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Cost Overrun and Time Delay Risk Assessment in Local Road Bridge Construction using Fuzzy Inference System

by

Neeraj Thakur

A THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Cost Overrun and Time Delay Risk Assessment in Local Road Bridge Construction using Fuzzy Inference System"** submitted to the Department of Civil Engineering in partial fulfilment of the requirement for the degree of Master of Science in Construction Management, is a record of an original work done under the guidance of Mr. Shakil Manandhar, Team Leader, Local Road Bridge Support Unit. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.

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The undersigned certify that we have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Cost Overrun and Time Delay Risk Assessment in Local Road Bridge Construction using Fuzzy Inference System"** submitted by Neeraj Thakur in partial fulfilment of the requirements for the degree of Master of Science in Construction Management.

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ABSTRACT

Motorable Local Road Bridge Programm is a project implemented by Department of Local Infrastructure initiated from February, 2011. Since its initiation, construction of 346 bridges have been completed through this program using unit rate NCB contract. The current phase of this project has set target for completing construction of additional 200 bridges in coming four years.

The aim of this research is to assess and analyze the risk factors resulting in cost overrun and time delay of completed bridges and use this knowledge for mitigation of risks in future projects.

Risk factors were identified and classified through literature review. A fuzzy inference system based model was developed using MATLAB for calculation of risk indices based on questionnaire survey. A set of 57 bridges were sampled from the entire population for validation of model.

The study identified Government regulations/contract awarded to lowest bidder, inadequate budget allocation and unexpected ground condition as the highest ranked risk factor causing cost overrun and time delay in local road bridge construction. Risk management plan including risk response planning for mitigation was prepared for the principal risk factors.

Risk indices obtained from the study can be used as weightage factors for developing a neuro-fuzzy based prediction model.

Keywords: *Fuzzy Logic, Bridge Construction, Risk Assessment, Cost-Overrun, Time Delay*

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LIST OF ACRONYMS

BNP	Best Non-Fuzzy Performance
CIAA	Commission for Investigation of Abuse of Authority
CPA	Contract Price Adjustment
DoR	Department of Roads
DoLIDAR	Department of Local Infrastructure and Agricultural Roads
DoLI	Department of Local Infrastructure
DPR	Detailed Project Report
EIA	Environmental Impact Assessment
EOT	Extension of Time
EPA	Environment Protection Act
EPR	Environment Protection Rules
FIC	Fuzzy index for Cost-Overrun
FIT	Fuzzy Index for Time Delay
IEE	Initial Environment Examination
IPC	Interim Payment Certificate
LBS	Local Bridge Section
LD	Liquidated Damage
LRBSU	Local Road Bridge Support Unit
MATLAB	Matrix Laboratory
MOF	Ministry of Finance
MLRBP	Motorable Local Road Bridges Program
NCB	National Competitive Bidding
OSH	Occupational Safety and Health

PI	Probability Index
PMI	Project Management Institute
PMBOK	Project Management Book of Knowledge
PPA	Public Procurement Act
PPMO	Public Procurement Monitoring Office
PPR	Public Procurement Regulation
SDC	Swiss Development Cooperation
SI	Severity Index
SPSS	Statistical Package for the Social Sciences
TA	Technical Assistance
VO	Variation Order

CHAPTER 1 INTRODUCTION

1.1 Background

According to the fifteenth five-year plan, FY 2019/20 – 2023/24, (NPC, 2019), Nepal plans to reach the level of a middle-income country by 2030 along with graduating to a developing country from the ranks of a Least Developed Country by 2022. Development of internal and international interconnectivity is one of the important long-term national strategies adopted by the government to achieve this goal.

Construction is a major sector which contributes to the development of a country. According to the Economic Survey, 2077/78 (MoF, 2020), the contribution of construction sector to the GDP of the country in in FY 2077/78 is projected to be 5.7%. This value was 5.9% in FY 2076/77. In present context, construction sector is playing a vital role in multidimensional impact on development of the country. (Bista & Dahal, 2018)

Transportation infrastructure is an important component of construction industry in Nepal. A large amount of national budget is allocated to the construction of transport infrastructures such as roads and bridges.

Prior to the adoption of federal system of governance in Nepal, there were two major government organizations involved in the construction of roads and bridges in Nepal. The Department of Roads (DoR) was responsible for the construction and maintenance of transportation infrastructure along Strategic Road Network (SRN) whereas the Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) was responsible for construction and maintenance of roads and bridges along the Local Road Network (LRN).

Motorable Local Road Bridges Program (MLRBP) is a program implemented by Department of Local Infrastructure (DoLI) (formerly DoLIDAR) since February, 2011 with the technical assistance of Swiss Government through Swiss Development Cooperation (SDC). The major aim of this program is to construct bridges along non-strategic roads so that safe and dependable all-weather access to rural parts of Nepal can be ensured. The first phase of this program started from February 2011 and ended on May 2016. The second phase which was an interim phase commenced on June 2016 and ended on February 2017. The Phase I and Phase II focused on the bridge design, planning, selection and prioritization, together with capacity building of the public and private sectors involved in the bridge building businesses. The phase III was initiated in March 2017 and ended on December 2020. This phase included expansion, scaling up and consolidation. A total of 346 bridges have been completed by this program through unit rate National Competitive Bidding (NCB) contract from Phase I to Phase III.

With the promulgation of new constitution, Nepal transitioned into federal system of governance.

The table below summarizes the budgets and expenditure to date on an annual basis, expressed in millions of Rupees. Overall, these figures show an encouraging and consistent upward trend. The budgets dipped slightly during FY 16/17 and 17/18 but have now recovered. Similarly, expenditure dropped in FY 17/18. Both of these factors may be due to changeover in the government system and the associated uncertainties.

Table 1. 1 Budget and Expenditure of MLRBP (LRBSU, 2020)

Budget in Mio NPR	**11-12**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**
Construction Budget	377	406	1305	1348	3124	2615	2880	3963	7336
TA Budget	167	321	550	700	340	380	380	380	300
Overall Budget	544	728	1855	2048	3464	2995	3260	4343	7339
Construction Exp.	347	375	734	1069	1331	2314	1977	2122	
TA Expenditure	76	130	317	740	566	365	182	216	
Overall Expenditure In million NPR	**423**	**506**	**1050**	**1808**	**1897**	**2679**	**2158**	**2338**	

The agreement for MLRBP Phase IV was signed on November 29, 2020 between the Government of Nepal and the Government of Switzerland. This phase will be in operation from January 2021 to December 2024. This phase was envisioned as the consolidation and exit phase. In addition to supporting regular Technical Assistance including capacity building on planning, designing, construction supervision and contract management of bridges along non-strategic road. The scope will also include technology transfers involving research and development for innovative bridge design. One of the major output of this phase to construct 200 bridges along provincial and rural roads.

1.2 Statement of Problem

The failure to complete construction contracts within the stipulated time is a major problem in Nepalese construction industry. According to a study carried out by CIAA, (2020) considering the time duration up to Mangsir 2075, a total of 1,848 contracts worth Nrs. 118.01 Arba were not completed within the stipulated time. Such contracts include works ranging from construction of birthing center in rural areas to construction of water supply projects, road projects, bridge projects, highway upgradation and transmission line projects. The study also pointed out that the failure to complete the project could have negative impact on employment and socio-economic sectors.

A completed bridge catalogue is prepared for bridges constructed through Motorable Local Road Bridges Programme on an annual basis. The catalogue includes salient features such as location, contract date, expected date of completion, actual date of completion, name of the access road. It also includes information such as span, foundation type, superstructure type, span arrangement and carriageway width. Information regarding estimated amount, contract amount and total expenditure are also catalogued. Study of this catalogue has shown that time delay and cost overrun are common occurrence in local road bridge construction.

Poor cost performance is a very common occurrence in construction projects and this phenomenon is more severe in developing countries. This is a major concern for all the stakeholders involved in the project. (Baloi & Price, 2003)

Construction projects do not operate in isolation, rather they interact with the external environment. The project environment can be further divided into inner layer or internal environment; operational environment; and outer layer or general environment. The operational and general environment together make up the external environment. The assessment and decision-making process of a risk depends upon the type of data of available. For deterministic problems, data are known with certainty and for stochastic problems, the uncertainty inherent in the problem is represented by the means of probability distribution. The problem is said to be uncertain if the data is completely unknown. Most of the risks inherent in constructions projects are stochastic and uncertain because of which a well algorithm and decision-making process cannot be developed. Thus, risk assessment and management in construction projects is case-specific and relies heavily on past experience and human judgement.

Considering the unique nature of risk assessment and management in construction projects, Fuzzy logic can be a valuable tool in modelling such risks.

1.3 Research Questions

a) What are the risk factors causing cost-overrun and time delays in construction of bridges along local roads?
b) Can Fuzzy Inference System be used to model the risk factors occurring in bridges constructed along local roads?
c) Which risk factors are the most important and should be given the highest attention to minimize cost overrun and time delay?

1.4 Research Objectives

The major objective of this study is to assess the risk factors causing cost overrun and time delay in bridge constructed along local roads. The specific objectives of this research are as follows:

a) To form a model based on fuzzy inference system to calculate cost overrun risk index and time delay risk index using questionnaire survey.
b) To validate the fuzzy inference system model by testing correlation with sampled bridges.
c) To rank cost overrun and time delay factors and prepare risk mitigation plan for major risk factors

1.5 Significance of Study

A large amount of budget of Government of Nepal is allocated towards construction of transportation infrastructures such as roads and bridges. In addition to the Federal government, Provincial and Local government have also started allocating budget for construction of motorable bridges. In F/Y 77/78, Federal Government allocated Nrs 2.29

Arab and the seven provincial governments allocated a total of Nrs 5.02 Arab for construction of bridges along local and provincial roads. (LRBSU, 2020)

The lack of attention by public entities in various stages of public procurement has lead to possibilities of corruption in contract management, inability to achieve the project objectives, difficulties for the public and a great deal of loss to the government. (CIAA, 2020)

Bridge construction is a high priority program for all levels of government. A major chunk of taxpayer's money is invested into transport infrastructure. This study will help identify, assess and provide recommendation for appropriate measure of risk management in bridge construction.

1.6 Scope and Limitations

The central theme of this study is to assess the cost overrun and time delay related risks in construction of bridge along local roads. The risk factors are assessed on the basis of model developed using fuzzy inference system. The limitations of this study are as follows:

a) This study only includes bridge constructed along LRN, but does not include the bridges constructed along SRN.
b) The study only includes the bridge constructed by Local Road Bridge Program (LRBP) through unit rate National Competitive Bidding (NCB) Contract.
c) The whole population of 346 bridge cannot be analyzed in detail to determine the risk factor, thus, sampling is done to make inferences regarding the whole population.
d) The research is based on respondent's own perception rather than an actual case study.

1.7 Organization of Thesis

The study is organized into five chapters as follows:

a) Chapter 1 (Introduction): This chapter provides a general background of the research study. It comprised of background, statement of problem, research questions and objectives, significance of study, scope and limitations, and organization of the thesis.

b) Chapter 2 (Literature Review): This chapter identifies, evaluates and synthesizes the relevant literature in a particular field of research. This chapter provides the basic foundation for the study.

c) Chapter 3 (Research Methodology): This chapter provides the process used for collection of data, testing of data, formation of risk model and the technique used for validation of the model.

d) Chapter 4 (Data Analysis and Discussions): This chapter analyses the results obtained from the model and provides discussion of important parameters.

e) Chapter 5 (Conclusion): This chapter provides the conclusion of the study based on the objectives. The chapter also explores the possible further studies.

CHAPTER 2 LITERATURE REVIEW

A Literature review constitutes the process of identifying, evaluating and synthesizing the relevant literature within a particular field of research. According to W.R. Borg, the literature in any field forms the foundation upon which all future work will be built. If we fail to build the foundation of knowledge provided by the review of literature our work is likely to be shallow and naïve and will often duplicate work that has already been done better by someone else.

2.1 Project Risk

Project Management Book of Knowledge (PMBOK), (PMI, 2004) defines project risk as an uncertain event or condition that, if it occurs, has a positive or a negative effect on at least one project objective, such a time, cost, scope or quality (i.e., where the project time objective is to deliver in accordance with the agreed upon schedule; where the project cost objective is to deliver within the agreed-upon cost; etc.). A risk may have one or more causes and, if it occurs, one or more impacts. Risk conditions could include aspects of the projects or organization's environment that may contribute to project risks, such as poor management practices, lack of integrated management systems, concurrent multiple projects, or dependency on external participants who cannot be controlled.

Project Cost Overrun Risk: A cost overrun can be broadly defined as the amount by which the actual expenditure exceeds the agreed upon contract amount. In Construction projects, cost overrun manifests itself in the form of VO and CPA.

Project Time Delay Risk: A time delay in project can be defined as the increase in duration above the stipulated time for completion of the project.

Project Risk Management

According to PMBOK, The project risk management processes include the following:

1. Risk Management Planning
2. Risk Identification
3. Qualitative Risk Analysis
4. Quantitative Risk Analysis
5. Risk Response Planning

6. Risk Monitoring and Control

Qualitative Risk Analysis

Qualitative risk analysis includes the methods for prioritizing the identified risks for further action, such as Quantitative risk analysis, risk response planning. Organizations can improve the project's performance effectively by focusing on high-priority risks. Qualitative risk analysis assesses the priority of identified risks using their probability of occurring, the corresponding impact on project objectives if the risks do occur, as well as other factors such as the time frame and risk tolerance of the project constraints cost, schedule, scope and quality.

Probability and Impact Matrix

Risks can be prioritized for further quantitative analysis and response, based on their risk rating. Ratings are assigned to risks based on their assessed probability and impact. Evaluation of each risk's importance and hence, priority for attention is typically conducted using a look-up table or a probability and impact matrix.

Probability and Impact Matrix

Probability	Threats					Opportunities				
0.90	0.05	0.09	0.18	0.36	0.72	0.72	0.36	0.18	0.09	0.05
0.70	0.04	0.07	0.14	0.28	0.56	0.56	0.28	0.14	0.07	0.04
0.50	0.03	0.05	0.10	0.20	0.40	0.40	0.20	0.10	0.05	0.03
0.30	0.02	0.03	0.06	0.12	0.24	0.24	0.12	0.06	0.03	0.02
0.10	0.01	0.01	0.02	0.04	0.08	0.08	0.04	0.02	0.01	0.01
	0.05	0.10	0.20	0.40	0.80	0.80	0.40	0.20	0.10	0.05

Impact (ratio scale) on an objective (e.g., cost, time, scope or quality)

Each risk is rated on its probability of occurring and impact on an objective if it does occur. The organization's thresholds for low, moderate or high risks are shown in the matrix and determine whether the risk is scored as high, moderate or low for that objective.

Fig 2. 1 Probability and Impact Matrix (PMI, 2004)

The dark gray area in the figure above represents high risk; the medium gray area represents low risk; and light gray area represents moderate risk. Usually, these risk rating rules are specified by the organization in advance of the project, and included in organizational process assets. Risk rating rules can be tailored in the Risk Management process to the needs and requirements of the specific project. (PMI, 2004)

Planning Risk Response: The PMBOK 6th edition has proposed five alternative strategies for dealing with threats

1. Escalate: This strategy is applicable when the project team or the project sponsor agrees that a threat is outside the scope of the project or that the proposed response would exceed the project manager's authority. Escalated risks are managed at the higher level and not at the project level. It is important that ownership of escalated threats is accepted by the relevant party in the organization. These risks are not further considered by the project team.
2. Avoid: This is when the project team adopts the strategy of eliminating the threat or protect the project from its impact. It is usually adopted for high-priority threats with a high probability of occurrence and a large negative impact. This may involve changing aspect or objective of the project. Examples include practices such as removing the cause of a threat, extending the schedule, changing the project strategy, or reducing scope. They can also be avoided by clarifying requirements, obtaining information, improving communication, or acquiring expertise.
3. Transfer: This involves transferring the risk to a third party to manage the risk and to bear the impact if the threat occurs. This method often involves payment of a risk premium to the party taking on the threat. This method may include use of insurance, performance bonds, warranties, guarantees, etc.
4. Mitigate: Action is taken towards reducing the probability of occurrence and/or impact of a threat. Early mitigation action is often more effective than trying to repair the damage of the threat that has occurred. Adopting fewer complex processes, conducting more tests are examples of mitigation actions. Where it is not possible to reduce probability, a mitigation response might reduce the impact by targeting factor that drive the severity.

5. Accept: Risk acceptance acknowledges the existence of a threat, but no proactive action is taken. This is recommended for low priority threats, and may also be applicable where it is not possible or cost effective to address a threat in any other way.

2.2 Review of previous studies

A detailed review of previous studies was done to identify risk factors causing cost overrun and time delay in bridge construction. Some of the major studies reviewed have been tabulated below:

Table 2. 1 Past Research

Sharma, S., Goyal, P. K. (2019). Fuzzy assessment of the risk factors causing cost overrun in construction industry.
Timilsina, S. P., Ojha, S. K., & Dhungana, B. R. (2020). Causes of Delay in Construction of Motorable Bridges under "Design and Build Model" of Bridge Project, Department of Roads, Nepal
Karunakaran, S., Malek, M.A., & Ramli, M.Z. (2019). Causes of Delay in construction of Highway Projects. A Review.
Bista, S.B., & Dahal, R.K. (2018). Assessment of Low Bidding in Bridge construction with special reference to Nepal.
Suwal, A., & Shrestha, S. (2016). Causes of Delays of Motorable Bridge Construction under Postal Highway Projects, Department of Roads.
Shah, K.J., & Apte, M.R. (2015). Causes of Delay in Construction of Bridge Girder.
Islam, M.S., & Trigunarsyah, B. (2017). Construction Delay in Developing Countries : A Review.
Haseeb, M., Lu, X., Bibi, A, Dyian, M. U., & Rabbani, W. (2011). Problems of Projects and Effects of Delay in the Construction Industry of Pakistan.
Pourostam, T., & Ismail, A. (2011). Significant factors causing and effects of delay in Iranian Construction Projects.
Azhar, N., & Farooqui, R. U., Ahmed, S. M. (2008). Cost overrun factors in construction industry of pakistan
Shah, R.(2016). An Exploration of causes for delay and cost overrun in construction projects: A case study of Australia, Malaysia & Ghana

Timilsina et al., (2020) identified a total of 56 causes for delay of bridge construction through the use of different techniques. They used secondary sources such as literature review and primary source such as pilot survey of three groups of respondents who were involved in the construction of motorable bridges built under the Design and Build Model. The research identified delay in bridge construction as the most serious problem which can even slow down the national development. The research classified delays into three types namely excusable, non-excusable and concurrent.

