)^2 + (b - a) \times (d - a) + (d - a)^2]$	\$ 5, 548, 706

PERT	$\frac{a + 4 \cdot \left(\frac{b+c}{2}\right) + d}{6}$	\$ 5, 352, 680
Monte Carlo (500 iterations)	<i>related to the generated probability distribution function</i>	\$ 6, 059, 263

The results shown in (Table 5.2) can be used as input for the developed CFSS to calculate contingencies at the cost items, packages and project levels as will be demonstrated later in this example. The results also show validity of the proposed method and its developed computer application.

The uncertainty measures incorporated in this thesis could be calculated in order to investigate the reliability and the quality of the NEST’s project results. It should be noted that the generated set of measures, indices and ratios such as 1) fuzziness measure (F), 2) ambiguity measure (AG), 3) possibility measure (P), 4) necessity measure (N), 5) m_λ measure, 6) fuzzy number quality index (FNQI), 7) agreement index (AI), 8) fuzziness expected value ratio (FER), and 9) ambiguity expected value ratio (AER) provides key pattern for vagueness and imprecision; so indicative of the uncertainty associated with project cost estimate as shown in (Table 5.3) as illustrated in the discussion below. Let us consider “A” a fuzzy number of the NEST project’s total cost calculated using the proposed method. The contingency estimating of NEST project could be calculated using the possibility measure. The estimation of contingency equals [X-EV (A)] where the possibility that the NEST project’s expected value (EV (A)) will not exceed the targeted value X is equal or less than 10% could be represented by the following equation:

$$\text{Contingency} = X - \text{EV}(A), \quad \text{where,} \quad P(A \in [X, +\infty[) \text{ is } \leq 0.1 \quad (5.6)$$

Table 5.3 the Proposed Method Uncertainty Modeling Associated with NEST Project

Measure / Index	Formula	Value
Fuzziness Measure $F(A)$	$\frac{(b - a) + (d - c)}{2}$	\$ 1, 076, 555
Ambiguity Measure $AG(A)$	$\frac{d + 2c - 2b - a}{6}$	\$ 376,352
Possibility Measure $P(A \in [6.0M, 8.8M])$	$\text{Sup}_{x \in [a,b]} \mu_A(x)$	0.49
Necessity Measure $N(A \in [6.0M, 8.8M])$	$1 - \text{Sup}_{x \notin [a,b]} \mu_A(x)$	0.0
m_λ Measure $m_{\lambda=0.5}$	$\lambda \times P(A) + (1 - \lambda)N(A)$	0.254
FNQI ($\alpha=\beta=0.5$)	$\frac{\alpha \times F(A) + \beta \times AG(A)}{(\alpha + \beta)}$	\$ 726,453
Agreement Index $AI(N_1, N_2)$	$\frac{\text{Area}(N_1 \cap N_2)}{\text{Area}(N_1)}$	0.191
FER (A)	$\frac{F(A)}{\text{EV}(A)}$	0.197
AER (A)	$\frac{AG(A)}{\text{EV}(A)}$	0.069

Where, $\left\{ \begin{array}{l} N_1 = \text{fuzzy estimation (in \$M) of NEST project} \\ \text{by proposed method } N_1[4.64, 5.16, 5.2, 6.83] \\ N_2 = \text{maximum fuzzy value (in \$M) of NEST} \\ \text{project in this case a symmetric triangular fuzzy} \\ \text{number was considered } N_2[6.0, 6.0, 8.8, 8.8] \\ \alpha, \beta = \text{the fuzziness and ambiguity measures} \\ \text{weights respectively} \end{array} \right.$

As a numerical example of the NEST project the calculated contingency (using CFSS) is:

$$P(A \in [X, +\infty[) = 0.1 \rightarrow X = \$ 6,664,142$$

$$\text{Contingency (NEST)} = X - \text{EV(NEST)} = 6,664,142 - 5,456,373 = \$1,207,769.$$

The numerical example shows that with a total project's cost equal \$6.67 million (includes a contingency = \$1.21M and an expected value = \$5.46M) there is only 10% possibility of exceeding that cost.

A reverse calculation also can be performed using the possibility of not exceeding the expected value added to a certain amount of contingency. For example, if an owner decides to use \$1.0 million dollar only as contingency and wants to check the possibility that the total cost of the project (EV+C) can be exceeded. In this case, if in the NEST project the City of Edmonton allocated \$1.0 million contingency, then the possibility of not exceeding the project total cost can be calculated as:

$$\text{Contingency} = X - \text{EV}(A) \rightarrow X = \text{Contingency} + \text{EV}(A)$$

$$X = 1 + 5.46 = \$6.46 \text{ M} \rightarrow P(A \in [6.46, +\infty]) = 22\% \text{ (calculated using CFSS)}$$

This example shows that the possibility of exceeding the NEST project's total cost (C+EV) equals 22%.

Now, there is possibility to examine a number of scenarios. As can be seen from Fig. 5.3, the possibility of exceeding the allocated budget is 0.0 while the possibility of exceeding the expected value of the project estimated cost is $P(A \in [5.46\text{M}, +\infty]) = 0.84$ with an agreement index of 0.52. Also, the possibility of having project cost at 6.0 million is $P(A \in [6\text{M}, +\infty]) = 0.49$. It should be noted here that it would not have been possible to get a meaningful probability value at this cost estimate using the theory of probability. This will expand the applicability of the proposed method to not only contingency estimating, but also to range cost estimating.

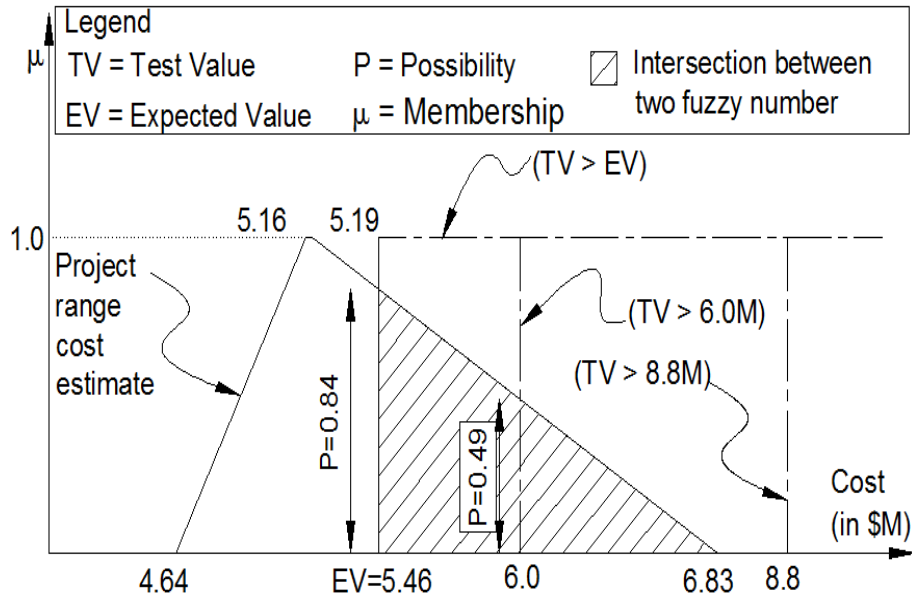


Fig. 5.3 Possibility and Agreement Index

Furthermore, an itemized comparison between the aforementioned methods except Monte Carlo simulation “MCS” (because the data is not available) at the cost item’s level was implemented as shown in (Fig. 5.4). The itemized comparison among these methods proves that the proposed method can yield accurate estimates at the work package level as well as at the project’s level.

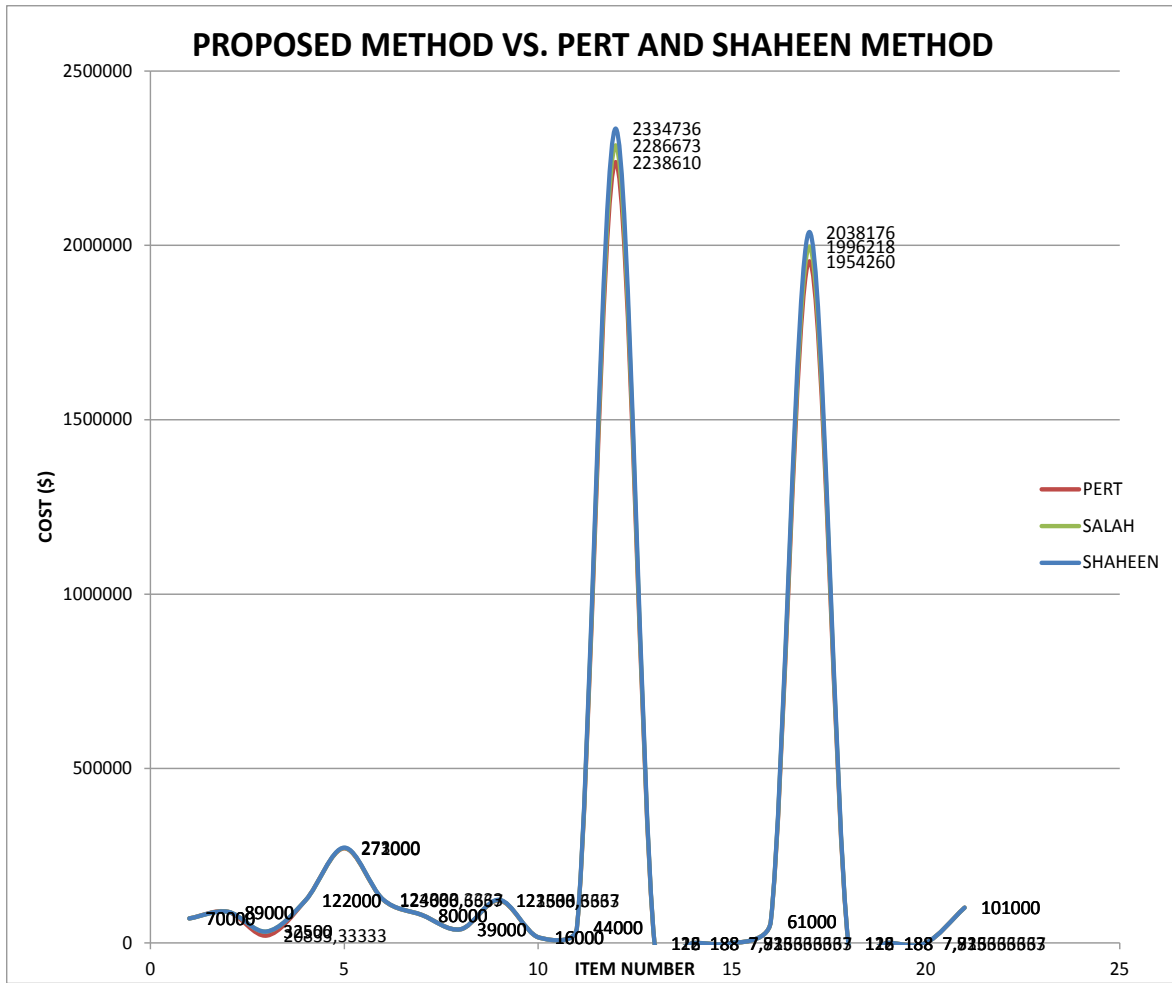


Fig. 5.4 Itemized Comparison among Proposed Method, PERT and Shaheen Method

5.2.2 Case Study 2

Paek et al. (1993) used the project of an urban highway construction in California as the case study. In this research the project is referred to as the UHCOC project. The UHCOC project was projected to cost \$800 million. The risk plan associated with this project treats both positive risks (threats) and negative risks (opportunity). The cost data of this project is summarized in Table 5. 4 and Table 5. 5. For unifying the data in order to comply with the automated computer application’s input format the following operations were applied:

1. Converting the most likely range [a, b] to the “b” and “c” elements of the fuzzy number’s quadruple (a, b, c, d).
2. Converting the largest likely range [c, d] to the “a” and “d” elements of the fuzzy number’s quadruple (a, b, c, d).
3. Modifying the negative risks’ contingency values to negative fuzzy numbers’ quadruples (-d, -c, -b, -a) instead of (a, b, c, d).

The above modifications are important to unify data input of the methods used for comparison. The positive risks data or threats (after modification) are illustrated in (Table 5. 4). The positives risks are classified into two types: 1) risks associated with estimation, and 2) risks not associated with estimation.

Table 5. 4 UHCOC Positive Risks Data Input

Positive risk elements	a	b	c	d
Estimation Risks				
Topsoil quantity overrun – 150,000 cu. Yd.	255	285	315	345
Additional retaining walls and pilings under retaining walls	3500	4500	5250	5500
Additional wick-drain pipe	120	142	150	150
Additional remedial excavation in lieu of wick-drain pipe	1400	1800	2000	2400
Rock quantity overrun – drill and shoot by 25%	2550	3230	3570	4250
Additional 1-mi hauling distance of drill and shoot rock	2000	2375	2625	3000
Disposal fee \$1.0 / cu. Yd for drill and shoot rock	4165	4753	5047	5635
Increase in all storm drainage pipe by 6 in.	1040	1170	1430	1560
Increase in reinforced concrete pipe quantity by 15%	1360	1615	1700	1700

Positive risk elements	a	b	c	d
Non-Estimation Risks				
Schedule Acceleration	5250	6750	7500	8625
DBE by 20%	800	900	1000	1150
Design Growth (e.g. bigger cuts, more bridges)	3000	5100	6600	7500
Design or approval delays	2800	3600	4400	5200
Regulatory Agencies	3750	4750	5250	6000
Disposal of excess materials	4250	4750	5000	5500

Similarly, the negative risks' elements were generated as shown in Table 5. 5. The negative risks (or threats) are classified into two types: 1) risks associated with estimation, and 2) risks not associated with estimation risks. The negative risks are very important in contingency estimation since they contribute negatively to the estimate of the contingency for it decreases the total project's contingency.

Table 5. 5 UHCOC Negative Risks Data Input

Negative Risk Elements	a	b	c	d
Estimation risks				
Less remedial excavation in lieu of wick-drain pipe	-300	-300	-297	-285
Less retaining walls and pilings under retaining walls	-4600	-4200	-3800	-3200
Negative Risk Elements				
Fatten Slopes on site waste from drill and shoot rock	-3000	-3000	-2700	-2400
Less tire/track/repair cost	-1265	-1133	-1067	-935

Less equipment maintenance cost	-1404	-1260	-1140	-996
Piling reduction by 6ft per pile under bridge	-900	-900	-873	-720
Replace 78R-value rock with 50R-value rock	-2415	-2300	-2185	-1725
Non-Estimation Risks				
Schedule Deceleration	-5750	-5000	-4750	-3750
Less design approval delays	-2600	-2200	-1800	-1400

Based on the negative and the positive risks' data shown in Table 5. 4 and Table 5. 5, the project contingency was estimated as shown in Fig. 5. 5. The positive risks' elements represent package 1 (P_1) and the negative ones represent package 2 (P_2) while each cost item represents a risk (R_i).

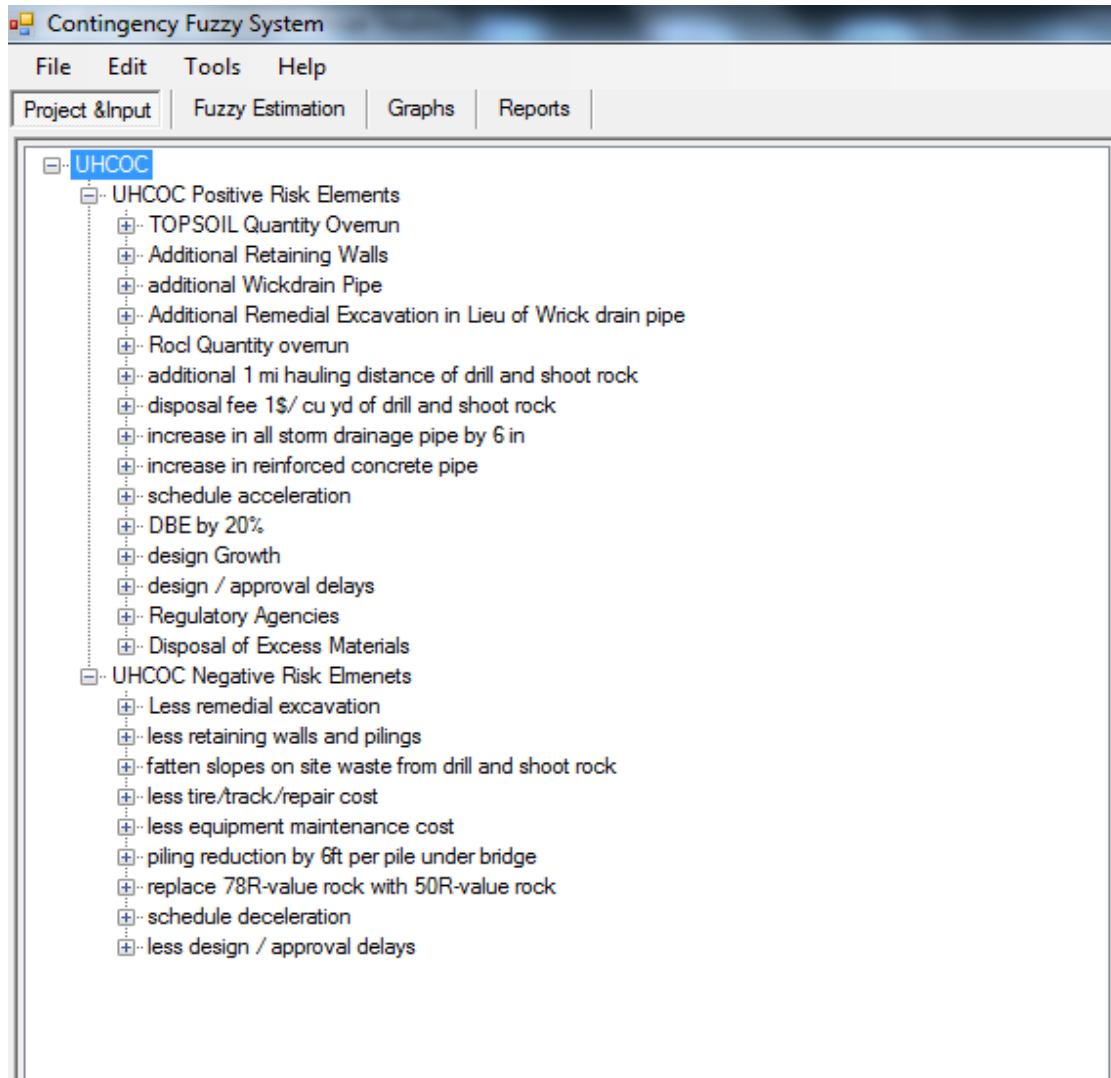


Fig. 5. 5 Data Input of UHCOC Project Case Study

The total contingency is equal the difference between the contingency needed to mitigate the impact of positive risks and negative risks.

$$TC = TC_{Positiverisks} - TC_{negativerisks} \quad (5.7)$$

But since, the negative risks values were modified to be negative fuzzy numbers this allows the use of the same contingency estimating formula that was used in the first case study:

For Packages:

$$\text{Contingency (Pj)} = \sum_{i=1}^n \text{Contingency(Ri)} \quad (5.8)$$

While total contingency could be calculated as follows:

$$\text{TC} = \sum_{j=1}^m \text{Pj} \quad (5.9)$$

The Pj is the package's estimated contingency which equals a positive fuzzy number for the threats and a negative fuzzy number for the opportunities. The results of this case study are shown in Fig. 5. 6.