Karunakaran et al., (2019) have listed shortage of materials, failure of material and equipment, poor communication and interaction, poor project planning and scheduling followed by frequent design changes, unforeseen additional work, labor issues, weather, improper construction method, inexperienced contractors and poor sire investigation as cause for significant delay.

The outcome of a study carried out in Malaysia to identify the significant factor causing cost overrun in large construction projects was categorization of the factors into seven groups which was then validated through interview with five experts of the industry. The study identified fluctuation of prices of material, cash flow and financial difficulites faced by the contractor and poor site management and supervision as the top 3 most influencing factors causing cost overrun in the project. (Rahman et al., 2013)

Bista & Dahal (2018) have identified low bidding as the major cause of delay along with underlying factors such as unrealistic norms, unrealistic district rates, ambiguities in the contract document, and social acceptance.

Suwal & Shrestha (2016) have identified the main cause of delay are unusual low bid by contractors, delay in receiving clearances from various government authorities, poor site management and supervision by contractors due to large number of works in hand, lack of planned pre-execution of the project.

Samarghandi et al., (2016) carried out a study in Iran to determine reasons for delay and cost overrun in Construction projects. A statistical model was developed in this research to determine quantitative value of each factor's importance. The study classified factors into four groups as contractor defects, owner defects, consultant defects and law, regulation and other general defects. The significant delay factors were identified to be inaccurate budgeting and resource planning, inaccuracies in technical documents and outdated mandatory terms in contract.

Shah & Apte (2015) have concluded the major reasons for the delay are related to contractor's performance such as site management, labor productivity, and lack of expert proficiency in supervision, etc. The client was held responsible for the delay in issuing drawings and design.

Islam & Trigunarsyah (2017) have concluded that main reason for the delay as financial issues like; contractor's cash flow problem, and delay in progress payment by the employer, managerial issues such as poor site management, contractor related factors, i.e, improper planning and scheduling, and employer-related factor like order for design change during construction are the most severe factor that result in delay all over the developing world. The research conducted in Pakistan regarding effects of delays in the construction industry concluded that the most common factor of delay is a natural disaster in Pakistan like floods and earthquakes and some others like-financial and payment problems, improper planning, poor site management, insufficient experience, shortage of materials and equipment, etc. (Haseeb et al., 2011)

Pourrostam & Ismail (2011) have concluded that major cause of delay are delay in progress payment by employers, change orders by an employer during construction, poor site management and supervision, ineffective planning and scheduling of project by contractor, financial difficulties of a contractor, slowness in the decision-making process by an employer, delays in producing design documents, late in reviewing and approving design documents by an employer, poor contract management by consultant and problems with subcontractors.

Azhar et al., (2008) identified 42 factors causing cost overrun in Pakistan's construction industry. The top ten factors were identified to be: fluctuation in prices of raw materials, unstable cost of manufactured materials, high cost of machineries, lowest bidding procurement procedures, poor project (site) management/ poor cost control, delays between design and procurement phases, incorrect/inappropriate method of cost estimation, additional work, improper planning and unsupportive government policies.

A study of Australia, Malaysia and Ghana concluded that the top three causes for delay and cost overrun in construction projects in Australia were planning and scheduling deficiencies, method of construction and effective monitoring and feedback process, in Ghana were delay in payment certificates, underestimating of project cost and complexity and size of projects whereas for Malaysia the factors were Contractor's improper planning, poor site management and inadequate contractor's experience. (Raj Kapur Shah, 2016)

Sharma & Goyal (2019) identified 55 important risk factors causing cost overrun in Indian Construction Project. The research identified fluctuation in price of material, lowest bid procurement policy, inflation inappropriate government policy, mistakes and discrepancies in the contract document, inaccurate time and cost estimate, additional work, frequent design change, unrealistic contract duration and financial difficulties faced by the contractor as the top ten factors causing cost overrun in Indian Construction Industry. The research used a new cost overrun factor index, namely fuzzy index for calculation of cost overrun. This research proposed a new fuzzy based model for estimate the risk magnitude of risk factors. The fuzzy logic theory has the potential to deal with the vagueness and uncertainty and subjective nature of any problem and it is capable of handling the almost same analogous which is found in the complex construction projects.

2.3 Fuzzy Logic

2.3.1 Introduction

There is a relation between precision and uncertainty in a problem.

The degree of precision in defining a problem decreases as the uncertainty in the problem increases. Binary logic operates in extremes i.e., the value is either true of false. It does not consider the degree of truth between the extreme ends.

The solution of most engineering problems requires understanding of precision, information and complexity. Most of the phenomenon we observe around us are based on human judgment, a form of judgment which is imprecise. Although such imprecise information is unsuitable to computer application, they are valuable to humans. The beauty of fuzzy logic is it allows modelling of uncertain and difficult to manage data. (Ross, 2004)

Historical perspective: Probability theory was the predominant theory used in scientific application from the period of 1800's to 1900's. The concept of Fuzzy sets introduced by Zadeh in 1965 and Max Black's study in vagueness paved new avenues for the study of uncertainty. Zadehs work in fuzzy logic challenged the classical view of binary (two-valued) logic. (Klir & Yuan, 1995)

2.3.2 Fuzzy Sets and Memberships

The notion of a fuzzy set provides a convenient point of departure for the construction of a conceptual framework which parallels in many respects the framework used in the case of ordinary sets, but is more general than the latter and, potentially, may prove to have a much wider scope of applicability, particularly in the fields of pattern classification and information processing. Essentially, such a framework provides a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria of class membership rather than the presence of random variables. (Lofti A Zadeh, 1965)

For example, let us consider the value of inflation in Nepalese Economy. We have to assess if the inflation is above 6% in country. In a binary sense, the inflation is either above 6% or not. There is no subjectivity attached to this decision. For instance, if "high" is a set defined as inflation equal to or greater than 6%, a computer program would not recognize the inflation value of 5.99% as being a member of the set "high". The problem in this condition is assessing the uncertainty in the following question: Is the value of inflation almost high? The uncertainty in this case is the result of ambiguity and vagueness of the adjective nearly. An inflation value of 5.9% could clearly be a member of the set "almost high". In the first situation, the uncertainty of a year’s inflation is unknown, is 6% or not is binary; the value is or is not, and we can produce a probability assessment of that parameter based on collection of annual data of past years. But the uncertainty of whether the inflation is almost high is non-random. The degree to which the inflation approaches a high value is fuzzy. In reality, "high-inflation" is a matter of degree and is relative. For instance, during stable economic conditions, a 6% inflation rate could be high whereas during tumultuous economy, this rate could be considered low. So, a 6% rate can be high in one context and low in another.

In the real (fuzzy) world, high inflation value can overlap with non-high inflation values, an impossibility when one follows the precept of classical binary logic.

The idea of set membership is different for classical sets and fuzzy sets. The members of classical sets have a definite value of membership. An element is either the member of the set or not. Fuzzy sets contain objects that satisfy imprecise properties of membership, thus membership of an object in a fuzzy set can be approximate. For example, the value of inflation between 5% to 7% is precise (Crisp); the set of heights in the region around 6% is imprecise, or fuzzy.

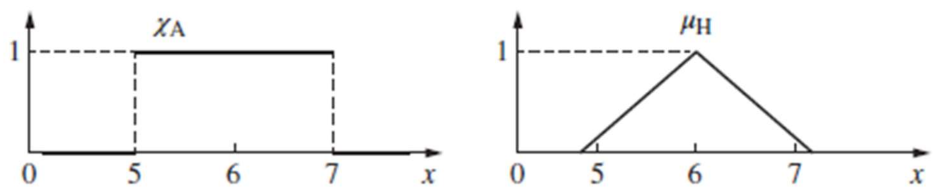


Fig 2. 2 Fuzzy Membership Values

For our example of the universe of values of inflation, suppose set A is the crisp set of all values between 5%<x<7% shown in figure below. A particular year, x1, has inflation of 6%. The membership of this individual year in crisp set A is equal to 1, or full membership. Another year, say x2, has a value of 4.9%. The membership of this individual in Set A is equal to 0. In these cases the membership in a set is binary, either an element is a member of a set or it is not.

The idea of binary membership was further extended by Zadeh to include various "degress of membership" on the real continuous interval [0,1]. The boundary points of 0 and 1 represent no membership and full membership respectively. Similar to the indicator function for crisp sets, infinite number of values in between the endpoints can represent various degrees of membership for an element x in some set on the universe.

Zadeh defined "Fuzzy sets" as the sets on the universe X that can accommodate "degree of membership".

2.3.3 Logic and Fuzzy Systems

Logic for humans is a way to quantitatively develop a reasoning process that can be replicated and manipulated with mathematical precepts.

Fuzzy Systems

Natural Language is perhaps the most powerful form of conveying information that humans possess for any given problem or situation that requires solving or reasoning. This power has largely remained untapped in today's mathematical paradigms; not so anymore with the utility of fuzzy logic.(Ross, 2004) Although our spoken language has elements of ambiguity and vagueness, humans have little trouble in expressing and communicating our thoughts. In order to develop a model for representing the human thought process, we must first be able to formulate the natural language.

Human language consists of individual terms (words) that can be regarded as the most basic units of expression. The combination of these basic units makes up phrases of our natural language. For instance, terms such as high, medium, low, very and few are individual words and their combinations such as Very high inflation are composite terms. If we define the atomic terms and combination of atomic terms as elements and sets on a universe of natural language terms, say universe X. We aim to map this term to another universe called Y, as a universe of cognitive interpretations, or meanings. Since, the interpretation of elements in the universe Y can be vague, they can be best represented using fuzzy sets. Thus, these basic terms or linguistic variables as Zadeh defined it, can be interpreted using fuzzy sets.

With these definitions and foundations, we can now establish a formal model of linguistics using fuzzy sets.

2.3.4 Fuzzy Rule Based Systems (FRBS)

Fuzzy rule-based systems are an extension of traditional rule-based systems, where the humanistic knowledge about a problem and the interaction between its variables is expressed through fuzzy sets and fuzzy logic.

Components

The uncertainty and vagueness in human knowledge in FRBS are represented by the means of linguistic variables and their values that are defined in fuzzy sets using membership functions.(Magdalena, 2015) The generalized Modus Ponens and generalized Modus Tollens are the commonly used Fuzzy logic inference method for approximate reasoning. In this sense, Fuzzy Logic provides a unique framework for inference in rule-based systems. There is a clear demarcation between the knowledge and reasoning component of FRBS.

Mamdani proposed the first model of FRBS that dealt with real inputs and outputs that used fuzzy system using the fuzzy control application.(Mamdani, 1974) The initial application of Mamdani FRBS was in Fuzzy Logic Controller (FLC). Currently, control is one the many applications of FRBS.

The prototype structure of a Mamdani FRBS is shown in the figure below. The knowledge base is populated by the available knowledge about the problem in the form of fuzzy IF-THEN rules. The processing component, on the basis of knowledge base conducts the inference process on the inputs.

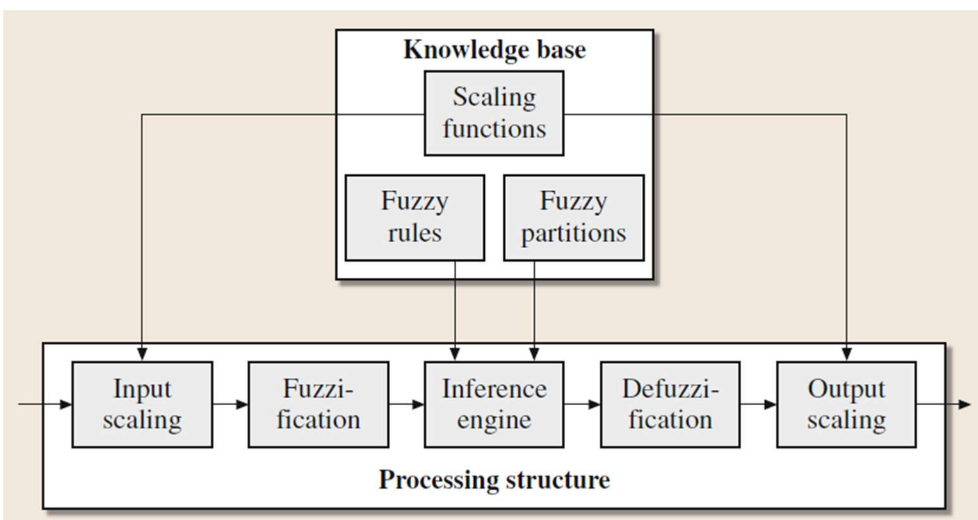


Fig 2. 3 General Structure of a Mamdani FRBS (Magdalena, 2015)

Knowledge Base

Knowledge base is the collection of information developed by human experience which is used to model the relationship between input and output of a process. The knowledge is expressed by the means of rules, and the most common rule structure in Mamdani FRBSs involves the use of linguistic variables. Thus, while dealing with multiple inputs-single output systems, these linguistic rules possess the following form

IF X_1 is LT_1 and X_2 is LT_2 and …. And X_n is LT_n THEN Y is LT_o,

With X_i and Y being, respectively, the input and output linguistic variables, and with LT_i being linguistic terms associated with these variables.

The knowledge base can be further divided into two types of information. The first level of information is the linguistic variables which provide the fuzzy rule semantics in the form of fuzzy partitions.(Magdalena, 2015) These fuzzy partitions are defined by the use of membership functions. The second level of information is the linguistic rules which constitute the knowledge of experts.

Fuzzy Partitions/ Frames of Cognition

Fuzzy partitions define the sets of linguistic terms with different variables. These variables are defined by the membership functions and used in the linguistic rules. Different types of membership functions, such as triangular, trapezoidal, parabolic etc. can be used to define a fuzzy partition. The figure below shows a fuzzy partition using triangular membership functions.

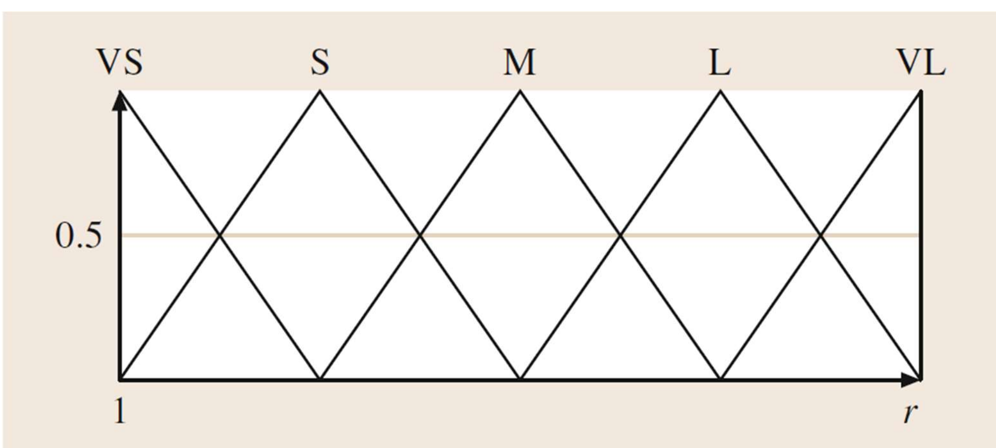


Fig 2. 4 Fuzzy Partition (Magdalena, 2015)

This structure provides a natural framework to include expert knowledge in the form of fuzzy rules. The partition shown in the figure above used five linguistic terms {very small, small, medium, large, and very large} with the interval [*l, r*] being its domain (Universe of discourse). Also shown is the membership function associated to each linguistic term.

Rule Base

The rule base is composed of linguistic rules that are joined by logical operators. Since the rule base is composed of multiple rules, there can be multiple processes for a single input. The rule base can be represented by different means. It can be in the form of listed rules. Another possibility is a rule matrix (also known as decision table) which is a compact representation for the same set of linguistic rules.

Let us consider an FRBS consisting of two input variables a_1 and a_2 and a single output variable b which are defined as {*low, medium, high*}, {*few, normal, many*} and {*unsatisfactory, satisfactory, excellent*} respectively. A rule base can be defined of five linguistic rules

R_1: IF X_1 is low and X_2 is few THEN Y is unsatisfactory,

Also

R_2: IF X_1 is low and X_2 is normal THEN Y is unsatisfactory,

also

R_3: IF X_1 is medium and X_2 is few THEN Y is satisfactory,

also

R_4: IF X_1 is high and X_2 is normal THEN Y is satisfactory,

also

R_5: IF X_1 is high and X_2 is many THEN Y is excellent,

These set of rules can be conveniently represented using the decision table shown below:

Table 2. 2 Decision Table

X_2	*X1*		
	Low	*Medium*	*High*
Few	*Unsatisfactory*	*Satisfactory*	
Normal	*Unsatisfactory*		*Satisfactory*
Many			*Excellent*

Processing Structure

FRBS operates through the interaction between knowledge and reasoning. As shown in Fig 2.3, the Mamdani FRBS can be broken down into following components:

- Input Scaling normalizes the values of input variables into the domain where the input fuzzy partitions are defined. This process is also known as domain adaptation.
- The Fuzzification interface transforms crisp input data into fuzzy values for further processing.
- The inference engine performs the roles of mapping inputs to several resulting output according to the information stored in the knowledge base.
- The defuzzification interface transform fuzzy values into crisp values.
- Output scaling transforms defuzzified values from the domain of fuzzy partitions to the output variables.

Input/Output Scaling

Input/Output scaling performs the function of transforming the input/output variables to/from the universe of discourse in which they were defined. Scaling can be achieved through different

Means: Linear and Non-linear functions. A general linear scaling function has the form:

$f(x)=\lambda \, . \, x + \upsilon$

in which the scaling factor λ has a multiplying effect that enlarges or reduces the operating range, which in turn decreases or increases the sensitivity of the system with respect to the input variable, or the corresponding gain in the case of an output variable. The second parameter υ shifts the operating range and plays the role of an offset for the corresponding variable.

A commonly used nonlinear scaling function is

$$f(x) = sign(x) \cdot |x|^{\alpha}$$

The nonlinear scaling increases ($\alpha > 1$) or decreases ($\alpha < 1$) the relative sensitivity in the region closer to the central point of the interval and has the opposite effect when moving away from the central point. (Magdalena, 1997)

Fuzzification Interface

This interface equips Mamdani FRBS to handle crisp input values. This maps crisp input values into the universe of discourse of those inputs. The membership functions of the fuzzy set *A'* defined over the universe of discourse *U* associated to a crisp input value x_o is computed as

$$\mu_{A'} = F(x_o)$$

In which *F* is a fuzzification operator.

The most common choice for the fuzzification operator *F* is the point wise or singleton fuzzification, where *A'* is built in singleton with support x_o i.e., it presents the following membership function:

$$\mu_{A'(X)} = \begin{cases} 1, & if\ x = xo \\ 0, & otherwise \end{cases}$$

Inference System

This part of the FRBS maps the fuzzy inputs to the fuzzy outputs using the relation defined through fuzzy rules. The usual fuzzy inference scheme employs the generalized Modus Ponens, an extension to the classical Modus Ponens. (Lotfi A Zadeh, 1973)

IF X is A THEN Y is B

X is A' THEN   Y is B'

Considering *A* and *B* to be fuzzy sets, and *X* and *Y* as linguistic variables, the above expression is a fuzzy conditional statement. A fuzzy conditional statement like this one represents a fuzzy relation between A and B.

Types of Fuzzy Rule Based Systems

Mamdani was the first to propose a FRBS. Various types have been further described below:

Linguistic Fuzzy Rule-Based Systems

A Mamdani FRBS provides a natural framework to include expert knowledge in the form of linguistic rules. This knowledge can be easily combined with rules which are automatically generated from data sets that map system inputs to system outputs. Each rule is a description of a condition-action statement that exhibits a clear interpretation to a human – for this reason, these kinds of systems are usually called linguistic or descriptive Mamdani FRBSs. This property makes Mamdani FRBSs appropriate for applications in which the emphasis lies on model interpretability, such as fuzzy control and linguistic modelling.

Variants of Mamdani FRBS

The Mamdani FRBS has some limitations. Accuracy of this model decreases as the complexity of the problem increases because of the structure of the linguistic rules. Some other drawbacks of this system are as follows:

- Sharply defined partitioning of input and output variables results in reduced flexibility of the statement.
- Partitioning of the input space becomes difficult when input variables are mutually dependent.
- As the complexity of the system increases, homogeneous partitioning of input and output space becomes inefficient and does not scale well.
- As the number of variables and linguistic terms in the system increases, the size of knowledge base and number of rules increases.

The variants of linguistic Mamdani FRBSs attempt to solve the above-mentioned problems by making the linguistic tule structure more flexible.

Disjunctive normal form (DNF) Mamdani FRBS

This variant aims at different rule structure with the following form:(González et al., 1994)

IF X_1 *is* $\tilde{A}_1$ *and …. and* X_n *is* $\tilde{A}_n$

THEN Y is B ,

Where each input variable Xi takes as its value a set of linguistic terms $\tilde{A}_i$, whose members are joined by a disjunctive operator, while the output variable remains a usual linguistic variable with a single label associated. Thus, the complete syntax for the antecedent of the rule is

X_1 *is* $\tilde{A}_1 = \{A_{11}$ *or … or* $A_{1/1}\}$ *and … and* X_n *is* $\tilde{A}_n = \{A_{n1}$ *or … or* $A_{n/n}\}$

This expression contains an additional *connective* different than the *and* considered in all previous rules. The *or* connective is computed through a t-conorm, the maximum being the most commonly used. The major advantage of this variant is the ability to incorporate multiple rules into a single expression

Approximate Mamdani-Type Fuzzy Rule-Based Systems

This variant provides better accuracy at the cost of reduced interpretability. In an approximate FRBS, each rule defines its own fuzzy sets instead of using a linguistic label pointing to a particular fuzzy set of the partition of the underlying linguistic variable. Thus, an approximate fuzzy rule has the following form:

IF X_1 *is* A_1 *and …and* X_n *is* A_n *THEN Y is B*

The major difference with respect to the rule structure considered in linguistic Mamdani FRBSs is the fact that the input variable X_i and the output one Y are fuzzy variables instead of linguistic variables and, thus A_i and B are not linguistic terms (LT_i) but independently defined fuzzy sets that elude an intuitive linguistic interpretation.

Therefore, approximate FRBSs do not rely on fuzzy partitions defining a semantic context in the form of linguistic terms.

Takagi-Sugeno-Kang Fuzzy Rule-Based Systems

Different from working with linguistic rules used in the Mamdani FBRS, Sugeno et al. (Takagi & Sugeno, 1985) proposed a new model based on rules whose antecedents are defined in linguistic variables by the consequent is represented by a function of the input variables. The most common form of this kind of rules is the one in which the consequent expression contains a linear combination of the variables involved in the antecedent

IF X_1 *is* A_1 *and … and* X_n *is* A_n

THEN $Y = p_o + p_1.X_1 + ... + p_n.X_n$

Where X_i are the input variables, Y is the output variable, and $p = (p_o, p_1, ..., p_n)$ is a vector of real parameters. Regarding A_i, they are either a direct specification of a fuzzy set or a linguistic label that points to a particular member of a fuzzy partition of a linguistic variable.

The output of a TSK FRBS, using a KB composed of *m* rules, is obtained as a weighted sum of the individual outputs provided by each rule, Y_i, $i = 1, ... , m$, as follows:

$$\frac{\sum_{i=1}^{m} hi\,.\,Yi}{\sum_{i=1}^{m} hi}$$

in which $h_i = T(A_{i1}(x_1), ..., A_{in}(x_n))$ is the matching degree between the antecedent part of the i^{th} rule and the current inputs to the system, $x_o = (x_1, ..., x_n)$. T stands for a conjunctive operator modeled by a t-norm. Therefore, to design the inference engine of TSK FRBSs, the designer only selects the conjunctive operator *T*, with the most common choices being the minimum and the product. As a consequence, TSK Systems do not need defuzzification, being their outputs real numbers. (Magdalena, 2015)

TSK FRBS have been successfully applied to a large variety of practical problems. The main advantage of these systems is that they present a set of compact system is that they present a set of compact system equations that allows the parameters p_i to be estimated by means of classical regression methods, which facilitates the design process. However, the main drawback associated with TSK FRBSs is the form of the rule consequents, which does not provide a natural framework for representing expert knowledge that is afflicted with uncertainty.

Singleton FRBS

In this system, the rule consequent takes a single real-valued number. Its rule structure is the following

IF X_1 *is* A_1 *and … and* X_n *is* A_n *THEN Y is* y_o

Utility of Fuzzy Systems

Similar to the algebraic function which maps input variable to an output variable, a fuzzy system maps an input group to an output group. Fuzzy system allows the use of linguistic propositions. The basis of fuzzy system is the Stone-Weierstrass theorem.

The main application of fuzzy system is in the modeling of complex systems which are not composed of analytic function or numerical relation. Fuzzy system is useful in establishing relation between large number of inputs and outputs. Fuzzy system is applicable to vague, unclear and completely unknown data. The system is also useful in situations which require quick and approximate results for preliminary estimates.

In a robust system, the effect of change in input on the output is not significant as the system is capable of incorporating uncertainty to a certain extent. In traditional form, mathematical models of a system are constructed based on assumptions and simplifications. The uncertainties in individual inputs to the system are then considered. Contrary to the traditional model, a fuzzy system incorporates uncertainties in both input and output during the formation of system. This makes fuzzy system robust.

Limitations of Fuzzy System

Fuzzy systems can be described as shallow models. This is because they are primarily used in deductive reasoning. There is a difference between a mathematical model which correlates the input and output of a system and a model which incorporates the underlying phenomenon. (Arciszewski et al., 2002)

The model which can describe the inherent process is a deep model whereas the model which does not describe the underlying process is a shallow model.

2.3.5 Propertied of Membership Functions, Fuzzification, and Defuzzification

Properties of Membership Function

The basic terminology used in membership functions have been described below:

Core: The core of a membership function constitutes full membership in the set Ã. The elements x of the universe is such that $\mu\tilde{A}(x) = 1$

Support: Support of a membership function constitutes a non-zero membership in the set Ã. The elements x of the universe is such that $\mu\tilde{A}(x) > 0$.

Boundaries: Boundaries constitute a partial membership in the set Ã. The elements x of the universe is such that $0<\mu\tilde{A}(x) < 1$.

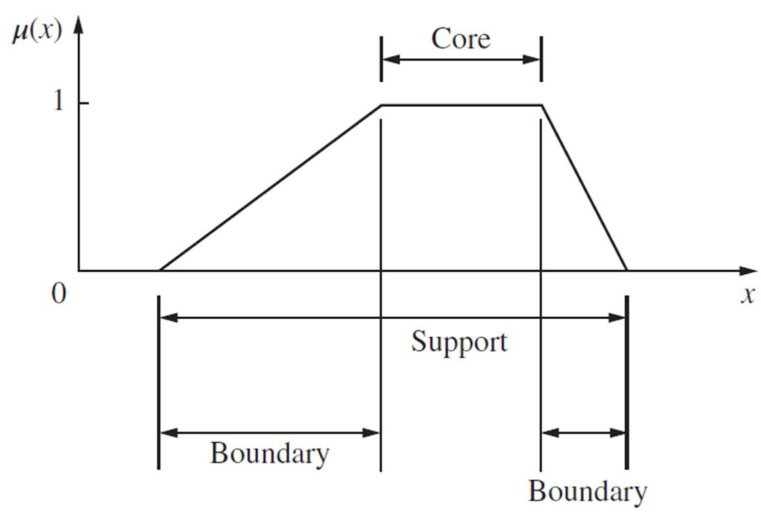


Fig 2. 5 Membership Function (Ross, 2004)

A normal fuzzy set is one whose membership function has at least one element x in the universe whose membership value is unity.

A convex fuzzy set is described by a membership function whose membership values are strictly monotonically increasing, or whose membership values are strictly monotonically decreasing, or whose membership values are strictly monotonically increasing then strictly monotonically decreasing with increasing values for elements in the universe.

The crossover points of a membership function are defined as the elements in the universe for which $\mu\tilde{A}(x) = 0.5$.

The height of a fuzzy set is the maximum value of the membership function, that is $hgt(\tilde{A}) = \max\{\mu\tilde{A}(x)\}$. If the $hgt(\tilde{A})<1$, the fuzzy set is said to be subnormal.

The different types of membership functions used are

1. Triangular Membership Function
2. Trapezoidal Membership Function
3. Gaussian Membership Function
4. Generalized bell Membership Function
5. Sigmoid Membership Function

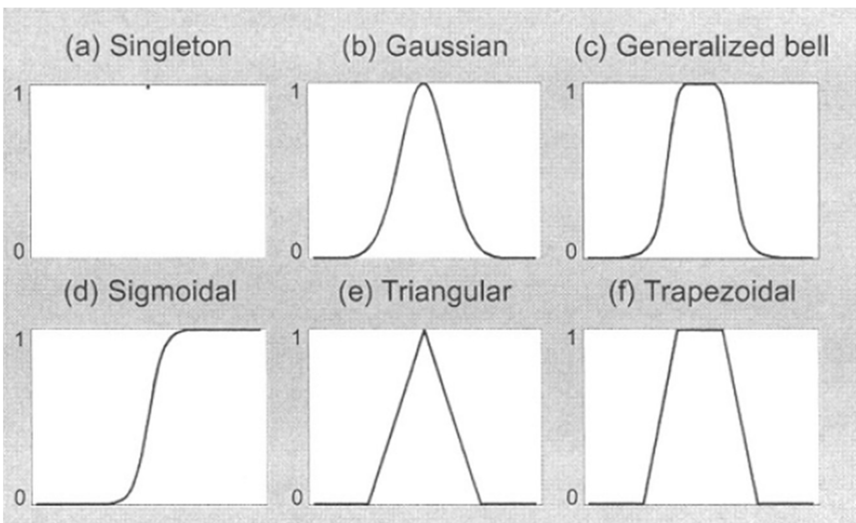


Fig 2. 6 Types of Membership Functions (Pedrycz, 1994)

The commonly used triangular membership functions constitute an immediate solution to the optimization problems emerging in fuzzy modelling. The triangular membership function with the one-half overlap level produce zero value of the reconstruction error. (Pedrycz, 1994)

2.4 Provisions in Public Procurement Act (2007)

2.4.1 Evaluation of bids

According to the clause 25(5) of the act, Bid shall be evaluated in accordance with the criteria and methodology set forth in the bidding documents; and in carrying out such evaluation, the bid with the lowest bid prices shall be determined by making comparison of the evaluated price of the other bids. On examination, the qualification of the bidder of the bid having the lowest bid price is conformity with the qualification evaluation criteria set forth in the bidding documents, such bid shall be lowest evaluated substantively responsive bid. The PPA and PPR have provisions of awarding contract to the lowest evaluated substantively responsive bid.

2.4.2 Variation Order

According to the clause 54 of the act, a variation order can be issued if the circumstances that could not be foreseen at the time of signing of procurement contract arise in the course of implementation of the procurement contract. The competent authority can issue a variation order of up to 25% and the variation above this value has to be issued as per the decision made by the Government of Nepal Council of Ministers. An expert committee has to be formed prior to issuing variation order.

2.4.3 Price Adjustment in Procurement Contract

According to the clause 55 of the act, if the price needs to be adjusted in the course of implementation of a procurement contract having duration exceeding Twelve months the competent authority may adjust price. For national level competitive bidding contracts concerning construction works , if the price of any construction materials is increased or decreased unexpectedly by more than ten percent of the previous price, price shall be adjusted as prescribed by deducting ten percent in the amount so increased or decreased. The act has also clearly stated that price adjustment cannot be made where the work under contract is not completed within the period prescribed in such contracts and has taken more time due to the delay by the person who has obtained procurement contract or if procurement contract is concluded on the basis of lump sum contract or fixed budget.

2.4.4 Provision concerning Extension of Contract Period

According to the clause 56 of the act, the condition for extension of time shall be mentioned in the contract. The act states that if the period of procurement contract is to be inevitably extended due to force majeure, failure of the Public Entity to make available the materials to be made available by it or other reasonable causes, the competent authority may extend the period on the prescribed grounds upon submission of application by the person obtaining procurement contract.

2.5 Provision in the Public Procurement Regulation (2007)

2.5.1 Procedure relating to variation

The rule 118 of the regulation has set out the procedure related to variation in a contract. The rule stated that if it is required to issue a variation order of a construction work, the order shall set out the following details and be certified by the chief of public entity who has the authority to approve such variation:

a) Whether the drawing, design and specification etc. of the construction work need to be changed or not and where such change is to be made, whether the basic nature or scope of the construction work will be changed or not.
b) Technical justification and reason for the variation quantity of work.
c) Whether it is included in the approved budget program or not.

2.5.2 Price Adjustment

A per the rule 119 of the regulation, the following matters shall be set out in the procurement contract regarding price adjustment:

a) Circumstances in which price adjustment may be made
b) The formula to determine it,
   In determining a formula pursuant to this clause, the formula shall be so determined as to adjust the price only of labor, material and equipment used in the work completed.
c) Maximum amount of price adjustment
d) Component of price to be used in the formula under clause (b) (the price of labor, equipment, materials, fuel etc.),
e) The relevant price indices to be used to adjust each price component.
f) The manner of measuring the fluctuations of exchange rate between the currency to be used for making payment,
g) Baseline data to be taken for taken for the application of the price adjustment formula,
h) Interval of time for the application of the price adjustment formula,

i) Minimum price escalation to be demonstrated by the application of the price adjustment formula and other conditions and restrictions to be fulfilled for the application of the provision relating to price adjustment.

According to the rule, the maximum amount of price adjustment to be made shall not generally be more than twenty five percent of the original contract price. The procurement contract may provide that if the amount of price adjustment exceeds that price, the public entity may terminate the procurement contract or negotiate with the construction entrepreneur, supplier, service provider or consultant in order to limit the contract price within the approved budget or may pursue other measures or that additional budget shall be arranged.

2.5.3 Extension of period of procurement contract

According to the rule 120 of the regulation, on receipt of an application for contract period extension, the competent authority may make, or cause to be made inquiry into the matter. The following matters should be considered:

a) Whether the concerned construction entrepreneur, supplier, service provider or consultant has made best efforts to complete the work under the procurement contract in time or not,
b) Whether the concerned public entity has provided the construction entrepreneur, supplier, service provider or consultant with the matters required to be provided under the contract or not,
c) Whether the delay in work has been made because of the requirement of documents
d) Whether the delay in work has been made because of a *force majeure* event or not.

If the reason referred to in the application appears to be reasonable, the authority accepting the bid may extend the term up to fifty percent of the original term of the contract. The extension beyond this period has to be approved by the Council of Minister of Government of Nepal. CIAA has provided its recommendation regarding the loopholes and the improvements that can be made to the existing public procurement rules and regulations. The latest amendments to the public procurement regulation have made it mandatory for the public entity to call for bids only after the budget has been ensured and project site made available for construction. The amendment has also made provision for a maximum time extension of Fifty percent of the initial contract duration. Contractors/Suppliers have been granted an year for completing their projects and also made provisions to ensure that contracts are awarded according to the financial and technical capacity of the bidder. Similarly time durations have been fixed for public entities to make decisions regarding contractual issues such as time extension. (CIAA, 2020)

CHAPTER 3 RESEARCH METHODOLOGY

Research is the systematic, controlled, empirical and critical investigation of hypothetical propositions about presumed relations among natural phenomena. (Kerlinger, 1970)

Research methodology is specific procedures of techniques used to identify, select, process and analyze information about a topic. In a research, methodology section allows the readers to critically evaluate a study's overall validity and reliability. The methodology section answers two main questions; how was the data collected or generated? How was it analyzed?