The calculated fuzzy estimate (TC) of UHCOC Project is the following fuzzy number:

[13,955,000; 25,356,000, 33,150,000, 43,029,000]

The expected value of the positive risks, calculated by using the expected value's formula of the trapezoidal fuzzy number, is \$ 48 007 750, and that of negative risks is \$ 19 135 250

The estimated contingency's expected value of UHCOC Project could be calculated using the equation (5.7) as follows:

$$\text{Contingency (UHCOC)} = 48,007,750 - 19,135,250 = \underline{\$ 28,872,500.}$$

report of :UHCOC								
Project Name	Package Name	Item Name	Fuzzy Estimation	Item Fuzzy Rep.	Package Fuzzy Rep.	ProjectFuzzy Rep.	Expected Value	variance
		schedule accelerat		[5250 , 6750 , 7500 , 8625]			7031.25	221324.57386
		DBE by 20%	[800 , 900 , 1000 ,	[800 , 900 , 1000 , 1150]			962.5	10028.93519
			[3000 , 5100 , 660				962.5	10028.93519
		design Growth		[3000 , 5100 , 6600 , 7500]			5550	412500
			[2800 , 3600 , 440				5550	412500
		design / approval		[2800 , 3600 , 4400 , 5200]			4000	266666.66667
			[3750 , 4750 , 525				4000	266666.66667
		Regulatory Agenci		[3750 , 4750 , 5250 , 6000]			4937.5	91737.68939
			[4250 , 4750 , 500				4937.5	91737.68939
		Disposal of Exces		[4250 , 4750 , 5000 , 5500]			4875	67708.33333
					[36180 , 45649 , 51762 , 58440]		4875	67708.33333
							48007.75	9656609.11277
							-295.5	-381.25
		Less remedial exc		[-300 , -300 , -297			-295.5	-381.25
				[-300 , -300 , -285]			-3950	16018.51852
		less retaining walls		[-4600 , -4200 , -3			-3950	16018.51852
				[-4600 , -4200 , -3800 , -3200]			-2775	-25625
		fatten slopes on sit		[-3000 , -3000 , -2			-2775	-25625
				[-3000 , -3000 , -2700 , -2400]			-1097.75	3391.57703
		less tire/track/repai		[-1256 , -1133 , -1			-1097.75	3391.57703
				[-1256 , -1133 , -1067 , -935]			-1200	7536
		less equipment ma		[-1404 , -1260 , -1			-1200	7536
				[-1404 , -1260 , -1140 , -996]			-848.25	-14119.60598
		piling reduction by		[-900 , -900 , -873			-848.25	-14119.60598
				[-900 , -900 , -873 , -720]			-2156.25	-65692.03869
		replace 78R-value		[-2415 , -2300 , -2			-2156.25	-65692.03869
				[-2415 , -2300 , -2185 , -1725]			-4812.5	14612.26852
		schedule decelerat		[-5750 , -5000 , -4			-4812.5	14612.26852
				[-5750 , -5000 , -4750 , -3750]			-2000	66666.66667
		less design / appro		[-2600 , -2200 , -1			-2000	66666.66667
				[-2600 , -2200 , -1800 , -1400]			-2000	66666.66667
					[22225 , -20293 , -18612 , -15411]		-13135.25	-359516.59944
							13955.25356 , 33150 , 43029]	28872.5
								33572723.87896

Fig. 5. 6 UHCOC Case Study Report

The output summary of proposed method, PERT, and the method proposed by Paek (1993) is shown in Table 5. 6.

Table 5. 6 Comparison of Results (Case 2)

Method	Expected Value Formula	Total Project Estimation
Proposed Method	$\frac{a + b + c + d}{4}$	\$ 28, 872, 500
Paek (1993)	$\frac{V1 + V2}{2(W1 + W2)}$	\$ 28, 968, 350
PERT (Moselhi,1993)	$\frac{a + 4 \cdot \left(\frac{b+c}{2}\right) + d}{6}$	\$ 29, 292, 000

Where:

$$V1 = d^3 \cdot (d + 3 \cdot a - 3 \cdot c) - d^2 \cdot (4 \cdot a \cdot c + a \cdot c + b \cdot c) \quad (5.10)$$

$$V2 = a^3 \cdot (3 \cdot d - 3 \cdot c - a) + a^2 \cdot (4 \cdot c \cdot d + b \cdot d + b \cdot c) \quad (5.11)$$

$$W1 = d^2 \cdot (2 \cdot d - 7 \cdot a - c + 2 \cdot b) + 3 \cdot (a \cdot d) \cdot (b - c) \quad (5.12)$$

$$W2 = a^2 \cdot (7 \cdot d - 2 \cdot a - 2 \cdot c + b) - (b \cdot c) \cdot (d - a) \quad (5.13)$$

The itemized comparison of proposed method with PERT and Paek et al. (1993) proposed method shown in Fig. 5.7. The graph shows that differences among the three methods are relatively small and it is hard to distinguish between them except at some points they showed little difference which will be explicitly discussed in Chapter 6.

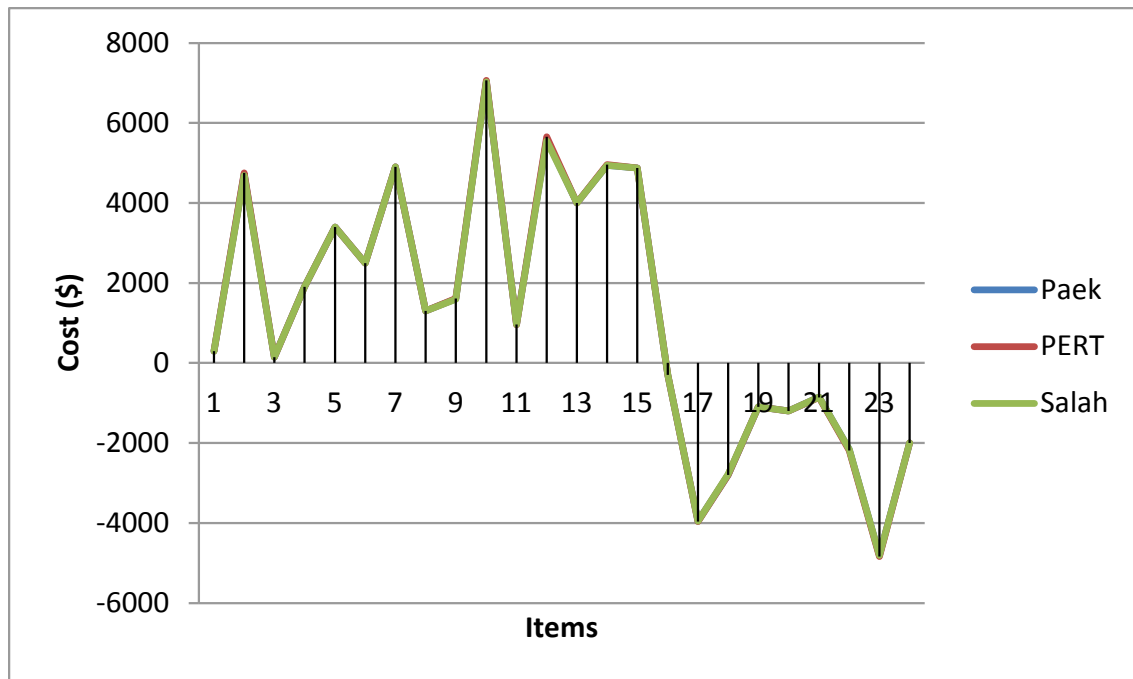


Fig. 5.7 Itemized Comparison

The results of the both case studies, as summarized in Appendix B, prove the validity and accuracy of the proposed method for contingency estimating.

For the contingency management, two case studies on depletion of contingency over project durations were analyzed in the literature review chapter supports the developed contingency management method on two fronts; 1) the inclusion of different depletion models, as well as, 2) the factors used in chapter three to provide the decision support for the selection of most suitable depletion curve.