In this research, I have utilized the unique capacity of fuzzy inference system to quantify the risk magnitude of various factors from the qualitative linguistic data provided by the experts. The accuracy and reliability of the data obtained from the fuzzy inference model is validated through comparison with sample set of completed bridges.

3.1 Conceptual Framework

A conceptual framework is a synthesis of interrelated components and variables which help in solving a real-world problem. The development of a conceptual framework begins with a deductive assumption that a problem exists, and the application of processes, procedures, functional approach, models, or theory may be used for problem resolution.(Leshem, 2007)

A conceptual framework has been prepared for the research. Various steps of the research have been summarized graphically in the conceptual framework. The framework shows the step-by-step process adopted in the research. In the first stage, the risk factors are identified and classified to generate a questionnaire survey. The survey is distributed to respondents from client, consultant and contractor. The risk factors are ranked by using the fuzzy inference model. Similarly, the data is verified using the analysis of sampled bridges. After verifying the correlation between the two data series, the results obtained from the model are further assessed to obtain results.

The sampled bridges are studied in detail to understand the risk factors causing cost overrun and time delay. The secondary sources of data were EOT recommendations provided by consultants, internal memo used by the public entities executing the project and field reports. Further clarifications were obtained through primary sources of data such as stakeholders involved in the project. A case specific approach was adopted to better understand risk factors. Individuals involved in sampled bridges were interviewed personally and through telephone communication to identify the specific cause for cost overrun and time delay.

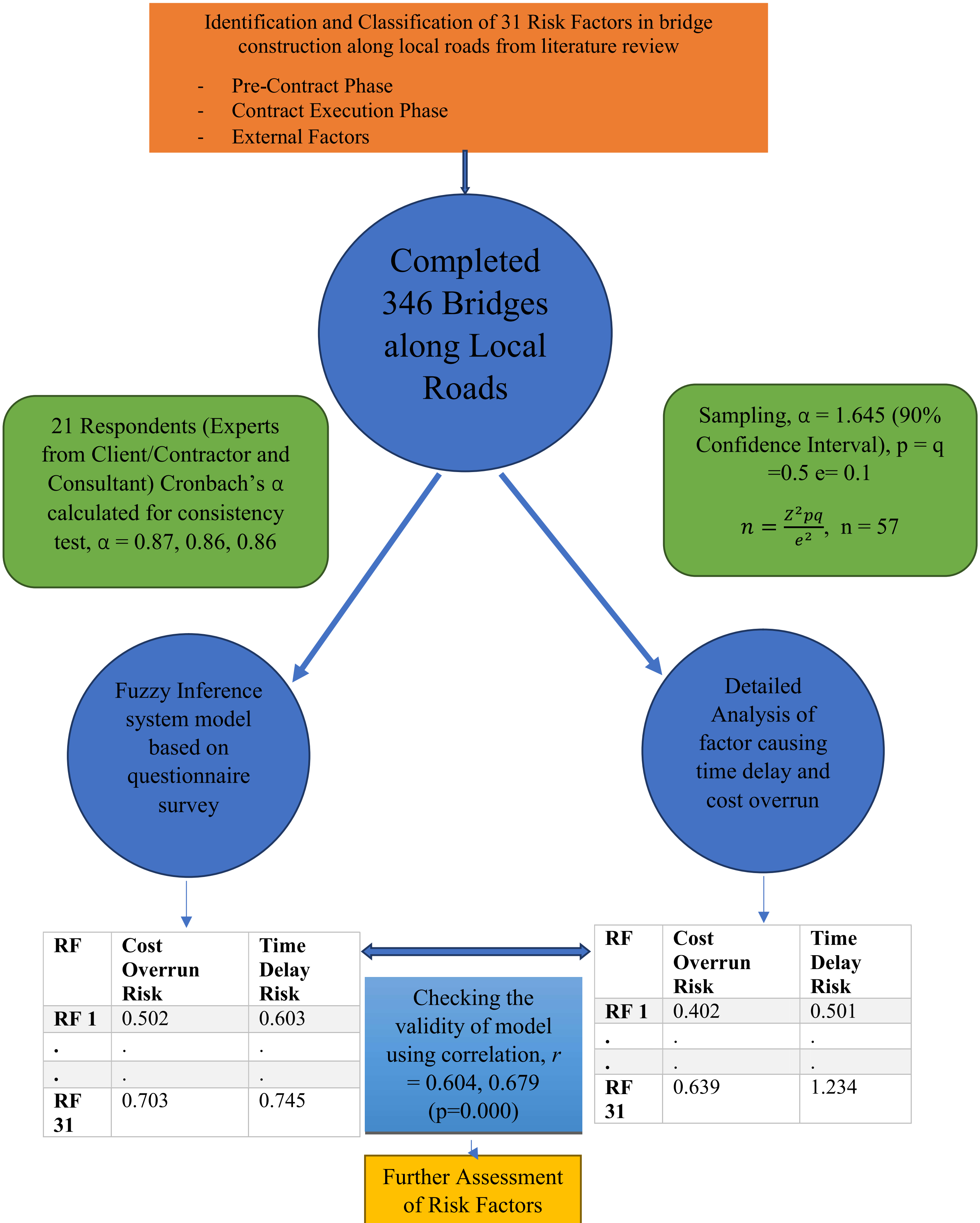


Fig 3. 1 Conceptual Framework

3.2 Cost overrun and time delay factor identification

Extensive literature review was done to identify the factors causing cost overrun and time delay in construction projects. Factors were identified for both developed and developing countries. The risk factors were also identified for various geographical regions. On the basis of the above studies and with the opinion of experts in local road bridge construction, 31 risk factors were identified. The factors were further sub-grouped into following three categories based on the period of contract when they can be mitigated:

A. Risk Factors in Pre-Contract Phase
B. Risk Factors in Contract Execution Phase
C. External Risk Factors

The table below shows the commonly occurring risk factors in local road bridge construction.

Table 3. 1 Risk Factor Identification

Risk Factor Number	Risk Factor
	A. Risk Factors in Pre-Contract Phase
RF 1	Unexpected Ground Condition
RF 2	Faulty Design
RF 3	Unrealistic Cost Estimate
RF 4	Land Acquisition Issues
RF 5	Inappropriate Project Selection
RF 6	Unscientific Contract Duration
RF 7	Utility Relocation (Electric Poles, Irrigation Canals)
RF 8	Environmental Permits
RF 9	Government Regulation/Contract Awarded to Lowest Bidder
RF 10	Social Issues at Site
RF 11	Regional Topography and access to site
RF 12	Ineffective Contract Document
	B. Risk Factors in Contract Execution Phase
RF 13	Inadequate Budget Allocation/ Delay in Payments
RF 14	Frequent Transfer of Project Staff
RF 15	Unrealistic Low Bid
RF 16	Lengthy Decision-Making Process/Bureaucratic Hurdles
RF 17	Inexperienced Consultant
RF 18	Inexperienced Contractor/Sub-Contractor
RF 19	Delay in approval of design
RF 20	Outdated Construction Technique/Practices
RF 21	Safety Related Issues
RF 22	Shortage of Equipment
RF 23	Improper Financial Management/ Misuse of Mobilization

RF 24	Lack of Coordination/Cooperation between Stakeholders
RF 25	Contractual Disputes
RF 26	Contractor's Financial Problems
	C. External Risk Factors
RF 27	Political Instability
RF 28	Force Majeure
RF 29	Large Variation in Raw Material Prices
RF 30	Non-availability of Construction Material
RF 31	Non-availability of Skilled/Unskilled Manpower

3.3 Reliability Test:

Cronbach's alpha is a measure of internal consistency. This parameter is a representation of the closeness of a set of items are as a group. This value is considered to be a measure of scale reliability. In a strictly technical manner, this parameter is not a statistical test but a coefficient of reliability/consistency.

A high level for α implies that the items are highly correlated. However, α is dependent on the number of items in a test. A large number of items can result in a high value of α and a small number of items may result in smaller value. Adding more relevant items to the test can increase α. Poor interrelatedness between test questions can also cause low values, so can measuring more than one latent variable.(Lavrakas, 2008) Some typical values of α and associated reliability have been shown in table below:

Table 3. 2 Alpha cronbach value (Konting et al., 2009)

Alpha Cronbach Value (α)	Interpretation
0.91-1.00	Excellent
0.81-0.90	Good
0.71-0.80	Good and Acceptable
0.61-0.70	Acceptable
0.01-0.6	Non acceptable

3.4 Model Development using Fuzzy Logic Toolbox of the MATLAB program software

The assessment of risk magnitude of the factors causing cost overrun and time delay is based on fuzzy theory. Following steps are performed to calculate the risk magnitude for cost overrun and time delay using Fuzzy Logic Toolbox of the MATLAB program software. (Toolbox, 1995)

3.4.1 Defining Input and Output

The two major inputs in risk assessment are the probability of occurrence of a risk and the severity of the risk if the risk were to manifest itself. Therefore, the Probability Index (PI) and Severity Index (SI) for risk factors associated with cost overrun (PI, SIC) and time delay (PI, SIT) are used as input variable in this model. The output of the model is the risk magnitude for an individual risk factor denoted by risk magnitude for cost overrun (FIC) and risk magnitude for time delay (FIT) as shown in Fig. 3.2 and Fig. 3.3.

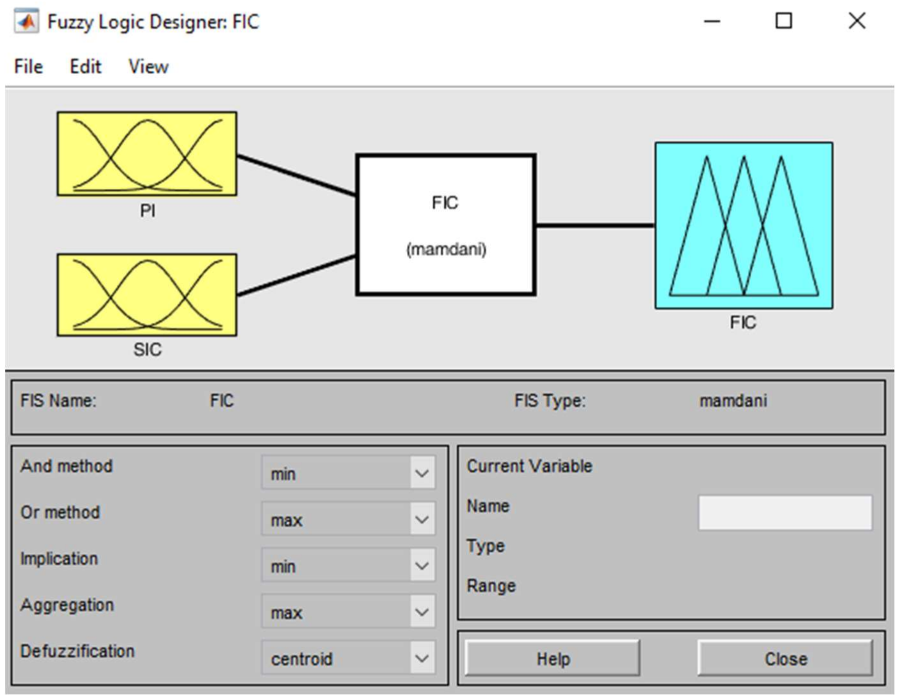


Fig 3. 2 Fuzzy Logic Designer (FIC)

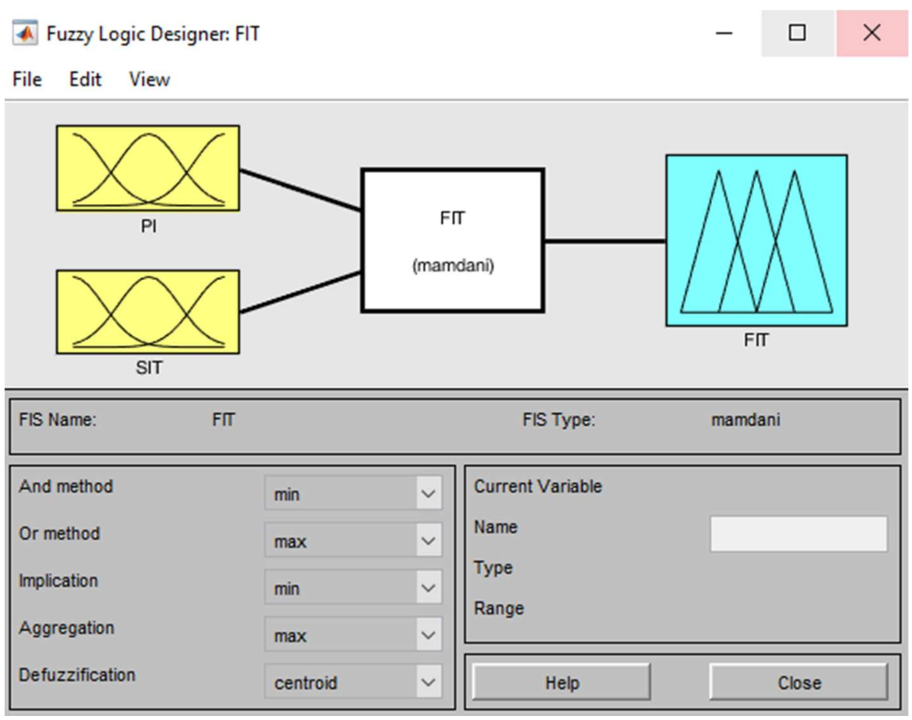


Fig 3. 3 Fuzzy Logic Designer (FIT)

3.4.2 Membership Function

Triangular membership function has been used in this research for input and output variables. The triangular fuzzy values of each linguistic variable such as PI, SIC, SIT, FIC and FIT have been shown in Table 3.3 and Table 3.4. The graphical presentation of membership function for these variables have been shown in Fig, Fig and Fig respectively

Table 3. 3 Input Table

Fuzzy variable	Fuzzy Number
Very Low	0, 0, 0.25
Low	0, 0.25, 0.50
Medium	0.25, 0.5, 0.75
High	0.5, 0.75, 1
Very High	0.5, 1, 1

Table 3. 4 Output Table

Fuzzy Variable	Fuzzy Number
Low	0, 0, 0.3333
Medium	0, 0.3333, 0.6667
High	0.3333, 0.6667, 1
Very High	0.6667, 1, 1