In Chapter 6, the results of the contingency estimating and management obtained based on the proposed method are highlighted along with the advantages and limitations of the method.

CHAPTER SIX

RESULTS DISCUSSION

6.1 Introduction

Project managers are usually opposed to the introduction of new applications and tools. Typically the old “tired and true” methodology is more comfortable because of reasons such as: 1) complexity of new method, 2) time or resources consuming, difficulty to verify and the need for an experienced to apply the method. The proposed contingency estimating method was designed with the end user in mind. The proposed method is easy to use while still remaining: 1) accurate, 2) fast, 3) verifiable, and 4) applicable without the historical data records. In addition, the coded user-friendly tool generates dual analytical and graphical outputs that support the project managers’ decision making.

Furthermore, the proposed contingency management method gives a wide range of possibilities to deplete contingency with any convenient strategy (aggressive or passive) based on the project manager skills and company’s policy. The tailored depletion (custom depletion) curve increases the of project managers control over depleted contingency compared to the estimated contingency at any milestone. This comparison provides significant information about contingency depletion performance.

In this chapter, the results of the selected case studies will be discussed and a comparison, based on the relative error, between the proposed contingency estimating’s method and other methods will be presented. Furthermore, the limitations of the proposed method, advantages, and disadvantages over the other methods will be identified. Also, the

possible improvement of the proposed method will be suggested to satisfy the project managers' expectations.

6.2 Contingency Estimating

The results of proposed method compared to results of the considered case studies MCS, and PERT shown in Table 5.2 and Table 5. 6 were found to be similar. In addition, relative error between NEST, UHCOC, MCS and PERT and proposed method are:

$$\text{Err}_{\text{NEST}} = \frac{\text{EV}_{\text{NEST}} - \text{EV}_{\text{PM}}}{\text{EV}_{\text{NEST}}} = 1.67\%$$

$$\text{Err}_{\text{UHCOC}} = \frac{\text{EV}_{\text{UHCOC}} - \text{EV}_{\text{PM}}}{\text{EV}_{\text{UHCOC}}} = 0.33\%$$

$$\text{Err}_{\text{PERT}}(\text{NEST}) = \frac{\text{EV}_{\text{PERT}} - \text{EV}_{\text{PM}}}{\text{EV}_{\text{PERT}}} = 1.9\%$$

$$\text{Err}_{\text{MCS}}(\text{NEST}) = \frac{\text{EV}_{\text{MCS}} - \text{EV}_{\text{PM}}}{\text{EV}_{\text{MCS}}} = 9.9\%$$

$$\text{Err}_{\text{PERT}}(\text{UHCOC}) = \frac{\text{EV}_{\text{PERT}} - \text{EV}_{\text{PM}}}{\text{EV}_{\text{PERT}}} = 1.4\%$$

Where; EV_{PM} is the expected value of proposed method, EV_{PERT} is expected value of same case study calculated by PERT method, EV_{NEST} is expected value of NEST case study calculated using Shaheen et al. (2007) proposed method, EV_{MCS} is expected value of the Monte Carlo Simulation calculates by Shaheen et al. (2007), and EV_{UHCOC} is expected value of UHCOC case study calculated using Paek et al. (1993).

The above results show that the proposed method is an effective contingency estimating method. In addition, the relative errors of the proposed method and PERT (1.9 % and 1.4%) in both case studies were acceptable. However, the relative error of the proposed

method and Monte Carlo Simulation (500 iterations) is relatively high (9.9%) but still within the acceptable range (<10%). This indicates the accuracy and indicates usefulness of the proposed method.

The advantages introduced in this discussion prove that the proposed method is:

- Accurate compared to other methods.
- Simple, given it has no complicated calculations involved and it is supported by a user-friendly computer aided tool which eliminates the need to an experienced user.
- Supportive and informative method, since it offers a set of indices and measures that address vagueness and imprecision associated with estimated cost at the cost item, work package and project levels, as well as possibility of having project cost at a specific crisp value or within a specified cost range.
- Need-less resources, since it doesn't require historical data records to construct probability density functions for the cost items involved and it doesn't require large simulation.
- Direct and flexible. Since it offers multiple options to introduce convenient estimation based on expert's experience without any restriction on the input shape (i.e. the expert can use null, crisp, uniform, triangular, and trapezoidal fuzzy number). This eliminates the expert's subjectivity and his gut-feel estimation.

The disadvantages are limited since all the disadvantages are related to the proposed method's assumptions:

- Assumption 1: This assumption was considered for the automated tool that coded using VB.NET. This tool assumed three levels (item, package, and cost) of Risk

Break down Structure only. In reality, this can be insufficient for a mega project that may include several packages, sub-packages, and multi-level risks.

- Assumption 2: All risks associated with investigated project assumed to be identified; however the unknown risks cannot be estimated because it will be identified just when they happen.
- Assumption 3: the proposed method assumed that risk is represented by one of the four types of fuzzy numbers. However, the membership of a fuzzy number can have any shape.

Based on the aforementioned assumptions, the proposed method is able to: 1) deal with identified risks only, 2) incorporate limited types of fuzzy representation, and 3) consider three levels of risk breakdown structure only.

6.3 Contingency Management

The proposed method for contingency management was generated from current practice. Usually, the company's experience and the learned lessons from similar projects in the past generate the company's practice in contingency management. The contingency depletion procedure currently followed by companies is governed by several factors such as: 1) project manager's strategy (i.e. passive or aggressive), 2) the project type and complexity (i.e. infrastructure, airport), 3) the project delivery system and contract type (i.e. traditional, fast track, GMP), and 4) the company's financial capacity.

The factors affected the contingency management and depletion, were considered in the proposed method. In addition, the proposed tailored depletion (custom depletion) curve is a new procedure to deplete, manage, and control the project contingency. This procedure

presents an effective and comparative tool of depleted contingency versus estimated contingency and gives ability to monitor and control them at any contingency milestone. However, the proposed depletion curves have different advantages and disadvantages based on different factors. Therefore, a flexible selection procedure, based on the IF-AND-THEN approach, was proposed. The selection procedure changed based on the aforementioned factors affecting the contingency depletion.

It is noted that actual depletion curve is also associated with unknown risks which may occur over project durations. The occurrence of unknown risks or unforeseen risks may affect the shape of depletion curve un-predictably.

The flexibility of the proposed method and selection procedure can overcome the current practice's limitations or assumptions. This procedure is based on the project characteristics and the actual factors affecting project's contingency depletion such as : 1) the available information (i.e. project type, details, risks type, financial capacity, learned lessons and experience etc...), and 2) the project manager's preferred strategy in contingency depletion (i.e. passive or aggressive).

The subjectivity involved in decision making of a contingency depletion curve selection can be considered as a limitation since it is related to the reliability and availability of information. Otherwise, it is a useful and supportive methodology since it increases ability the ability of project manager to check contingency depletion performance at any milestone as shown the selected case studies.

Finally, the proposed method for contingency management can be followed and applied instead of the current practices. The proposed method decreases the decision making

subjectivity, eliminates the trial and error intentions, and offers an effective selection procedure based on reliable information (i.e. company's past experience and learned lessons).

The chapter 7 includes: 1) summary of this research contributions, 2) conclusions about the proposed methods, 3) few future research recommendations.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This study presents a contingency estimating method based on fuzzy set theory. The methodology encompasses three major fronts; 1) assessment of contingency which represents the cost items associated with the project by fuzzy numbers based on experts' judgement, 2) application of fuzzy set theory on input in order to calculate the fuzzy representation at cost item, package, and project levels, and 3) defuzzification of the calculated fuzzy numbers using one of the defuzzification methodologies (i.e. center of area) in order to estimate the contingencies represented by these fuzzy numbers.

As well, an automated computer application called Contingency Fuzzy System Software (CFSS) was developed. CFSS was coded using VB.net to automate the application of the developed method. The developed software allows contingency estimators and the contingency managers to evaluate and monitor contingency at the work package and project levels. The outputs reports generated by the CFSS are detailed and informative which increases the project manager's ability to address the contingency analytically and graphically using a wide range of scenarios pertinent to contingency estimating and management over project duration.

New contingency management methodology is introduced; based on "tailored/custom depletion" curve and the depletion curve selection procedure. The depletion baseline

improves contingency management efficiency and facilitates its monitoring and controlling over project durations. The methodology allows for the utilization of five different types of depletion curves: 1) Linear, 2) Basic/S-Curve, 3) Back-End Loading, 4) Front-End Loading, 5) Tailored or custom. The first four curves are identified from the subjective practice of the project managers and companies based on their past experience. The selection procedure, using the IF-AND-THEN type approach, is introduced based on several factors such as; project type, project manager strategy, company financial support, risk impact, and severity as well as rate of occurrence. Actual case studies were analyzed to demonstrate the accuracy and usefulness of the proposed method for contingency estimating. Two case studies drawn from literature were analysed in order to support the decision for the selection of the most suitable depletion curve. The case studies results were discussed based on comparison among the proposed methods and those commonly used in literature. In this chapter, contributions of this research, conclusions, and some recommendations for future research will be presented.