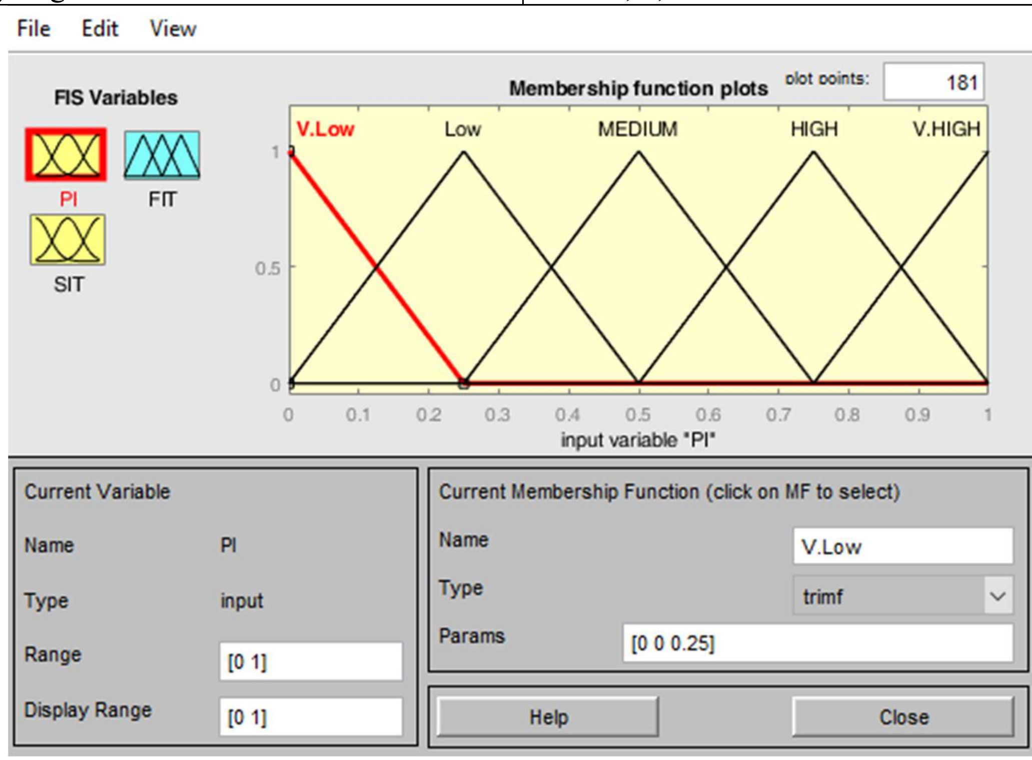


Fig 3. 4 Membership function for PI

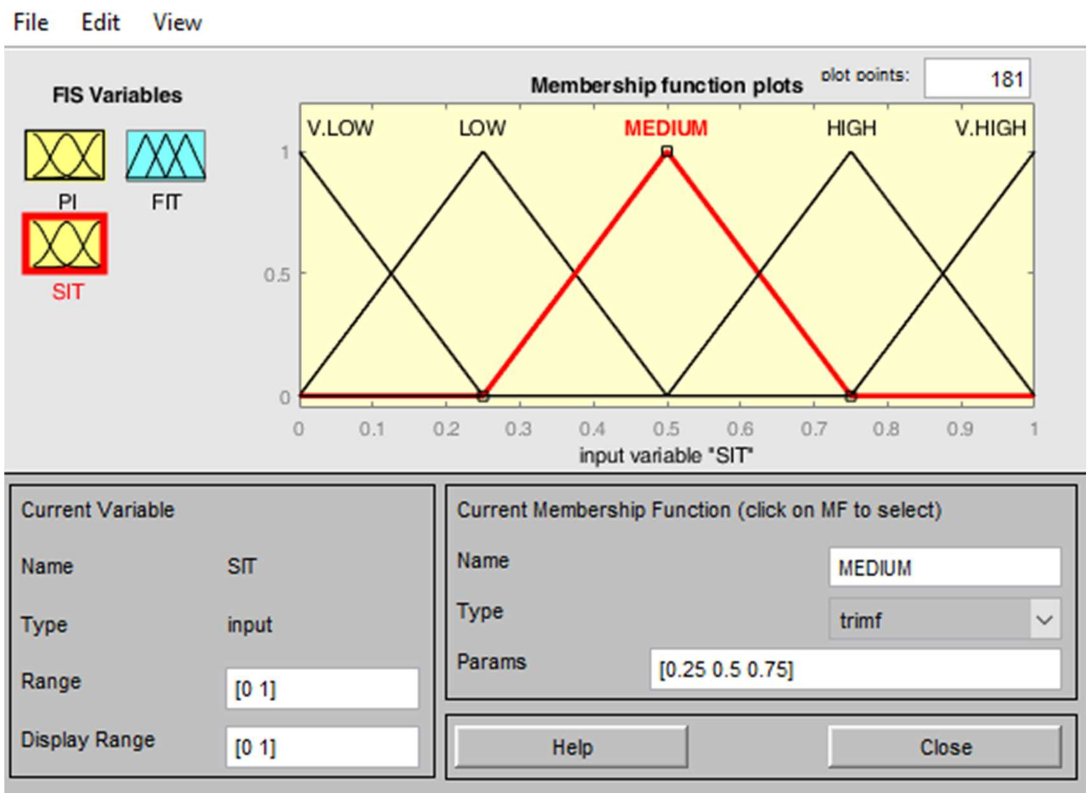


Fig 3. 5 Membership function for SIT

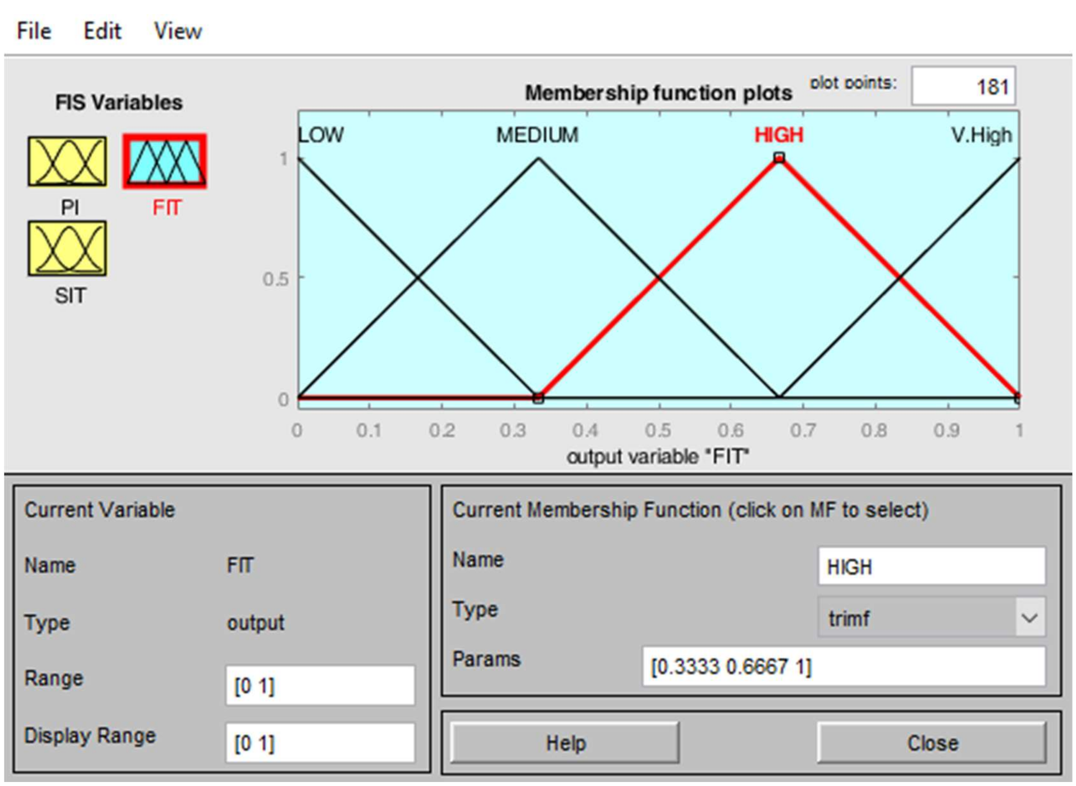


Fig 3. 6 Membership function for FIT

3.4.3 Formation of Rules

We use the probability index and the severity index as the antecedent part of the IF-THEN rule and FIC or FIT as the consequent part. The relationship among these parameters is needed to introduce logical rules for the two inputs (probability index and severity index for each factor) and output FIC/FIT. PMBOK risk matrix shown below is used to define the relationship between inputs and outputs.

Table 3. 5 Risk Matrix

Fuzzy Index for cost overrun/ time-delay	Probability of Occurrence				
	Very Low	Low	Medium	High	Very High
Severity Level					
Very Low	Low	Low	Medium	High	High
Low	Low	Low	Medium	High	Very High
Medium	Low	Medium	High	Very High	Very High
High	Medium	High	High	Very High	Very High
Very High	High	High	Very High	Very High	Very High

In general, if x is the number of fuzzy sets representing one input variable and y is the number of fuzzy sets representing second input variable, then maximum number of propositions that can be written is x*y. Since, there are five fuzzy sets in both the variable, the total number of propositions is 25. Some examples of these propositions are as follows:

1. If probability index is Medium and severity index is High then fuzzy index for cost overrun or time delay is High.
2. If probability index is High and severity index is Medium then fuzzy index for cost overrun or time delay is Very High.
3. If probability index is Very High and severity index is High then fuzzy index for cost overrun or time delay is Very High.

The above displayed rules are generated using the rule editor of Fuzzy Logic Toolbox of the MATLAB program software as shown in Fig. 3.7. The rule editor automatically generates rule statements based on the descriptions of the input and output variables defined with the FIS Editor.

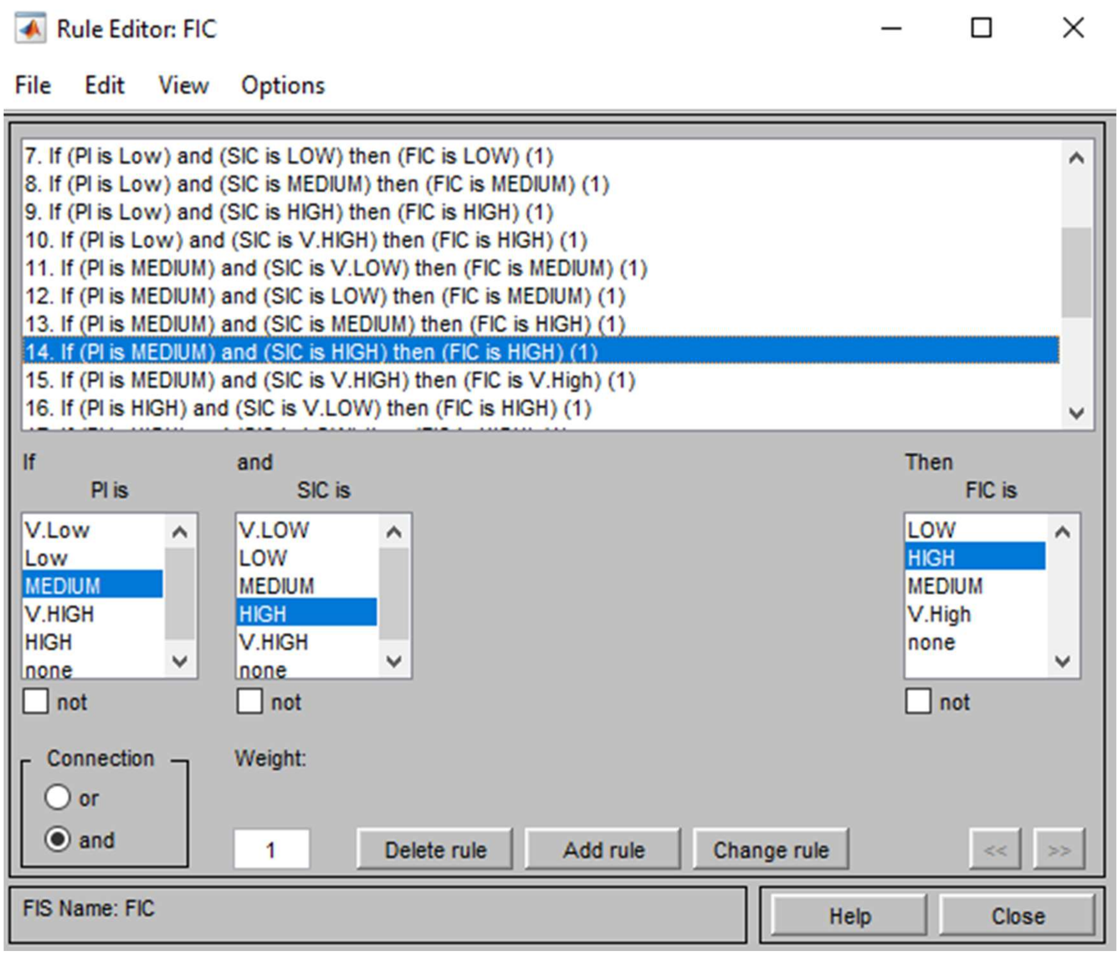


Fig 3. 7 Rule Editor: FIC

3.4.4 Defuzzification

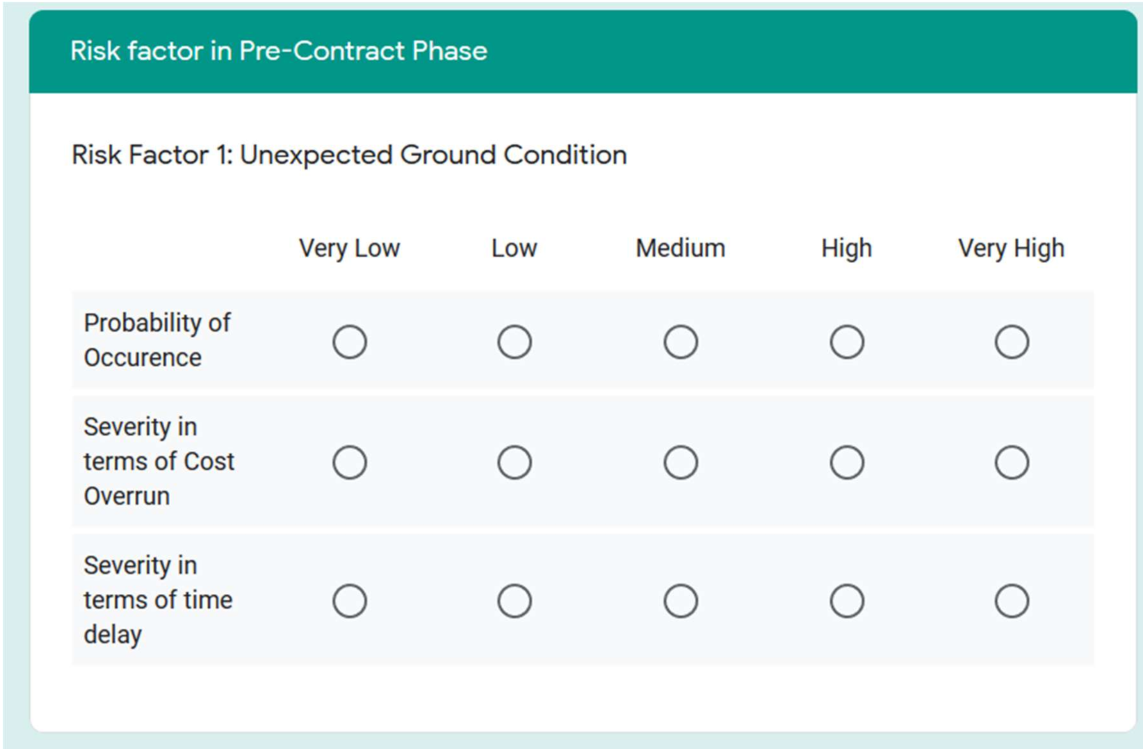
Crisp output value is generated from the combined fuzzy output through the process of defuzzification. The magnitude of Fuzzy Index for Cost-overrun (FIC) and Fuzzy Index for Time-delay (FIT) is determined as an exact number within the interval of 0 and 1. The Rule Viewer represents a complete roadmap of the whole fuzzy inference process. The graphical representation enables us to visualize the inference process. The complete procedure is shown in the rule viewer window of Fuzzy Logic Toolbox of the MATLAB program software as shown in Fig. 3.8.

Fig 3. 8 Rule Viewer: FIC

3.5 Data Collection

The data was collected from experts of different stakeholders (Client, Supervision Consultant and Contractor). For this purpose, a questionnaire survey was prepared and dispatched to individuals with long term experience in local road bridge construction. The data obtained from MLRBP bridge catalogue was used to determine the contractors who had frequent involvement in the construction of 346 bridges. Similarly, mid to high level technical experts of LRBSU were requested for their input into the research. Program Coordinators and Project Engineers involved in LBS/DOLI provided their expert opinions based on their long-term managerial experience in local road bridge construction.

A set of questionnaires used has been attached in Appendix A.



Risk factor in Pre-Contract Phase

Risk Factor 1: Unexpected Ground Condition

	Very Low	Low	Medium	High	Very High
Probability of Occurence	○	○	○	○	○
Severity in terms of Cost Overrun	○	○	○	○	○
Severity in terms of time delay	○	○	○	○	○

Fig 3. 9 Questionnaire Survey

3.6 Average of Expert's Opinion

To calculate the average of expert's opinion, the fuzzy average operation for aggregate method that is known as the "Triangular Average Formula" is used.

Triangular Average Formula for n number of experts. Consider n experts and fuzzy number

$A_i = (a_1^{(i)}, a_m^{(i)}, a_2^{(i)})$, i = 1, 2, 3 … n.

The average of n fuzzy number can be calculated as

$A_{avg} = (A_1 + ….. + A_n)/n$

$A_{avg} = ((a_1^{(1)}, a_m^{(1)}, a_2^{(1)}) + ….. + (a_1^{(n)}, a_m^{(n)}, a_2^{(n)}))/n$

Using the above formula, Average value of Probability Index (PI) and Severity Index (SI) can be determined. To obtain a crisp value, the fuzzy value (a_1, a_m, a_2), then get converted into best non fuzzy performance (BNP) value using the following formula :

$((a_2-a_1) + (a_m-a_1))/3 + a_1$

Using the probability and severity index FIC of a specific risk factor can be calculated. This represents the magnitude of the risk factor. A typical calculation sample for Risk Factor 17 has been shown in Appendix B.

3.7 Data Verification

3.7.1 Sample Size Determination

The most ideal case for determining the characteristics of a population is to study the entire population. The population includes a total of 350 bridges constructed through unit rate NCB contract in different districts of Nepal in a period of 8 years. The economical and practical limitations of the approach of using the entire population compels us to resort to sampling. Researchers mostly prefer using formulas for determining the sample size.(Singh & Masuku, 2012) Most commonly used formulas include Cochran's formula, Cohen's formula, Yamane's formula and Rao's formula.

Total sample size n is calculated from the finite population as shown below using Cochran equation.

$$n = \frac{Z^2pq}{e^2}$$

Where, Z : Z-score for level of significance (for 90% confidence interval) = 1.645 (from the Z table)

$p = q = 0.5$ (for maximum sample size)

e = margin of error = 10% =0.1

$$n = \frac{1.645^2 * 0.5 * 0.5}{0.1^2}$$

n = 67.65 i.e., approximately 68 samples

For finite population:

$$n = \frac{n}{1 + \frac{n-1}{population\ size}}$$

$$n = \frac{68}{1 + \frac{68-}{346}}$$

$n = 56.96$ (Approximately 57 samples)

Cost overrun and time delay data for 57 bridges constructed along non-strategic roads were collected and analyzed in detail.

The sampled bridges are studied in detail to understand the risk factors causing cost overrun and time delay. The secondary sources of data were EOT recommendations provided by consultants, internal memo used by the public entities executing the project and field reports. Further clarifications were obtained through primary sources of data such as stakeholders involved in the project. A case specific approach was adopted to better understand risk factors. Individuals involved in sampled bridges were interviewed personally and through telephone communication to identify the specific cause for cost overrun and time delay.

3.7.2 Process for calculating the time delay

Time delay value for an individual risk factor =

$$\frac{Number\ of\ days\ extended\ due\ to\ occurence\ of\ a\ risk\ factor}{Initial\ contract\ duration\ of\ the\ project}$$

3.7.3 Process for calculating the cost overrun

a) Variation

Cost overrun value for an individual risk factor =

$$\frac{Variation\ amount\ due\ to\ occurence\ of\ a\ risk\ factor}{Initial\ contract\ amount\ of\ the\ project}$$

b) Contract Price Adjustment

First the approximate CPA in case of no time extension is calculated using the following formula:

CPA without EOT = *Average Price Adjustment Coefficient x Mobilization deduction coefficient x Contract Amount*

This value is deducted from the actual CPA to obtain the additional CPA because of time extension.

Additional CPA because of EOT = *Actual CPA given – CPA without EOT*

The additional CPA is now distributed according to the weightage of time extension factors as follows

Cost overrun value for and individual risk factor =

$$\frac{Number\ of\ days\ extended\ due\ to\ occurence\ of\ a\ risk\ factor}{Initial\ contract\ duration\ of\ the\ project} \text{x} \frac{Additional\ CPA\ because\ of\ EOT}{Initial\ contract\ amount\ of\ the\ project}$$

A detailed sample calculation of Bridge Number-17 has been included in the Appendix C.