7.2 Research Contributions

The contributions made in this research consist of a comprehensive study of contingency estimating and management method and the development of contingency estimating and management methods. The development made in this research includes:

- New method for contingency estimating based on fuzzy set theory
- Automated software used to estimate, monitor and control contingency at the work package and project levels.

- New method for contingency management based on risk-driven contingency depletion over project durations.
- Depletion curve selection procedure based on a set of impact factors and the use of IF-AND-THEN type approach.
- Documentation of current practice in contingency management based on company policies, project manager's experience, and management skills.

7.3 Conclusion

In this thesis, estimating contingency using fuzzy set theory was proven to be effective and does not require large data as in the case of computer simulation. The results obtained using the developed method are comparable to those generated by other methods such as: 1) PERT, 2) the method of Shaheen et al. (2007), 3) the method of Paek et al. (1993), and 4) Monte Carlo Simulation. The use of fuzzy set theory has an advantage of providing easier, faster, and reliable output, with the capacity to examine a wide range of scenarios; some cannot be considered using any probability-based method. The collection of data from experts using proposed procedure will encourage them to express their knowledge using different formats (e.g. crisp fuzzy number, triangular fuzzy number). The analysed case studies (NEST and UHCOC) along with their results confirmed validity and accuracy of the proposed contingency estimating method.

Similarly for the contingency management, the analyzed case studies proved usefulness of the proposed method for contingency management and its depletion over project durations. The proposed method helps to establish a systematic methodology for

contingency depletion, based on the depletion curves extracted from the common practice and the consideration of past experience of the organizations involved.

The depletion curve selection procedure also is flexible in selecting suitable planned depletion curve for projects based on several risk-driven impact factors. The proposed selection approach (IF-AND-THEN) combines project factors, management skill factors, risk factors, and company factors (e.g. financial capacity) in search of reasonable, logical, and systematic contingency depletion curve selection.

7.4 Future Work

Based on the subjects' richness and the needs associated with contingency management and estimating subjects, the following is recommended for future work:

- 1) Improving contingency estimation automated tool by implementing multi-level risk activities with multi-level of risk breakdown structure (e.g. more than three);
- 2) Methods generalization could be done by considering additional fuzzy number shapes with different membership functions; and
- 3) The contingency estimating method can be re-compared to the Monte Carlo Simulation with different probability density function and number of iterations.

This work is certain to become the basis for a considerable number of valuable research studies.

- 4) The developed contingency management method can be applied to a real project to measure its effectiveness.

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APPENDICES

Appendix A: Extracts from in Use Policies on Contingency Management


A.1 Attachment F - Approval Requirements for Contingencies and Supplemental Work (Source: <http://www.dot.ca.gov/hq/construc/sw/approvaltable.html>)

	State Project	FHWA Delegated Project	High Profile Project
Contingencies greater or less than standard 5%	1	1 & 2	1 & 2
Justification for Supplemental Work Items Memorandum	3	3	3
Supplemental Work non-excluded items greater than 5% and less than 10%	4	4	4
Supplemental Work non-excluded items greater than or equal to 10%	5	5 & 6	5 & 6
Supplemental Work Items: On FHWA pre-approved supplemental work items list	7	7	8
Supplemental Work Items: On acceptable supplemental work items list	7	7	9
Supplemental Work Items: Not on FHWA pre-approved supplemental work items list or acceptable supplemental work items list	10	10	11

Note:

1. District director requests approval from Chief Engineer
2. FHWA concurrence for contingencies greater than 5 percent and the increase in contingencies is greater than \$200,000
3. Justification of supplemental work items memorandum completed for every project by the project engineer
4. District director approves requests
5. District director requests approval from chief, Division of Construction
6. FHWA concurrence must be obtained when total cost of expected non-excluded supplemental work items exceeds 10 percent and is greater than \$200,000
7. No approval of the justification of supplemental work items memorandum is required
8. FHWA supplemental work approval letter attached to justification for supplemental work items memorandum
9. FHWA supplemental work approval letter attached to justification for supplemental work items memorandum and non-federal funding source must be identified for supplemental work items not approved by FHWA
10. District director requests approval from chief, Division of Construction
11. District director request approval from chief, Division of Construction. Attach to request FHWA approval for non-listed item or non-federal funding source must be identified for supplemental work items not approved by FHWA

A.2 Orange County Public Schools: Request of Use GMP Contingency
 (Source:<https://www.ocps.net/fa/manual/Documents/>)

	Request For Use Of GMP Contingency		CP
	FACILITIES SERVICES	PROCESS & PROCEDURES MANUAL	542

School Name:		Request No.:	
Project Name:			
OCPS Project No.:		Requested Funding Source:	
Architect/Engineer:		OCPS FPM initial adjacent to appropriate box:	
Contractor/CM @ Risk:		<input type="checkbox"/>	GMP CM Contingency
Contractor/CM Address:		<input type="checkbox"/>	GMP Owner Contingency
OCPS Facilities Proj. Manager:			
Scope of Work:			

Construction Manager Contingency – Total Amount

Owner Contingency – Total Amount

Description:	Quan.	Unit	Labor Unit Cost	Labor Cost	Mater. Unit Cost	Mater. Cost	Subcontractor Cost	Equip. Cost	CM Mark-up	Total Cost
SUBTOTAL										
Sales Tax										
TOTAL (NOT TO EXCEED)										

Approvals:

OACR/ Project Manager
 ≤ \$5,000 _____
 Date: _____

OCPS Sr. Facilities Manager
 > \$5,000 ≤ \$ 10,000 _____
 Date: _____

OCPS Facilities Program Dir.
 > \$10,000 ≤ \$25,000 _____
 Date: _____

Requestor:
Construction Manager/Contractor:

Company Name/Print

_____ Date: _____

By Signature / Title

Approval:
 OCPS Chief Facilities Officer
 > \$25,000 ≤ \$50,000 _____
 Date: _____

NOTE: Attach "GMP Contingency Log" as part of this Request For Use Of GMP Contingency (CP 542, Page 2).

GMP CONTINGENCY LOG

School/Name: _____	Starting Balance		
Project No.: _____	Balance Remaining		

No.	Date	Description	Cost	CM Contingency Balance	Owner Contingency Balance	Approval	Reason

STATES OF JERSEY



CONTINGENCY ALLOCATION: POLICY

**Presented to the States on 30th January 2012
by the Minister for Treasury and Resources**

STATES GREFFE

Introduction

The Allocation to Contingency is a fundamental part of the Medium Term Financial plan, as it gives the States a degree of flexibility in managing its finances over a longer time period. The use of Contingency expenditure is set out in the Public Finances

(Jersey) Law 2005 (Article 17).

There are a number of different ways the Allocation to Contingency can be made, as set out below –

- Amounts set as part of the Medium Term Financial Plan.
- Allocations from growth expenditure, as approved by the States as part of the annual budgeting process.
- Transfers from a head of expenditure within or after a financial year, if approved by the Minister for Treasury and Resources (and if the Minister responsible for the head of expenditure has approved the transfer).
- Allocations from revenue heads of expenditure under-spends that are not carried forward.
- Allocations from departmental income that are in excess of expectations.

There is a clear requirement to set out a policy to be considered alongside the submission of the Medium Term Financial Plan. In advance of this, it is useful to set

out how the new policy might be constructed by the Minister for Treasury and Resources.

What types of expenditure can come out of the Allocation to Contingency?

Contingency is set aside for unforeseen expenditure. It is proposed that 3 types of expenditure will come out of Contingency.

- **Permanent and Non-Repayable** – expenditure that is due to a change in circumstances or service requirements. The submissions for these allocations can be unlimited but cannot exceed the current balance of Contingency.
- **Short Term and Repayable** – expenditure that arises from departmental opportunities for ‘Invest to Save’ initiatives that arise outside of the Medium Term Financial Plan and which cannot be funded within departmental cash limits. Limits may be set in the MTFP on the individual and total values of this type of expenditure.
- **Variations in Expenditure that have a ‘Net Nil’ impact** – expenditure that may require variation between heads of expenditure (other than the need to comply with Generally Accepted Accounting Principles). These will have no overall impact on the Contingency balance, but will be reported publicly as part of reporting on all transfers to and from Contingency as required by the Law.

Proposed Allocation Process

A **Department** must present a case to the Treasurer of the States which explains:

- The nature of the expenditure and the reason it has arisen.
- Whether the expenditure is likely to recur and how future years will be funded.
- Why the expenditure cannot be absorbed within current limits – this should refer to the most recent in-year financial monitoring report, including current forecasts to out-turn and whether departmental contingencies have been used or why other services can’t be reprioritised. The role of the **Treasurer of the States** will be to challenge the request, ensure a solution to its ongoing funding has been considered and that due process has been followed. This will then be considered by the Minister for Treasury and Resources, and a report will be submitted to the Council of Ministers with a recommendation.

The Council of Ministers will consider the request, taking into account the Department’s submission and the Treasurer of the States’ and Minister for Treasury and Resources’ recommendation.

Minister for Treasury and Resources approval:

- The Minister will take into account the comments of the Council of Ministers.
- The Minister for Treasury and Resources will either –
 - ◆ refer unsuccessful requests back to the originating Department; or
 - ◆ approve a “public” Ministerial Decision for successful requests.

All relevant papers will be used to support the decision, including the Council of Ministers’ recommendation and the Ministerial Decision of the requesting department.

- All approved requests will be published by the Minister for Treasury and Resources and presented to the States on a 6 monthly basis.

A.5 Memorandum for Trail Project Construction Contingency, City of SAN JOSE

COUNCL AGENDA: 12-15-09
ITEM: 2.15



Memorandum

TO: HONORABLE MAYOR
AND CITY COUNCIL.

FROM: Katy Allen

SUBJECT: TRAIL PROJECT
CONSTRUCTION CONTINGENCY

DATE: 11-23-09

Approved

Date

11/30/09

COUNCIL DISTRICT: Citywide

RECOMMENDATION

- (a) Adopt a resolution amending City Council Policy No. 1-18, "Operating Budget and Capital Improvement Program Policy," to establish a ten percent construction contingency for Capital Improvement Program trail projects.
- (b) Adopt a resolution amending the authority delegated to the Director of Public Works under Resolution Nos. 72943 and 73532 (Streamlining the Award of Public Works Construction Contracts) to incorporate the contingency amounts specified in City Council Policy No. 1-18

OUTCOME

Approval of the recommendation would amend the existing capital project contract contingency policy to increase the contingency *for trail projects only* from 5 percent to 10 percent. Contingencies previously established for other project types will remain the same. Increasing the trail project contingency will help improve the cost effectiveness and timeliness of project delivery and conform with industry standards.

BACKGROUND

A project contingency is established at the time of contract award in order to provide funding to resolve unforeseen issues and to allow for continuity of construction when unexpected circumstances are encountered. When there is unspent contingency on the completion of a project, the unspent money is returned to the funding source to fund other projects. On the project level, under-funding the contingency can result in contract delays if unforeseen circumstances arise. On the program level, over-funding the contingency can unnecessarily tie up construction funds.

In November 2002, Council approved a comprehensive Contract Contingency Policy for Capital Improvement projects. This policy established a contingency in an amount equivalent to *five percent of the total contract amount for street, sidewalk or park projects*. Currently, trail

projects fall under the category of park projects and receive a five percent contingency at the time of contract award. As noted, any deviation from the established policy amount must be approved by Council on a project-by-project basis.

ANALYSIS

Fifteen trail projects have been awarded under the park projects category since the adoption of the Contract Contingency Policy for Capital Improvements. Although the five percent standard contingency remains sufficient for most park projects, trail projects have proven to be of higher complexity. Because the majority of trail projects require excavation for highway or bridge under-crossings, ramp structures and/or pedestrian bridges, the unforeseen issues that arise during construction are more closely associated with those found on utility or building (foundation) projects than on park projects. The following table lists the contingency used on the 15 trail projects awarded since 2002.

TABLE 1: San Jose Trail Projects 2002 – 2009

Base Contract Amount	Number of Trail Projects	Contingency Used		
		0 to 5 %	> 5 % to 10%	> 10%
Under \$1 Million	12	5	6	1
Over \$1 Million	3	1	0	2
Total	15	6	6	3

As shown above, 9 out of 15 trail projects exceeded the standard five percent contingency. Of the nine projects exceeding the standard contingency, seven of those projects had a base contract amount under \$1 million. When the contract amount is less than \$1 million, the streamlining policy approved by Council authorizes the Public Works Director to award the project. This delegation of authority was implemented to save time and money. However, when the recommended contingency exceeds the policy level of five percent, the project must go to Council for approval, negating any time and/or cost savings that may have been realized. In cases where construction is underway, the impacts can be even greater as construction may be disrupted. If the recommended ten percent contingency is adopted for trail projects, projects under \$1 million could be streamlined so long as the approved project budget is not exceeded.

A recent survey of California municipalities also indicates that a ten percent contingency is within industry standards. In June 2009, 35 California cities responded to an informal request for information on municipal change order policies (contract contingencies). The following table summarizes those responses.

	No. of Cities	Contingency (Percentage of contract cost)				
		10%	15%*	20%*	25%*	Other**
Formal Policy	22	13	1	1	3	4
No Policy (or Informal Policy)	13	2	-	-	-	8
Total	35					

* Percentage is based on a "Not to Exceed" amount.

** Contingency is either an established "Not to Exceed" amount for all contracts or is determined on a per project basis when going before city council for funding approval.

While many of the responding cities have smaller capital programs than San José, the response clearly indicates that the majority of municipalities that do have a formal policy establish a ten percent contingency as a percentage of the contract amount.

Amending the City of San José Capital Project Contract Contingency Policy as recommended will create a separate and distinct category for trail projects and establish an industry standard ten percent construction contingency for all future trail projects.

In order that the Public Works Director may utilize contingency amounts authorized in the Contingency Policy for all projects being awarded pursuant to the streamlining policy, it is also recommended that the streamlining policy be amended to incorporate all contingency amounts specified in the Contingency Policy, as such amounts may be amended from time to time.

EVALUATION AND FOLLOW-UP

This policy change conforms to the Public Works performance measurement for on-time, on-budget project delivery.

If Council adopts this resolution adjusting the construction contingency policy from five to ten percent for trail projects, then no further action through Council or Committee will be required.

PUBLIC OUTREACH/INTEREST

- Criterion 1:** Requires Council action on the use of public funds equal to \$1 million or greater. **(Required: Website Posting)**
- Criterion 2:** Adoption of a new or revised policy that may have implications for public health, safety, quality of life, or financial/economic vitality of the City. **(Required: E-mail and Website Posting)**

HONORABLE MAYOR AND CITY COUNCIL
11-23-09
Subject: Construction Contingency for Trail Projects
Page 4

- Criterion 3:** Consideration of proposed changes to service delivery, programs, staffing that may have impacts to community services and have been identified by staff, Council or a Community group that requires special outreach. **(Required: E-mail, Website Posting, Community Meetings, Notice in appropriate newspapers)**

Approval of this recommendation does not constitute a policy change that financially impacts public expenditures and does not meet any of the criteria above. This memorandum will be posted to the City's website for the December 15, 2009 Council agenda.

COORDINATION

This memorandum has been coordinated with the Parks, Recreation and Neighborhood Services Department, the City Attorney's Office and the City Manager's Budget Office.

CEQA

CEQA: Not a project.

/s/

KATY ALLEN
Director, Public Works Department

For questions please contact DAVE SYKES, ASSISTANT DIRECTOR, at 535-8300.



NAVAL SPECIAL WARFARE COMMAND

N44 FACILITIES ENGINEER BULLETIN

Issue No. 2008-01

10 June 2008

Type: Policy

Subject: Control of MILCON Contingency Funds and Release Authority

1. Purpose.

a. This bulletin sets policy and procedures for the use of MILCON contingency funds and the associated approval level required for use of those contingency funds for all Naval Special Warfare Command (NSWC) MILCON projects.

2. Background.

a. The United States Special Operations Command (USSOCOM) Directive 415-1 directs that for MILCON projects as part of the funding at award that amounts be provided for contingency and management of reserve. These contingency funds are to be used as required for changes to the construction and must have component (NSWC) level approval. Approved change order should fall into one of the following three categories:

- (1) To correct design errors or unforeseen field conditions.
- (2) To correct fire, safety, health, or environmental deficiencies.
- (3) To correct deficiencies caused by mission changes.

b. At time of award the goal is to make available contingency funds in the amount of 5% of the award contract amount. At times due to budget constraints, following consultation between the NSWC Program Manager and the executing Command Project Manager, the amount may be adjusted down to 2-3%, in order to keep the project within the Program Amount authorized by the U.S. Congress. Additionally it is the prerogative of USSOCOM to withhold contingency in varying amounts, in order to manage the overall SOCOM MILCON Program and to provide flexibility to quickly reassign funds between projects. HQ USSOCOM/SOCS-EN will send advance notice when this action is needed in any particular Fiscal Year.

c. In the past, NSWC has had an unwritten policy that use of contingency funds by the executing Command (NAVFAC or ACOE) requires the advance approval by either the NSWC Component Command Facility Engineer or by the NSWC MILCON Program Manager, depending on funding levels as follows:

- (1) Construction Changes less than or equal to \$25,000 – Approval by the Component Command Facility Engineer (NSWC Group One, NSWC Group Two, NSWC Group Three, NSWC Group Four, and NSWC Center).
- (2) Construction Changes greater than \$25,000 – Approval by the NSWC MILCON Program Manager.

3. Policy.

(a) Use: The use of contingency funds shall comply with the three categories of uses listed in USSOCOM Directive 415-1:

- (1) To correct design errors or unforeseen field conditions.
- (2) To correct fire, safety, health, or environmental deficiencies.
- (3) To correct deficiencies caused by mission changes.

NSWC Component Command Facility Engineers have latitude to interpret which category applies and have authority to authorize the use of contingency funds for purposes that are demonstrated to be in compliance with the purposes of these three categories.

Contingency funds are not available simply to fund desirables, to fund new interpretations, or as a tool to maximize building product obtained.

(b) Approval Levels: Use of contingency funds by the executing Command (NAVFAC or ACOE) shall have the advance approval by either the NSWC Component Command Facility Engineer or by the NSWC MILCON Program Manager, depending on funding levels as follows:

- (1) Construction Changes less than or equal to \$25,000 – Approval by the Component Command Facility Engineer (NSWC Group One, NSWC Group Two, NSWC Group Three, NSWC Group Four, and NSWC Center).
- (2) Construction Changes greater than \$25,000 – Approval by the NSWC MILCON Program Manager (MPM).