3.7.4 Testing Validity of the Model

The validity of the fuzzy inference system model is tested by comparing with the data obtained from file analysis of 57 sampled bridges.

Correlation:

A correlation exists between two variables when the values of one variable are somehow associated with the values of the other variables. A linear correlation exists between two variables when there is a correlation and the plotted points of paired data results in a pattern that can be approximated by a straight line. The linear correlation coefficient *r* measures the strength of the linear correlation between the paired quantitative x values and y values in a sample. The linear correlation coefficient *r* is computed by using the formula below. This coefficient is sometimes referred to as the Pearson product moment correlation coefficient in honor of Karl Pearson (1857-1936), who originally developed it. (Triola, 2011)

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{n(\sum x^2)-(\sum x)^2}\sqrt{n(\sum y^2)-(\sum y)^2}}$$

Hypothesis Testing

In conducting a formal hypothesis test to determine whether there is a significant linear correlation between two variables, the following null and alternative hypotheses that use *r* to represent the linear correlation coefficient of the population:

Null Hypothesis H_o: $r = 0$ (No Correlation)

Alternative Hypothesis H_1: $r \neq 0$ (Correlation)

The t test statistics can be found out using the following formula

Test Statistic

$$t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}}$$

With n-2 degrees of freedom

When using the above *t* test statistic, P-Values and critical values can be found using standard tables.

If the absolute value of the test statistic exceeds the critical values, reject H_o: $r = 0$. Otherwise, fail to reject H_o. If H_o is rejected, conclude that there is a significant linear correlation. If you fail to reject H_o, then there is not sufficient evidence to conclude that there is a linear correlation.

CHAPTER 4 DATA ANALYSIS AND DISCUSSION

The data obtained from the questionnaire survey of 21 respondents, values of cost-overrun index and time delay index of 31 risk factors based on the questionnaire survey, total cost overrun risk factor coefficient and total time delay risk factor coefficient of 31 risk factors obtained from 57 sampled bridges have been summarized and compared below. Tables, statistical analysis and figures have been used to display and compare the raw data more effectively. The data was collected primarily by the means of Google forms and hard copy questionnaire responses. The collected data was exported to Microsoft Excel for calculation of parameters such Cronbach's Alpha, PI, SI, BNP, FIC and FIT. SPSS was used for testing the hypothesis regarding correlation between the model and the sampled data.

4.1 Respondent Profile

The targeted respondents were professionals (Engineers, Project Managers, Bridge Design Engineers, Team leaders) who were primarily involved in the contract management for local road bridge construction. Team leader, bridge design engineers and regional bridge coordinators representing the consultants involved in the local road bridge program were requested to provide their inputs. A total number of seven respondents involved in a middle to high level management positions were requested to provide their input.

A total of seven respondents representing the clients were present. This included program coordinators and project engineers of the LBS, DoLI. To provide equal weightage to all stakeholders, 7 responses were recorded on behalf of contractor. The contractors with higher frequency of involvement in the LRBP program were asked to provide their input in the formation of model.

Different demographic information of respondents of the survey has been summarized and presented hereunder.

Age: Majority of the respondents fall in to the 31-40 age group (47.6%), followed by the age group 21-30 (33.3). The >50 age group constitutes the lowest number of respondents.

It is noteworthy that none of the respondents were from the age group <20 and 41-50. The figure below shows the distribution of respondents from various age groups.

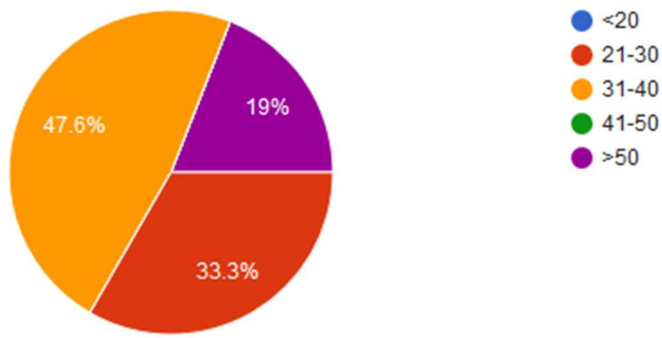


Fig 4. 1 Age Demographic of Respondents

Organization: Equal number of respondents (Seven, 33.3% each) were involved from Consultant/Non-Government Organization, Employer/Government Organization and Contractor/Private Sector. This was according to design to provide equal weightage to all the stakeholders and achieve an unbiased model.

Educational Qualification: The number of respondents who have completed undergraduate studies and graduate studies is almost equal. Out of total 21 respondents, 11 (52.4%) had completed Master's degree and 10 (47.6%) had completed Bachelor's degree. None of the respondents had a PhD qualification. The figure below shows the distribution based on educational qualification.

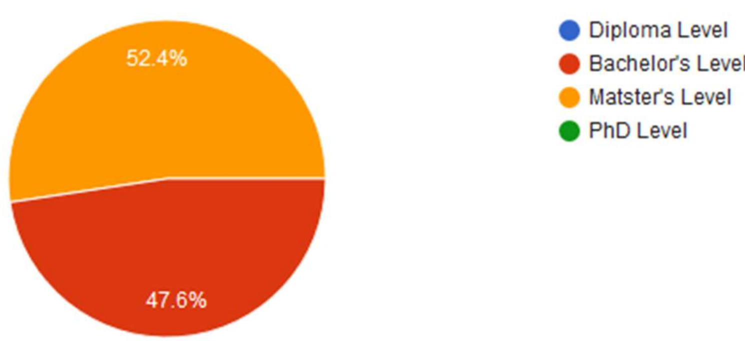


Fig 4. 2 Educational Qualification of Respondents

Overall Experience: Most of the respondents (13, 61.9%) have worked in civil engineering field for a period of 6-10 years. The age groups of 2-5 and >16 both had four number of respondents, each occupying 19% of the share of respondent demographics. It is noteworthy that none of the respondents had overall experience of 11-15 years. This is consistent with the age demographic of the respondents. The figure below shows the distribution based on overall experience.

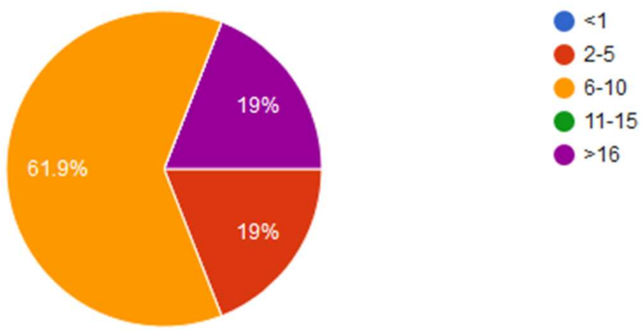


Fig 4. 3 Overall Experience of Respondents

Number of years worked in bridge construction: A large portion, almost half (52.4%) of the respondents have worked in bridge construction for 6-10 years. This is followed by the age group 2-5 years, which includes 28.6% respondents. 2 respondents (9.5%) have more than 16 years of experience in bridge construction. 1 respondent (4.8%) have less than one years of experience and another respondent (4.8%) had 11-15 years of experience in bridge construction. This data shows that almost all respondents have at least 2 years of experience in bridge construction. The figure below summarizes the demographic distribution for number of years worked in bridge construction.

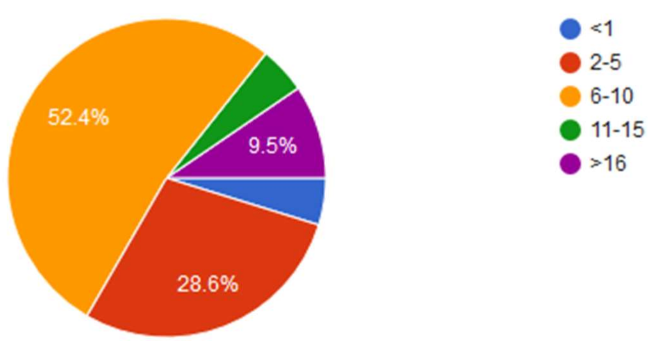


Fig 4. 4 Experience in Bridge Construction of Respondents

The table below summarizes the demographic information of the respondents

Table 4. 1 Demographic information of Respondents

Demographic Parameter	Categories	Frequency	Total Percentage
Age	<20	0	0
	21-30	7	33.33
	31-40	10	47.6
	41-50	0	0
	>50	4	19
Organization	Consultant/NGO	7	33.3
	Employer/Government Organization	7	33.3
	Contractor/Private Sector	7	33.3
	Academic	0	0
Educational Qualification	Diploma Level	0	0
	Bachelor's Level	10	47.6
	Master's Level	11	52.4
	PhD Level	0	0
Experience in Years	<1	0	0
	2-5	4	19
	6-10	13	61.9
	11-15	0	0
	>16	4	19
Number of Years worked in Bridge Construction	<1	1	4.8
	2-5	6	28.6
	6-10	11	52.4
	11-15	1	4.8
	>16	2	9.5

4.2 Internal Consistency Test

The values of Cronbach's Alpha (α) for the responses related to Probability of occurrence of a risk, severity in terms of cost overrun and Severity in terms of time delay was calculated using MS Excel. Detailed calculation sheet has been attached in Appendix. The output of consistency test has been shown in the table below:

Table 4. 2 Calculated Value of Cronbach's α

Parameter	Cronbach's Alpha (α)
Probability of Occurrence of a Risk	0.87
Severity in terms of Cost-Overrun	0.86
Severity in terms of Time-Delay	0.86

According to konting et. al., 2009, interpretation of this value is good.

4.3 Output of Fuzzy Inference System Model

4.3.1 Cost Overrun

The table below shows the values of probability of occurrence and the severity in terms of cost overrun for a specific risk factor obtained from the response of questionnaire survey by experts. The table also shows the Fuzzy Inference value for cost overrun obtained from the model.

Table 4. 3 FIC Values

RF No.	Risk Factor	PI	SIC	FIC
	A. Risk Factor in Pre-Contract Phase			
RF 1	Unexpected Ground Condition	0.631	0.675	0.713
RF 2	Faulty Design	0.409	0.619	0.526
RF 3	Unrealistic Cost Estimate	0.393	0.603	0.519
RF 4	Land Acquisition Issues	0.369	0.310	0.396
RF 5	Inappropriate Project Selection	0.397	0.504	0.524
RF 6	Unscientific Contract Duration	0.476	0.429	0.557
RF 7	Utility Relocation (Electric Poles, Irrigation Canals)	0.409	0.325	0.425

RF No.	Risk Factor	PI	SIC	FIC
RF 8	Environmental Permits	0.341	0.381	0.433
RF 9	Government Regulation/Contract Awarded to Lowest Bidder	0.742	0.472	0.791
RF 10	Social Issues at Site	0.508	0.349	0.472
RF 11	Regional Topography and access to site	0.591	0.619	0.692
RF 12	Ineffective Contract Document	0.357	0.365	0.443
	B. Risk Factor is Contract Execution Phase			
RF 13	Inadequate Budget Allocation/ Delay in Payments	0.667	0.591	0.741
RF 14	Frequent Transfer of Project Staff	0.615	0.302	0.499
RF 15	Unrealistic Low Bid	0.599	0.373	0.527
RF 16	Lengthy Decision-Making Process/Bureaucratic Hurdles	0.472	0.440	0.569
RF 17	Inexperienced Consultant	0.567	0.429	0.573
RF 18	Inexperienced Contractor/Sub-Contractor	0.552	0.492	0.659
RF 19	Delay in approval of design	0.472	0.357	0.478
RF 20	Outdated Construction Technique/Practices	0.615	0.369	0.532
RF 21	Safety Related Issues	0.651	0.306	0.538
RF 22	Shortage of Equipment	0.571	0.365	0.506
RF 23	Improper Financial Management/ Misuse of Mobilization	0.599	0.361	0.515
RF 24	Lack of Coordination/Cooperation between Stakeholders	0.544	0.365	0.496
RF 25	Contractual Disputes	0.413	0.579	0.541
RF 26	Contractor's Financial Problems	0.583	0.421	0.569
	C. External Risk Factors			
RF 27	Political Instability	0.544	0.417	0.552
RF 28	Force Majeure	0.468	0.643	0.602
RF 29	Large Variation in Raw Material Prices	0.464	0.536	0.606

RF No.	Risk Factor	PI	SIC	FIC
RF 30	Non-availability of Construction Material	0.452	0.413	0.532
RF 31	Non-availability of Skilled/Unskilled Manpower	0.476	0.389	0.512

4.3.2 Time Delay

The table below shows the values of probability of occurrence and the severity in terms of time delay for a specific risk factor obtained from the response of questionnaire survey by experts. The table also shows the Fuzzy Inference value for cost overrun obtained from the model.

Table 4. 4 FIT Values

RF No.	Risk Factor	PI	SIT	FIT
	A. Risk Factor in Pre-Contract Phase			
RF 1	Unexpected Ground Condition	0.631	0.694	0.713
RF 2	Faulty Design	0.409	0.476	0.534
RF 3	Unrealistic Cost Estimate	0.393	0.357	0.449
RF 4	Land Acquisition Issues	0.369	0.413	0.471
RF 5	Inappropriate Project Selection	0.397	0.444	0.512
RF 6	Unscientific Contract Duration	0.476	0.639	0.615
RF 7	Utility Relocation (Electric Poles, Irrigation Canals)	0.409	0.405	0.505
RF 8	Environmental Permits	0.341	0.524	0.463
RF 9	Government Regulation/Contract Awarded to Lowest Bidder	0.742	0.619	0.847
RF 10	Social Issues at Site	0.508	0.437	0.57
RF 11	Regional Topography and access to site	0.591	0.615	0.691
RF 12	Ineffective Contract Document	0.357	0.448	0.472
	B. Risk Factor in Contract Execution Phase			
RF 13	Inadequate Budget Allocation/ Delay in Payments	0.667	0.595	0.740
RF 14	Frequent Transfer of Project Staff	0.615	0.476	0.652

RF No.	Risk Factor	PI	SIT	FIT
RF 15	Unrealistic Low Bid	0.599	0.587	0.693
RF 16	Lengthy Decision-Making Process/Bureaucratic Hurdles	0.472	0.540	0.617
RF 17	Inexperienced Consultant	0.567	0.512	0.679
RF 18	Inexperienced Contractor/Sub-Contractor	0.552	0.643	0.676
RF 19	Delay in approval of design	0.472	0.540	0.617
RF 20	Outdated Construction Technique/Practices	0.615	0.524	0.702
RF 21	Safety Related Issues	0.651	0.393	0.566
RF 22	Shortage of Equipment	0.571	0.520	0.681
RF 23	Improper Financial Management/ Misuse of Mobilization	0.599	0.647	0.694
RF 24	Lack of Coordination/Cooperation between Stakeholders	0.544	0.552	0.673
RF 25	Contractual Disputes	0.413	0.532	0.541
RF 26	Contractor's Financial Problems	0.583	0.639	0.687
	C. External Risk Factors			
RF 27	Political Instability	0.544	0.579	0.673
RF 28	Force Majeure	0.468	0.687	0.609
RF 29	Large Variation in Raw Material Prices	0.464	0.464	0.599
RF 30	Non-availability of Construction Material	0.452	0.552	0.588
RF 31	Non-availability of Skilled/Unskilled Manpower	0.476	0.548	0.623

4.4 Output of sampled Bridges

A total of 57 bridges were analyzed in detail to calculate the quantitative impact of the identified 31 risk factors causing cost-overrun and time-delay. The table below summarizes the numeric value of cost overrun and time delay risk factor obtained from analysis of individual bridges.

Table 4. 5 Summary of Sampled Bridges

RF No.	Risk Factor	Cost Overrun value	Time Delay Value
	A. Risk Factor in Pre-Contract Phase		
RF 1	Unexpected Ground Condition	1.100	3.502
RF 2	Faulty Design	0.342	1.095
RF 3	Unrealistic Cost Estimate	0.564	0.332
RF 4	Land Acquisition Issues	0.000	0.500
RF 5	Inappropriate Project Selection	0.313	0.945
RF 6	Unscientific Contract Duration	0.139	0.817
RF 7	Utility Relocation (Electric Poles, Irrigation Canals)	0.000	0.618
RF 8	Environmental Permits	0.000	0.164
RF 9	Government Regulation/Contract Awarded to Lowest Bidder	0.215	4.783
RF 10	Social Issues at Site	0.094	0.759
RF 11	Regional Topography and access to site	1.007	4.667
RF 12	Ineffective Contract Document	0.070	0.000
	B. Risk Factors in Contract Execution Phase		
RF 13	Inadequate Budget Allocation/ Delay in Payments	0.794	3.728
RF 14	Frequent Transfer of Project Staff	0.000	0.000
RF 15	Unrealistic Low Bid	0.000	2.424
RF 16	Lengthy Decision-Making Process/Bureaucratic Hurdles	0.065	0.536

RF No.	Risk Factor	Cost Overrun value	Time Delay Value
RF 17	Inexperienced Consultant	0.052	1.511
RF 18	Inexperienced Contractor/Sub-Contractor	0.018	2.380
RF 19	Delay in approval of design	0.000	1.411
RF 20	Outdated Construction Technique/Practices	0.000	0.000
RF 21	Safety Related Issues	0.000	0.000
RF 22	Shortage of Equipment	0.000	1.058
RF 23	Improper Financial Management/ Misuse of Mobilization	0.010	4.225
RF 24	Lack of Coordination/Cooperation between Stakeholders	0.000	0.392
RF 25	Contractual Disputes	0.510	0.739
RF 26	Contractor's Financial Problems	0.022	2.900
	C. External Risk Factors		
RF 27	Political Instability	0.725	2.972
RF 28	Force Majeure	0.623	2.569
RF 29	Large Variation in Raw Material Prices	0.676	0.250
RF 30	Non-availability of Construction Material	0.207	2.659
RF 31	Non-availability of Skilled/Unskilled Manpower	0.023	1.549

4.5 Validation of the Model

Table 4. 6 Correlation Table

RF No.	From Model		From File Analysis	
	FIC	FIT	Cost overrun value	Time Delay Value
RF 1	0.713	0.713	1.100	3.502
RF 2	0.526	0.534	0.342	1.095
RF 3	0.519	0.449	0.564	0.332
RF 4	0.396	0.471	0.000	0.500

RF No.	From Model		From File Analysis	
	FIC	FIT	Cost overrun value	Time Delay Value
RF 5	0.524	0.512	0.313	0.945
RF 6	0.557	0.615	0.139	0.817
RF 7	0.425	0.505	0.000	0.618
RF 8	0.433	0.463	0.000	0.164
RF 9	0.791	0.847	0.215	4.783
RF 10	0.472	0.57	0.094	0.759
RF 11	0.692	0.691	1.007	4.667
RF 12	0.443	0.472	0.070	0.000
RF 13	0.741	0.740	0.794	3.728
RF 14	0.499	0.652	0.000	0.000
RF 15	0.527	0.693	0.000	2.424
RF 16	0.569	0.617	0.065	0.536
RF 17	0.573	0.679	0.052	1.511
RF 18	0.659	0.676	0.018	2.380
RF 19	0.478	0.617	0.000	1.411
RF 20	0.532	0.702	0.000	0.000
RF 21	0.538	0.566	0.000	0.000
RF 22	0.506	0.681	0.000	1.058
RF 23	0.515	0.694	0.010	4.225
RF 24	0.496	0.673	0.000	0.392
RF 25	0.541	0.541	0.510	0.739
RF 26	0.569	0.687	0.022	2.900
RF 27	0.552	0.673	0.725	2.972
RF 28	0.602	0.609	0.623	2.569
RF 29	0.606	0.599	0.676	0.250
RF 30	0.532	0.588	0.207	2.659
RF 31	0.512	0.623	0.023	1.549
Pearson Correlation Coefficient (r)			0.604	0.679

4.6 Hypothesis Testing

Hypothesis Testing is carried out to determine the significance of correlation found between the values obtained from the model and the value obtained from file analysis.