(c) Required supporting data: The attached 3-part form shall be filled out and executed for each contingency funds use requests in the order detailed below:

- (1) The executing Command Project Manager (PM) shall document the need for each use of contingency funds, by providing a description of the situation requiring additional funds, providing an independent government estimate of the cost or a detailed proposal from the contractor, and shall verify the rate and amount of SIOH that applies. The PM shall provide this

information using the attached 3-part form, filling out the top project information section and part 1, PM Validation Request section. The PM will forward the completed attached 3-part form with government estimate or contractor proposal to the NSW Component Facility Engineer (CFE) for validation and approval.

- (2) The CFE shall document on the 3-part form in Part II the category that the proposed contingency funds usage will fall under and whether they concur with the need, will verify that enough contingency funds remain, and indicate approval for use of funds with their authority by signing Part II.
 - (3) For requests of contingency funds greater than \$25,000, the CFE shall forward the 3-part form, with Parts I and II filled out to the WARCOM N44 MPM for review, check of contingency funds availability and balance, and for concurrence approval.
- (d) Notifications: The following email notifications are required.
- (1) For Construction changes less than or equal to \$25,000: Upon determination that the use of contingency funds are valid for one of the three approved categories of uses and that funds are available, the CFE shall forward the 3-part form, with Parts I and II filled back to PM, with a copy to the WARCOM N44 MPM.
 - (2) For Construction changes greater than \$25,000: Upon determination that the use of contingency funds are valid for one of the three approved categories of uses and that funds are available, the WARCOM N44 MPM shall forward the 3-part form, with Parts I, II, and III filled back to both the Component Facility Engineer and the PM.
- (e) Conformed Contract Modification Copies: The executing Command Project Manager shall ensure that the Contract Specialist involved in the action forward a pdf copy of the conformed contract modification to both the NSW Component Facility Engineer and the NSW MILCON Program Manager.

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Force Civil Engineering
COMNAVSPECWARCOM

A.7 Typical Contingency Drawdown from Managing Major Projects (MMP), (Source: <https://managingmajorprojects.com>)

TYPICAL CONTINGENCY DRAWDOWN PLAN				
#	Completion Milestone	Contingency		
		Contingency Amt '000	Drawdown % of total	Planned Completion Date
A	Engineering & Procurement			
1	Mechanical Eqpt Committed		4.00	
2	Electrical Tags Committed		1.00	
3	95% Instrumentation Tags Committed		4.00	
4	95% Piping Materials Committed		4.00	
5	Piping Isos 95% issued		2.50	
6	Engineering 95% Complete		7.50	
	Sub-Total Engineering			
B	Procurement			
7	95% Piping Spools Delivered		10.00	
8	95% E & I Bulk Matl Committed		4.00	
9	Substations Delivered		1.00	
10	Buildings Delivered		2.00	
11	Eqpt & Piping Modules Delivered		5.00	
	Sub-total Procurement		45.00	
B	Construction & Mech Completion			
1	Out of ground		5.00	
2	Modules set		6.00	
3	Equipment set		8.00	
4	Structural Steel Erected		5.00	
5	A/G Piping complete		15.00	
6	Final paving & Grading Complete		4.00	
7	Construction De-moblization		6.00	
8	Mechanical Completion		6.00	
	Sub-total Construction		55.00	
	TOTAL CONTINGENCY		100.00	

CC-06



Fig. A- 1 Typical Contingency Drawdown based on Activities

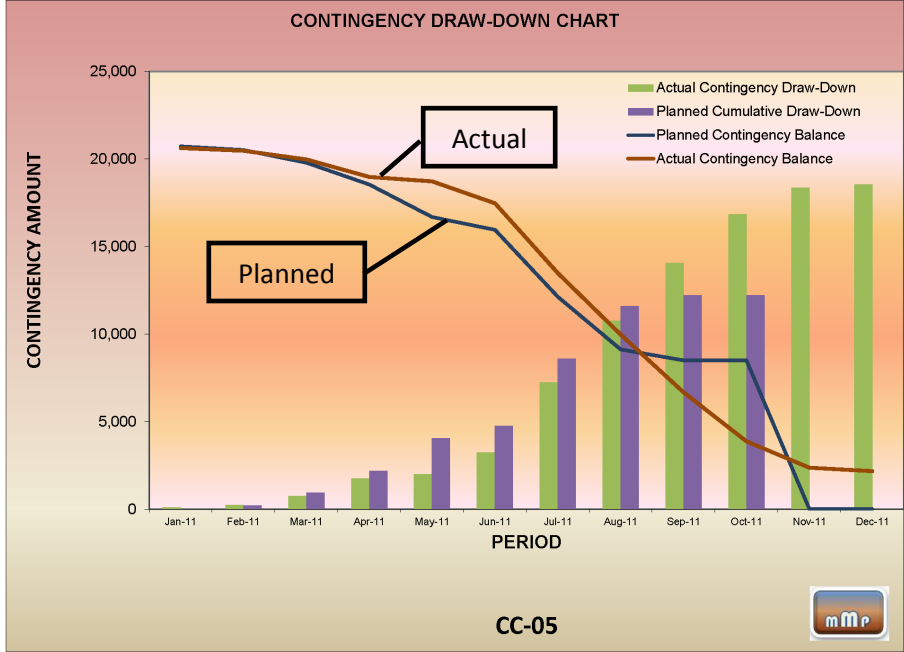


Fig. A- 2 Periodic Contingency Drawdown Curve: Actual vs. Planned

CONTINGENCY DRAWDOWN REPORT							
Month	Contingency \$ '000						
	Planned Incremental Drawdown	Planned Cumulative Drawdown	Planned Contingency Balance	Actual Incremental Drawout	Actual Cumulative Drawdown	Actual Contingency Balance	Actual Cumulative Drawdown
Total							

CC-07

Fig. A- 3 Contingency Drawdown Report

A.8 NASA presentation: “Risk-Weighted Cost Estimates Principles and practical Application”

**First Annual NASA
Project Management Conference**
March 2004

**RISK-WEIGHTED COST ESTIMATES -
PRINCIPLES
AND PRACTICAL APPLICATIONS**

Dr. Iqbal “Bob” Noor, P.E., CCE, PMP
Robert Martin, PMP
Paul Zimmermann, P.E., PMP

Entergy PMO LINK

Fig. A- 4 Risk Weighted Cost Estimates Principles and Practical Application (NASA)

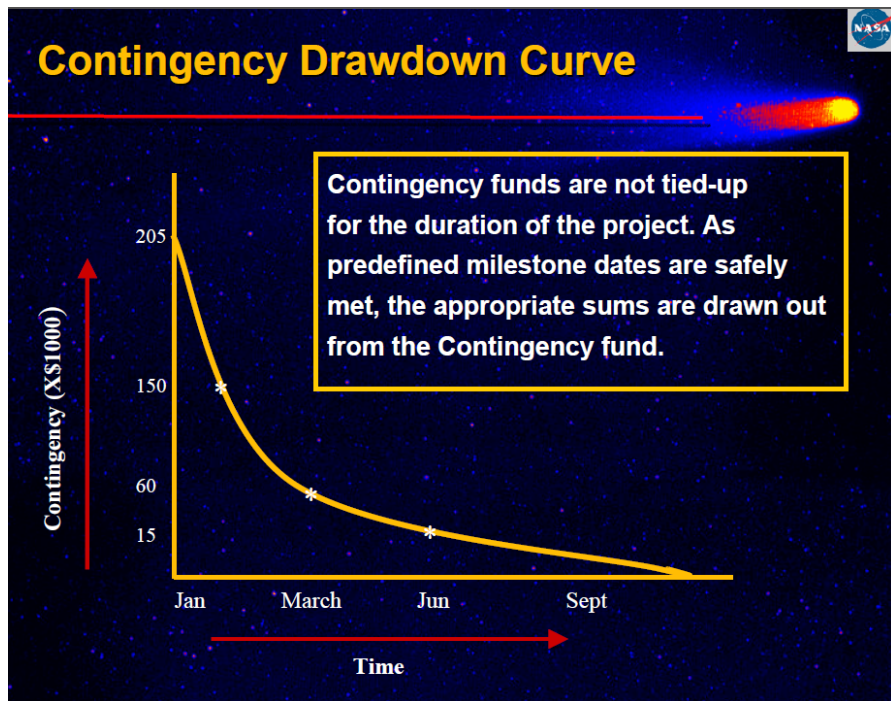


Fig. A- 5 Contingency Drawdown Curve and Project Milestones

Results - Capacitor Bank Project



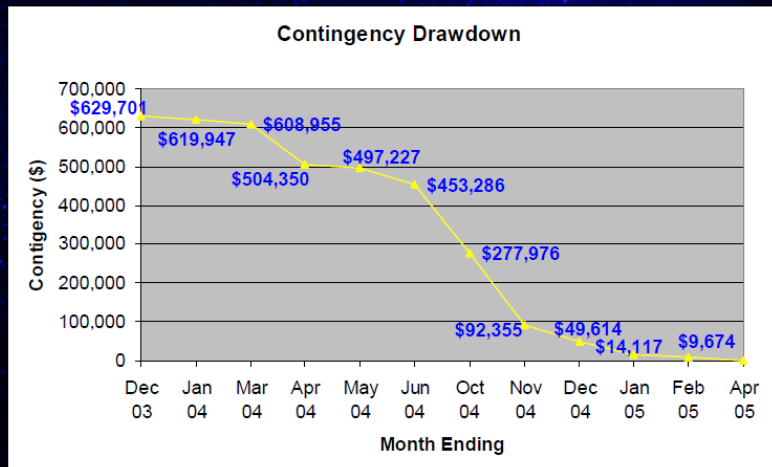
Base Cost Estimate	Post Peer Review Cost Estimate	Risk-Weighted Cost Estimate	Actual Final Project Cost
\$408,000	\$470,000	\$529,000	\$525,000

Major Risk Factors:

- Fault Current
- Mobile Transformer
- Cost of Additional Property
- Traps on Capacitor Bank to Block Carrier Signal
- Grounding Grid Additions

Fig. A- 6 Estimated Project Cost Post and Pre-Planning of Risks

Results - City of Jonesboro, AR



Managing Contingency through DrawDown Plots

Fig. A- 7 Project Contingency Drawdown

Appendix B: Data and Analysis Results for Contingency Estimating Case Studies.