4.6.1 Cost-overrun

Null Hypothesis H_o: $r = 0$
Alternative Hypothesis H_1: $r \neq 0$

Test statistics (t) = $\frac{r}{\sqrt{\frac{1-r^2}{n-2}}} = \frac{0.604}{\sqrt{\frac{1-0.604^2}{31-2}}} = 4.081$

For 29 degrees of freedom, $t_{critical,0.01,29} = 2.756$. Since $t > t_{critical}$, we reject the null hypothesis and accept the alternative hypothesis

4.6.2 Time-delay

Null Hypothesis H_o: $r = 0$
Alternative Hypothesis H_1: $r \neq 0$

Test statistics (t) = $\frac{r}{\sqrt{\frac{1-r^2}{n-2}}} = \frac{0.679}{\sqrt{\frac{1-0.679^2}{31-2}}} = 4.980$

For 29 degrees of freedom, $t_{critical,0.01,29} = 2.756$. Since $t > t_{critical}$, we reject the null hypothesis and accept the alternative hypothesis

Furthermore, the p-value is calculated from IBM SPSS and tabulated below.

Table 4. 7 Hypothesis Testing

Parameter	Pearson Correlation Coefficient (r)	Test Statistics	p-value
Cost Overrun	0.604	4.081	0.000
Time Delay	0.679	4.980	0.000

From this result, we can conclude that there is significant correlation between the values obtained from the model and the sample. Thus, the model has been validated and can be used for further risk assessment.

4.7 Assessment of individual risk factors.

Risk Factor 1 Unexpected Ground Condition

Unexpected Ground Condition is a very common problem in bridge construction. According to the questionnaire survey, this risk factor is the fourth most common risk factor. The high frequency of occurrence can be attributed to the difficulty in assessing the underground condition. Despite the presence of underground exploration techniques such as bore hole, there is uncertainty in underground strata.

Unexpected ground condition is a major factor contributing to the cost overrun in bridge projects. According to the Fuzzy inference model, it is ranked third among factors causing cost overrun. Unexpected ground conditions often lead to revision in the type of foundation. Bridge foundations are designed based on bearing capacity and other soil parameters obtained during DPR preparation. If these parameters are found to be different during construction process, the design has to be revised and in extreme conditions foundation type has to be changed. In case of some deep foundations, boring for pile and well sinking is not possible according to design and the foundation type has to be changed. Variation orders have to be issued to accommodate the change in design. Additional financial burden is created through EOT and accompanying CPA. In case of foundation type change, the construction equipments have to be changed. This leads to additional mobilization and demobilization expenditure. Contractors claim such amount which contributes to contract disputes and cost overrun.

Procurement contracts have to be often extended because of unforeseen ground conditions. Ground water table and slope stability are a major concern in open foundation. Bore hole logs and other exploratory mechanism are inefficient in predicting the water flow and slope stability. Unexpected water flow leads to additional drainage requirements and additional time for construction of foundation. For construction of deep foundation, difference in design and site conditions often leads to additional time requirement. This is also reflected in the time delay model as the factor ranked third among thirty-one factors.

Risk Factor 2 Faulty Design

According to the questionnaire survey, this risk factor was found to be relatively infrequent; ranked 24 among 31 factors. In accordance with the frequency of occurrence, the risk associated with faulty design in terms of cost overrun was found to be moderate overrun and low for time delay. Standard Superstructure drawings and typical sub-structure drawings have contributed towards lowering the risk associated with faulty design

Appropriate study should be carried out before finalizing design. Procurement of works without sufficient study and preparation followed by design review after award of contract has contributed towards delay and cost overrun. (CIAA, 2020)

Risk Factor 3 Unrealistic Cost Estimate

Unrealistic Cost Estimate was found to be highly infrequent according to the questionnaire survey. This factor is considered to be of low risk for cost overrun. Unrealistic cost estimate is common for ancillary structures such as protection works and approach road. Despite this common occurrence, the impact of such secondary structures in cost overrun is nominal. Unrealistic cost estimate has been ranked lowest by the fuzzy inference system time delay model. This result is justifiable as the unrealistic estimate is unlikely to cause major delay in bridge construction projects.

Risk Factor 4 Land Acquisition Issues

Land Acquisition Issues is among the least important factor in terms of probability of occurrence, cost overrun and time delay. This can be attributed to the point nature of the project and the fact that bridges are constructed over water bodies. Unlike linear infrastructure projects such as roads, irrigation canals and transmission towers, the extent of impact of bridge projects is limited. Since, most of the local road bridges are situated in existing road alignments, land acquisition issues are infrequent. Few land acquisition problems occur when the alignment has to be changed for locating suitable crossing point for the bridge. Considering the importance of bridge for all weather access, beneficiaries often offer up their land voluntarily for access road of bridge.

This risk factor is ranked lowest among 31 factors for cost overrun risk and 29^{th} for time delay risk. Thus, the risk associated is minimal.

Risk Factor 5 Inappropriate Project Selection

According to the questionnaire survey, this frequency of occurrence of this factor is very low. This can be explained by the fact that the MLRBP implemented a bridge prioritization and selection criteria. These criteria included the zone of influence, traffic count, beneficiaries, length of road made all weather accessible among other factors. Numeric ranking of bridges based on these criteria ensured appropriate and efficient project selection. Such practices should be given continuation in future bridge projects.

This risk factor is ranked 19 for cost overrun and 26 for time delay among 31 risk factors. Inappropriate project selection has low impact in terms of time delay.

Risk Factor 6 Unscientific Contract Duration

The likelihood of occurrence of unscientific contract duration in a bridge project is moderate. For instance, one of the bridges sampled from the population was located in mountainous region where it is impossible to carry out construction work during winter season. Despite this pre-determinable constraint, the contract period specified was kept same as equivalent projects in hill and terai region.

As per the fuzzy inference system model, the impact of this risk in terms of cost overrun is high and moderate for time delay. This risk factor is found to be relatively low risk compared to other factors considered for time delay. Despite the certainty in time extension, the magnitude is moderate for this risk factor. Considering the importance of this risk factor, further study is required to derive the appropriate contract duration. The parameters to be considered in derivation of this duration could be factors such as type of foundation, superstructure, geographical location of the bridge and access to site.

Risk Factor 7 Utility Relocation (Electric Poles, Irrigation Canals)

According to the questionnaire survey, this factor ranks 28 for the probability of occurrence. This risk is relatively uncommon for bridge projects. The limited extent of the project reduces the likelihood of problems related to utility relocation.

The fuzzy inference model ranks this risk among the least important factors for both cost overrun and time delay. The factor is ranked 30 and 27 for cost overrun and time delay respectively. In few bridge projects, minor irrigation scheme operating from the stream/river water have to be relocated. Considering the limited water flow of streams across which local bridges are constructed, the risk factor associated with relocating aforementioned irrigation schemes is quite low. Among the sampled bridge, there were few projects where the electric poles had to be relocated. But considering the relatively low number of relocation, the risk associated with both cost overrun and time delay where low.

Risk Factor 8 Environmental Permits

The respondents have regarded Environmental Permits as the least important factor in terms of frequency. This result can be attributed to the fact that most of the local bridges don't require environmental studies such as EIA and IEE. The criteria for environmental studies are related with the span of the bridge. Since most of local bridge spans are lower than the demarcated values of EPA and EPR, Environmental permit is not an important risk for bridge projects. Even for projects which require environmental study, the process for bridge is eased considering the limited impact region of the project.

Environmental permits have been placed in bottom three by the inference model for both cost overrun and time delay. Environmental permits become a serious risk factor for bridge which require cutting of trees. Few bridge projects have been delayed for months waiting for permission to cut trees. This has associated cost overrun consequences as well.

Risk Factor 9 Government Regulation/ Contract Awarded to Lowest Bidder

According to the questionnaire survey and the fuzzy inference model, this is the highest ranked risk factors in terms of probability of occurrence, cost overrun and time delay as well.

According to the Public Procurement Act, the contract is awarded to the lowest evaluated substantially responsive bid. The regulation also has provision of asking clarification from the bidder if the bid is found to have unbalanced rates or unrealistic low bid. The bid may be rejected specifying conditions such as front loading and contractor's lack of understanding of the project among other factors.

The practice of rejecting bids on the ground of unbalanced rates and unrealistic low bid is infrequent, because lowest responsive bid is considered as most economical to the procuring entity. The major factors influencing contractors to float an unrealistic low bid were found to be intention of winning the bid anyhow assuming the job performed will be accepted, mal-intention of pursuing claims and disputes, misuse of mobilization amount to manage financial problems, intention of performing sub-standard job compromising the quality of project in the absence of client. (Disti, 2011)

The research carried out by Disti, (2011) concerning scientific method for rejection of unrealistic low bids by adoption of a scientific method considering the following factors:

a. The method should be rational in all cases
b. The method should not discourage the innovative bidders

To generate a scientific basis for screening of bids, the following formulas have been studied in detail and tested:

1. Cumulative Probability Distribution (CPD) Approach
2. Average-Factor x Standard Deviation (AFSD) Approach (General)
3. Modified Average – Facot x Standard Deviation (m-AFSD) Approach
   i. Modified AFSD-1: $\mu - L1/E \times \sigma$
   ii. Modified AFSD-2: $\mu - L1/E \times \sigma$
   iii. Modified AFSD-3: $\mu - K(L1/E)^{p} \times \sigma$

   Where,

   μ = average value of all bids

   σ = standard deviation of all bids

   E = estimated value

   K = model constant

L1 = Lowest responsive bid

p = model power constant

The research found that Modified AFSD-3: $\mu - K(L1/E)^{p} \times \sigma$ was most suitable. The bid is awarded to the bidder for which the bid price is just above the value calculated from $\mu - K(L1/E)^{p} \times \sigma$ taking K = 3 and p =2.

Risk Factor 10 Social Issues at Site

The questionnaire survey ranks this factor as moderate probability of occurrence, low risk of time delay and very low risk of cost overrun. Social issues originate from the interaction between the local inhabitants and temporary stakeholders working in the project. Civil infrastructure operates within close proximity of local environment, this is especially true for local infrastructures. Despite the frequent occurrence of this factor, the impact in terms of cost overrun and time delay of this risk is moderate.

Risk Factor 11 Regional Topography and Access to site

Response to survey have indicated that probability of occurrence of this factor is frequent. This risk is very common in local road bridge construction site. There are relatively few non-strategic roads in Nepal which have all weather access. This places a constraint on the working time available for the construction of project. Regional Topography also greatly affects the construction of bridges. Meandering nature of bridge in the plain areas poses a great risk for approach road and protection works of bridge.

This factor has very high impact in terms of cost overrun and high impact for time delay according to the model. This can be interpreted with the example of few bridges in plain areas where an additional span was included to accommodate the regional topography causing outflanking of abutment structures. This is a very important factor which should be considered for risk mitigation. Appropriate hydrological study is necessary to understand and prevent risk related to regional topography.

Risk Factor 12 Ineffective Contract Document

This is one of the least frequent factors occurring in local road bridge construction projects according to the questionnaire survey. This factor has nominal importance in terms of both cost overrun and time delay. This can be attributed to the fact that PPMO standard bidding documents have incorporated recommendation obtained from real life management of contracts. For instance, in one of the sampled bridges, the bidder had failed to enter the price adjustment coefficients while submitting the bid. Despite this error, the contractor was awarded CPA through arbitration. The current document clearly states that failure to include coefficients implies forfeiting of right to claim CPA.

Risk Factor 13 Inadequate Budget Allocation/Delay in Payments

The respondents of questionnaire survey regarded this factor as one of the most commonly occurring risk. The evaluation and study of sampled bridges show that insufficient budget is allocated for projects at the beginning of fiscal year. Budget amendments are carried out at the end of fiscal year. It is very common for contractors in Nepal to work in a project according to the available budget.

The fuzzy inference system model ranked this factor as the second most important for both cost overrun and time delay. The inability to provide mobilization amount and payment of interim and final IPC within the stipulated time leads to claims and disputes for both time extension and additional payments. This risk factor is highly common in local bridge construction, but, appropriate measures can be taken to reduce the impact.

The inability to provide clear instructions to the contractors and carry out regular supervision is a shortcoming of the public entity. The line ministries and departments should carry out regular monitoring if or not the public entities have made payments according to the condition of contract. (CIAA, 2020)

Risk Factor 14 Frequent Transfer of Project Staff

According to the results of the questionnaire survey, frequent transfer of project staff is considered among the highly frequent risk factor. Despite the common occurrence of this risk factor, its impact for cost overrun is low and moderate for time delay. Frequent transfer of project staff disrupts the day to day working and smooth flow of project activities. It is notable to realize that none of the sampled bridges showed frequent transfer of project staff as risk for both cost overrun and time delay.

Risk Factor 15 Unrealistic Low Bid

This risk factor is regarded as frequent by experts involved in bridge construction along local roads. Despite the common occurrence, the cost overrun model predicts that impact of this risk is moderate. On the other hand, the impact of this risk for time delay is substantial.

Further research is warranted to better assess this risk and associated mitigation.

Risk Factor 16 Lengthy Decision-Making Process/Bureaucratic Hurdles

The respondents have regarded this factor as relatively infrequent risk factor. The model considers this factor as moderate risk for both cost overrun and time delay. Lengthy decision-making process can adversely affect the construction procedure at site and lead to additional time requirement and claims from contractors. It was observed in the analysis of sampled bridges that long duration required for issuing VO and EOT have often led to cost overrun and time delay. The latest amendment to the PPR has added provisions to make decision regarding EOT within contract period. This provision is likely to reduce the risks related to long decision-making process.

Risk Factor 17 Inexperienced Consultant

According to the questionnaire survey, inexperienced consultant is a frequently occurring risk in construction of bridges along local roads. This factor has high impact for both cost overrun and time delay. It was ranked 8 and 10 among 31 factors causing cost overrun and time delay respectively. Inexperienced consultants can adversely affect the decision making required at construction site. This often leads to additional time requirements and claims from contractor.

Risk Factor 18 Inexperienced Contractor/Sub-Contractor

The respondents regard this risk factor as moderately frequent. The factor is ranked 5 for cost overrun and 11 for time delay.

While evaluating sampled bridges, this factor was known to have LD consequences for the contractor. The lack of knowledge regarding contract management, material management and construction methodology can have long term implications both in terms of cost overrun and time delay.

Risk Factor 19 Delay in Approval of Design

This risk factor is regarded as low to moderately occurring risk by experts. As expected, this factor has relatively very low impact for cost overrun and moderate impact for time delay. It was ranked by the model at 26 and 17 for cost overrun and time delay respectively.

The sampled bridge observation shows that delay in approval of workshop drawing of steel bridges has led to EOT. The EOT has indirect consequence on the project cost through CPA, but the impact wasn't found to be substantial.

Risk Factor 20 Outdated Construction Techniques/Practices

As per the questionnaire survey, this risk factor is highly common. This factor was ranked 15 and 4 among 31 factors causing cost overrun and time delay respectively. This factor is less likely to increase the project cost but can have substantial impact on the time required for completion of project.

Sample bridge observation have indicated that outdated construction techniques for falsework/framework preparation and concreting batching, mixing and placing process have often led to additional time requirement for completion. Apart from the impact of this risk on cost and time, the quality related consequence is a subject requiring further study.

Risk Factor 21 Safety related Issues

According to expert opinion, safety related issues were found to be highly frequent. Despite the high frequency of occurrence, the model predicts this factor to have moderate and low impact in terms of cost overrun and time delay respectively.

It is noteworthy that safety related issues were not quoted for time extension and variation order issued for the sampled bridges. LRBP has recommended strict adherence to OSH guidelines but its implementation and impact is yet to be studied.

Risk Factor 22 Shortage of Equipment

The respondents regard this factor as frequently occurring risk. As expected, the impact of this factor for cost overrun is low and for time delay is high.

From the study of contract documents of sampled bridges, it was observed the shortage of equipment required for deep foundation like pile and prestressing equipment often led to additional time requirement.