Case Study 1: NEST Project – Fully Detailed Report

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
			[40,70,70,100]				70	150
		Mobilization- Move In		[40,70,70,100]			70	150
			[89,89,89,89]				89	0
		Power Installation		[89,89,89,89]			89	0
			[15,15,50,50]				32,5	102,08333
		Power-156Str.		[15,15,50,50]			32,5	102,08333
			[200,269,269,350]				272	939,5
		Excavate undercut		[200,269,269,350]			272	939,5
			[100,123,123,150]				124	104,38889
		Excavate Tail Tunnel to East		[100,123,123,150]			124	104,38889
			[80,80,80,80]				80	0

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
		Form and Pour Undercut		[80 , 80 , 80 , 80]			80	0
			[39,39,39,39]				39	0
		Form and Pour TailUndercut		[39,39,39,39]			39	0
			[100,120,120,150]				122,5	105,55556
		Form and Pour Shaft		[100,120,120,150]			122,5	105,55556
			[97,6,122,122,146,4]				122	99,22667
		Excavate Work Shaft		[97,6,122,122,146,4]			122	99,22667
	Main Work Shaft				[760,6,927,962,1154,4]		951	9974,98879
			[16,16,16,16]				16	0
		Excavate Access Shaft		[16,16,16,16]			16	0
			[44,44,44,44]				44	0

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
		Backfill Shaft and Install		[44 , 44 , 44 , 44]			44	0
	Access Manhole				[60,60,60,60]		60	0
			[1952,2142,5,2142,5,2910]				2286,75	42864,18056
		Tunnel and Install Segments-866m		[1952,2142,5,2142,5,2910]			2286,75	42864,18056
			[0,08,0,13,0,13,0,14]				0,12	0,00017
		Patch and Rub Tunnel Crown		[0,08,0,13,0,13,0,14]			0,12	0,00017
			[0,16,0,19,0,19,0,22]				0,19	0,00015
		Patch and Rub Tunnel-Final Cleanup		[0,16,0,19,0,19,0,22]			0,19	0,00015
			[0,01,0,01,0,01,0,01]				0,01	0
		Spoil Removal		[0,01,0,01,0,01,0,01]			0,01	0
	Tunneling(866m)				[1952,25,2142,83,2142,83,2910,37]		2287,07	42873,12007

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
			[61,61,61,61]				61	0
		Access Manhole Shaft		[61,61,61,61]			61	0
	Access Manhole Shaft				[61,61,61,61]		61	0
			[1704,1870,1870,2540]				1996	32648,66667
		Tunnel and Install Segments(756 m)		[1704,1870,1870,2540]			1996	32648,66667
			[0,01,0,13,0,13,0,14]				0,103	0,00087
		Patch and Rub Tunnel Crown		[0,01,0,13,0,13,0,14]			0,103	0,00087
			[0,16,0,19,0,19,0,22]				0,19	0,00015
		Patch and Rub Tunnel-Final Cleanup		[0,16,0,19,0,19,0,22]			0,19	0,00015
			[0,01,0,01,0,01,0,01]				0,01	0
		Spoil Removal		[0,01,0,01,0,01,0,01]			0,01	0

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
	Tunneling (756m)				[1704,18, 1870,33, 1870,33, 2540,37]		1996,303	32660,36501
			[101,101,101, 101]				101	0
		Removal Shaft		[101,101,101, 101]			101	0
	Removal Shaft				[101,101,101, 101]		101	0
NEST						[4639,03, 5162,16, 5197,16, 6827,14]	5456,373	1199931,7811

Case Study 2 Full Detailed Report

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
			[255,285,315,345]				300	375
		TOPSOIL Quantity Overrun		[255,285,315,345]			300	375
			[3500,4500,5250,5500]				4687,5	-64512,31061
		Additional Retaining Walls		[3500,4500,5250,5500]			4687,5	-64512,31061
			[120,142,150,150]				140,5	-248,00439
		additional Wick drain Pipe		[60,71,75,75]			70,25	-62,0011
			[1400,1800,2000,2400]				1900	43333,33333
		Additional Remedial Excavation in Lieu of Wick		[1400,1800,2000,2400]			1900	43333,33333
		Drain pipe	[2550,3230,3570,4250]				3400	125233,33333
		Rock Quantity overrun		[2550,3230,3570,4250]			3400	125233,33333

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
			[2000,2375, 2625,3000]				2500	44270,83333
		additional1mi hauling distance of drill and shoot rock		[2000,2375, 2625,3000]			2500	44270,83333
			[4165,4753, 5047,5635]				4900	93639
		disposalfee1\$/ cu.yd. of drill and shoot rock		[4165,4753, 5047,5635]			4900	93639
			[1040,1170, 1430,1560]				1300	14083,33333
		Increase in all Storm drainage pipeby6in		[1040,1170, 1430,1560]			1300	14083,33333
			[1360,1615, 1700,1700]				1593,75	-34168,22917
		Increase in reinforced concrete pipe		[1360,1615, 1700,1700]			1593,75	-34168,22917
			[5250,6750, 7500,8625]				7031,25	221324,57386
		schedule acceleration		[5250,6750, 7500,8625]			7031,25	221324,57386
			[800,900,1000, 1150]				962,5	10028,93519

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
		DBEby20%		[800,900,1000 1150]			962,5	10028,93519
			[3000,5100, 6600,7500]				5550	412500
		Design Growth		[3000,5100, 6600,7500]			5550	412500
			[2800,3600, 4400,5200]				4000	266666,66667
		design/approval delays		[2800,3600, 4400,5200]			4000	266666,66667
			[3750,4750, 5250,6000]				4937,5	91737,68939
		Regulatory Agencies		[3750,4750, 5250,6000]			4937,5	91737,68939
			[4250,4750, 5000,5500]				4875	67708,33333
		Disposal of Excess Materials		[4250,4750, 5000,5500]			4875	67708,33333
	UHCOC Positive Risk Elements				[36180,45649, 51762,58440]		48007,75	9656609,11277
			[-300,-300,- 297,-285]				-295,5	-381,25

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
		Less remedial excavation		[-300,-300,-297,-285]			-295,5	-381,25
			[-4600,-4200,-3800,-3200]				-3950	16018,51852
		Less retaining Wall sand pilings		[-4600,-4200,-3800,-3200]			-3950	16018,51852
			[-3000,-3000,-2700,-2400]				-2775	-25625
		Fatten slopes on Site waste from drill and shoot rock		[-3000,-3000,-2700,-2400]			-2775	-25625
			[-1256,-1133,-1067,-935]				-1097,75	3391,57703
		less tire/track/repair cost		[-1256,-1133,-1067,-935]			-1097,75	3391,57703
			[-1404,-1260,-1140,-996]				-1200	7536
		Less equipment maintenance cost		[-1404,-1260,-1140,-996]			-1200	7536
			[-900,-900,-873,-720]				-848,25	-14119,60598
		Piling reduction by 6ftperpileunder bridge		[-900,-900,-873,-720]			-848,25	-14119,60598

ProjectName	PackageName	ItemName	FuzzyEstimation	ItemFuzzy	PackageFuzzy	ProjectFuzzy	ExpectedValue	variance
			[-2415,-2300,-2185,-1725]				-2156,25	-65692,03869
		replace78R-value rock with 50R-value rock		[-2415,-2300,-2185,-1725]			-2156,25	-65692,03869
			[-5750,-5000,-4750,-3750]				-4812,5	14612,26852
		schedule deceleration		[-5750,-5000,-4750,-3750]			-4812,5	14612,26852
			[-2600,-2200,-1800,-1400]				-2000	66666,66667
		Less design/ Approval delays		[-2600,-2200,-1800,-1400]			-2000	66666,66667
	UHCOC Negative Risk Elmenets				[-22225,-20293,-18612,-15411]		-19135,25	-359516,59944
UHCOC						[13955,25356,33150,43029]	28872,5	33572723,87896