Risk Factor 23 Improper Financial Management/Misuse of Mobilization

According to the qualitative questionnaire survey, the frequency of occurrence of this factor was found to be high. The fuzzy inference system model ranks this risk factor as 21 and 5 among 31 factors responsible for cost overrun and time delay respectively. The large difference between the ranks for two parameters indicate that this risk has substantial impact on time delay but low impact on cost overrun.

The sampled bridge observation has shown that liquidated damages have been applied to the contractors who were involved in improper financial management.

Risk Factor 24 Lack of Coordination/Cooperation between Stakeholders

This factor was ranked 14 for the probability of occurrence, 25 for cost overrun and 12 for time delay by the fuzzy inference model among the total 31 risk factors.

It is noteworthy that very few incidents were noted in sampled bridges regarding this risk factor. Additional documentation and research regarding this factor are required.

Risk Factor 25 Contractual Disputes

The frequency of occurrence of this factor is relatively low. The model found the impact of contractual disputes on cost overrun to be moderate and low for time delay. The low frequency of occurrence and low risk index can be attributed to the limited economical scale of the project.

Risk Factor 26 Contractor's Financial Problems

According to the questionnaire survey, the frequency of this risk was found to be high in local road bridge construction projects. The impact of this risk on both cost overrun and time delay was also found to be high.

This factor can lead to termination of projects or large values of liquidated damages.

Risk Factor 27 Political Instability

The experts regard this risk factor to have moderate frequency of occurrence. Fuzzy inference model ranked political instability at 12 for cost overrun and 13 for time delay.

From the analysis of sampled bridges, it was observed that political disturbance after 2015 earthquake were a major factor contributing to both cost overrun and time delay.

Risk Factor 28 Force Majeure

The model shows that despite having low frequency of occurrence, the impact of force majeure in terms of cost overrun was found to be substantial and time delay was found to be moderate.

Earthquake and CoVID-19 were two major force majeure observed in sampled bridges. The occurrence of two major events in the study period have contributed to large value of both cost overrun and time delay factors in sampled bridges.

Risk Factor 29 Large Variation in raw material prices

Large variation in raw material prices is relatively infrequent in local road bridge construction. The model predicts this risk factor to have low impact in terms of time delay and substantial impact in terms of cost overrun.

The risk associated with large variation in raw material prices for cost overrun can be observed in sampled bridges through values of contract price adjustments.

Risk Factor 30 Non-availability of Construction material

This risk factor was found to have low frequency of occurrence, moderate impact in terms of cost overrun and low impact in terms of time delay.

In the sampled bridges, the time period after earthquake and blockade at the southern border faced the problems related to non-availability of construction material. The impact of this event in terms of time delay was found to be substantial.

Risk Factor 31 Non-availability of Skilled/Unskilled manpower

The occurrence of this risk factor was found to be low from the questionnaire survey. The fuzzy inference model predicts that impact of this risk on cost overrun is low and the impact on time delay is moderate.

The observation from sampled bridges has shown that the risk of non-availability of skilled/unskilled manpower is highest during festive seasons. It was observed that mostly foreign labors were involved in construction of deep foundations like pile and well. Similarly, most of the labors involved in steel bridge erection were non-Nepali. It can be observed that we rely on foreign skilled manpower for construction of some specific components of a project. This adds uncertainty to the risk of skilled and unskilled manpower. Further Study is required for such type of component.

Insufficient preparation at the pre-contract phase, inappropriate and inept contract management were found to be amongst the most important factor causing time delay in public procurement. Lack of sufficient human resource with expertise in contract management also contributes towards time delay. (CIAA, 2020)

4.8 Analysis of Date obtained from sampled bridges

Cost Overrun

The average value of cost overrun for sampled bridges was found to be 6.26% with a standard deviation of 7.12%. This includes cost overrun due to VO and CPA.

Time delay

The average value of time delay for 57 sampled bridges was found to be 80.36% with a standard deviation of 89.26%. The details have been tabulated on the next page.

Table 4. 8 Time Delay Analysis

Time period at Completion of Project	Number	Percentage of total
Completed within stipulated time	7	12.28
Completed with the addition of 25% of stipulated time	6	10.52
Completed with the addition of 50% of stipulated time	9	15.79
Completed with addition of more than 50% of stipulated time	35	61.40

Thus, from the sample it can be inferred that 12.28% of the bridge were completed within the initial contract period, 10.52% within 25% additional period, 15.79% within 50% additional period and a major portion, 61.40% of bridge were completed with the contract extension of greater than 50% of initial contract period. This data shows that time delay is a major risk issue in local road bridge construction.

CHAPTER 5 CONCLUSION

5.1 Summary of Research

This research was carried out with the aim of assessing the risk associated with cost overrun and time delay. A new model based on fuzzy logic was used to determine the indices relevant to time delay and cost overrun. This model was validated using the sample of 57 bridges obtained from the population of 346 bridges constructed along local roads. After the validation of model, individual risk factors were assessed in detail.

5.2 Conclusion of Research Objectives

a) A fuzzy inference system-based model was formed using the questionnaire survey for calculating risk index for cost overrun and time delay.

b) The model was validated by calculating the correlation coefficient and performing hypothesis testing.

c) The risk factors for cost overrun and time delay were calculated and ranked based on their arithmetic value. A risk management plan for the first ten risks has been shown below. The primary strategy for risk response planning has been shown.

5.3 Risk Management Plan

Risk management plan for the 10 highest values of Fuzzy Index for cost overrun

Table 5. 1 Risk Management Plan for Cost Overrun

RF No.	Risk Factor	Primary Strategy	Risk Management Plan
RF 9	Government Regulation/Contract Awarded to Lowest Bidder	-Avoid -Escalate	-The rule 65 of the Public Procurement Regulation, 2064 which has provisions for special evaluation should be used for bids which are front loaded and other conditions involving unbalanced low rate and unnatural low bid. - Since the provisions of rule 65 involve subjective judgment, higher authorities such as PPMO should be consulted for providing directives for special evaluation and objective method for screening unnatural bids.
RF 13	Inadequate Budget Allocation/ Delay in Payments	-Avoid -Mitigate -Escalate	-Initiation of contract only after expenditure source is assured. -Strict adherence to the procurement plan - Careful assessment of project progress and future need during budget preparation -Expedite budget amendment process through close coordination with line ministry and MoF.
RF 1	Unexpected Ground Condition	-Mitigate	-Detailed study of regional geology and use of appropriate ground exploration technique. -Increase the number of bore hole logs if the regional

RF No.	Risk Factor	Primary Strategy	Risk Management Plan
			geology is found to be highly varying.
RF 11	Regional Topography and access to site	-Mitigate	-Detailed hydrological study of river/stream especially for water bodies in plain terrain. -Calculation of appropriate contract duration depending upon the access to site.
RF 18	Inexperienced Contractor/Sub-Contractor	-Avoid -Mitigate	-Appropriate qualification and key experience criteria should be used in bid document. The bid capacity and work in hand for bidders should be evaluated. -The contracting party should be forced to perform their contracting duties and non-contractual sub-contracting to non-qualified contractors should be checked
RF 29	Large Variation in Raw Material Prices	-Mitigate	-Appropriate Scheduling and planning activities for project execution
RF 28	Force Majeure	-Transfer -Accept	-Adopt Suitable contingency plan in the contract document - Insurance for precaution against force majeure
RF 17	Inexperienced Consultant	-Mitigate	-Adopt appropriate selection criteria such as educational qualification and experience for consultant selection -Ensure that qualified consultants are regularly present at the construction site.
RF 16	Lengthy Decision-Making Process/Bureaucratic Hurdles	-Escalate -Mitigate	-Decision making process should be expedited through strict policy reform -Timeframe for decision making process should be fixed
RF 26	Contractor's Financial Problems	-Avoid	-Financial condition of the contractor should be assessed in detail during evaluation. -Adopt suitable financial qualification criteria.

Risk management plan for the 10 highest values of Fuzzy Index for time delay

Table 5. 2 Risk Management Plan for Time Delay

RF No.	Risk Factor	Primary Strategy	Risk Management Plan
RF 9	Government Regulation/Contract Awarded to Lowest Bidder	-Avoid -Escalate	-The rule 65 of the Public Procurement Regulation, 2064 which has provisions for special evaluation should be used for bids which are front loaded and other conditions involving unbalanced low rate and unnatural low bid. - Since the provisions of rule 65 involve subjective judgment, higher authorities such as PPMO should be consulted for providing directives for special evaluation and objective method for screening unnatural bids.

RF No.	Risk Factor	Primary Strategy	Risk Management Plan
RF 13	Inadequate Budget Allocation/ Delay in Payments	-Avoid -Mitigate -Escalate	-Initiation of contract only after expenditure source is assured. -Strict adherence to the procurement plan - Careful assessment of project progress and future need during budget preparation -Expedite budget amendment process through close coordination with line ministry and MoF.
RF 1	Unexpected Ground Condition	-Mitigate	-Detailed study of regional geology and use of appropriate ground exploration technique. -Increase the number of bore hole logs if the regional geology is found to be highly varying.
RF 20	Outdated Construction Techniques/Practices	-Mitigate	-Appropriate qualification criteria regarding equipment available with the bidder -Strict implementation of equipment requirement prescribed by the method statement.
RF 23	Improper Financial Management/Misuse of Mobilization	-Avoid	-Compel the contractor to provide documentation of mobilization amount expenditure and verification of such document. -Release of second tranche of mobilization only if the first tranche has been utilized in the project
RF 15	Unrealistic Low Bid	-Avoid -Escalate	-Adoption of suitable evaluation criteria -Reject unrealistic low bid through appropriate study and clear disqualification criteria through consultation with higher authority, Penalize such bidder
RF 11	Regional Topography and access to site	-Mitigate	-Detailed hydrological study of river/stream especially for water bodies in plain terrain. -Calculation of appropriate contract duration depending upon the access to site.
RF 26	Contractor's Financial Problems	-Avoid	-Financial condition of the contractor should be assessed in detail during evaluation. -Adopt suitable financial qualification criteria.
RF 22	Shortage of Equipment	-Mitigate	-Efficient planning and scheduling to ensure timely availability of equipment.
RF 17	Inexperienced Consultant	-Mitigate	-Adopt appropriate selection criteria such as educational qualification and experience for consultant selection -Ensure that qualified consultants are regularly present at the construction site.

Other factors to be considered in construction of bridges along local roads have been listed below:

5.4 Further studies

1. One of the important applications of the FIC and FIT indices can be in the application of artificial intelligence for developing a model which can predict the

possible time delay and cost overrun in a project depending upon the input parameters. This goal could not be achieved in the current research because of time limitations.

2. This research has found out that a study is required to determine the scientific contract duration required for completion of bridge project. The type of foundation, superstructure, span, geological location, climatic condition and construction methodology could be important parameters for this study.
3. The use of outdated construction techniques (such as equipment for piling, well sinking, concrete batching, mixing and placement) in bridge construction and its comparison with modern techniques to determine the time and quality difference can be valuable research.
4. Safety related issues in local road bridge construction is an unexplored technique. A study could be carried out to assess the current OSH practices and provide recommendations for improvement. Appropriate design of falsework and formwork and safe construction method for working above large water bodies could be an important field of research.
5. It was observed that most of the construction labor working in deep foundation construction and erection of steel bridges were foreigners. A study in this context regarding lack of Nepalese labor participation and the prevalent labor laws could provide valuable insights.

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APPENDICES

APPENDIX-A

QUESTIONNAIRE

QUESTIONNAIRE SURVEY

This questionnaire is a part of thesis which aims to determine the magnitude of risks associated with cost overrun and time delay in bridge construction across local roads of Nepal. The questionnaire will be used for academic research for partial fulfillment of the requirements for the degree of Masters of Science in Construction Management at Institute of Engineering, Pulchowk Campus, Lalitpur.

All personal information provided will be kept confidential and will be used for academic purpose only. The first set of questions are general questions related to demographics of respondents and their organization. The second set of questions ask the respondents to rate parameters related to a certain risk in a five point scale ranging from" Very Low" to" Very High". This survey should take about 10 minutes of your time and thank you for participating.

DEMOGRAPHIC INFORMATION

1. Your age in years?

   ◯ ≤ 20 ◯ 21-30 ◯ 31-40 ◯ 41-50 ◯ ≥ 50

2. Your Gender?

   ◯ Male ◯ Female ◯ Others

3. Your Educational Qualification?

   ◯ Diploma Level ◯ Bachelors Level ◯ Masters Level ◯ PhD Level

4. Your Experience in Years?

   ◯ ≤ 1 ◯ 2-5 ◯ 6-10 ◯ 11-15 ◯ ≥ 16

5. Number of Years you have worked in Bridge Construction?

   ◯ ≤ 1 ◯ 2-5 ◯ 6-10 ◯ 11-15 ◯ ≥ 16

6. Number of Bridge Projects you have been associated with?

   ◯ ≤ 5 ◯ 6-10 ◯ 11-30 ◯ 31-50 ◯ ≥ 50

RISK FACTORS

Each risk factor is to be rated in three parameters. These parameters include the probability of occurrence which is the likelihood of a risk materializing during project implementation. (सडक पुल निर्माणको क्रममा उल्लेखित जोखिम देखापर्ने सम्भावना कति रहेको छ?) The other two parameters are the level of impact in terms of time and cost if such risk occurs during implementation. *(उल्लेखित जोखिम देखापरेमा त्यसले निर्माण कार्यको लागि तोकिएको समय तथा अनुमान गरिएको खर्चमा कति असर पर्ने छ?)*

Based on your Knowledge and Experience, please rate each parameter from Very Low to Very High.

A. Risk Factors in Pre-Contract Phase

Risk Factor 1: Unexpected Ground Condition

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 2: Faulty Design

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 3: Unrealistic Cost Estimate

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 4: Land Acquisition Issues

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 5: Inappropriate Project Selection

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 6: Unscientific Contract Duration

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 7: Utility Relocation (Electric Poles, Irrigation Canals)

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 8: Environmental Permits

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 9: Government Regulation/Contract Awarded to Lowest Bidder

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 10: Social Issues at site

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 11: Regional Topography and Access to Site

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 12: Ineffective Contract Document

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

B. Risk Factors in Contract Execution Phase

Risk Factor 13: Inadequate Budget Allocation/Delay in Payments

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 14: Frequent Transfer of Project Staff

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 15: Unrealistic Low Bid

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 16: Lengthy Decision-Making Process/Bureaucratic Hurdles

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 17: Inexperienced Consultant

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 18: Inexperienced Contractor/Sub-Contractor

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 19: Delay in approval of design

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 20: Outdated Construction Techniques/Practices

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 21: Safety Related Issues

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 22: Shortage of Equipment

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 23: Improper Financial Management/Misuse of Mobilization

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 24: Lack of Coordination/Cooperation between Stakeholders

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 25: Contractual Disputes

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 26: Contractor’s Financial Problems

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 27: Political Instability

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

C. External Risk Factors

Risk Factor 28: Force Majeure

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 29: Large Variation in Raw Material Prices

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 30: Non-availability of Construction Materials

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

Risk Factor 31: Non-availability of Skilled/Unskilled Manpower

Parameter	Very Low	Low	Medium	High	Very High
Probability of occurrence					
Severity in terms of cost overrun					
Severity in terms of time delay					

APPENDIX-B

Typical calculation of FIC and FIT

Typical Calculation of FIC and FIT for RF 11: Regional Topography and Access to Site

Rating of Experts obtained from the questionnaire survey. These values are directly exported from the Google forms. The clipped data for a specific factor is in the following form:

Respondent Number	Risk Factor 11: Regional Topography and Access to Site [Probability of Occurence]	Risk Factor 11: Regional Topography and Access to Site [Severity in terms of Cost Overrun]	Risk Factor 11: Regional Topography and Access to Site [Severity in terms of time delay]
1	Medium	Medium	Medium
2	Medium	Medium	Medium
3	Medium	Low	Low
4	Low	Low	Low
5	High	High	Medium
6	Medium	Low	Low
7	High	Medium	Very High
8	Medium	High	High
9	Medium	Medium	Medium
10	Low	Medium	Low
11	High	High	High
12	Low	Low	Low
13	High	High	High
14	Medium	Very High	Very High
15	Very High	High	High
16	High	Very High	High
17	Medium	Very High	Very High
18	High	High	High
19	High	High	High
20	High	High	Very High
21	High	High	High

These fuzzy variables are converted into respective Fuzzy Number using the following relationship through coding in Ms. Excel.

Fuzzy variable	Fuzzy Number
Very Low	0, 0, 0.25
Low	0, 0.25, 0.50
Medium	0.25, 0.5, 0.75
High	0.5, 0.75, 1
Very High	0.5, 1, 1

The average value and Best Non-Fuzzy Performance (BNP) values are calculated as follows:

Respondent Number	Probability of Occurrence			Severity (Cost Overrun)			Severity (Time Delay)		
1	0.250	0.500	0.750	0.250	0.500	0.750	0.250	0.500	0.750
2	0.250	0.500	0.750	0.250	0.500	0.750	0.250	0.500	0.750
3	0.250	0.500	0.750	0.000	0.250	0.500	0.000	0.250	0.500
4	0.000	0.250	0.500	0.000	0.250	0.500	0.000	0.250	0.500
5	0.500	0.750	1.000	0.500	0.750	1.000	0.250	0.500	0.750
6	0.250	0.500	0.750	0.000	0.250	0.500	0.000	0.250	0.500
7	0.500	0.750	1.000	0.250	0.500	0.750	0.750	1.000	1.000
8	0.250	0.500	0.750	0.500	0.750	1.000	0.500	0.750	1.000
9	0.250	0.500	0.750	0.250	0.500	0.750	0.250	0.500	0.750
10	0.000	0.250	0.500	0.250	0.500	0.750	0.000	0.250	0.500
11	0.500	0.750	1.000	0.500	0.750	1.000	0.500	0.750	1.000
12	0.000	0.250	0.500	0.000	0.250	0.500	0.000	0.250	0.500
13	0.500	0.750	1.000	0.500	0.750	1.000	0.500	0.750	1.000
14	0.250	0.500	0.750	0.750	1.000	1.000	0.750	1.000	1.000
15	0.750	1.000	1.000	0.500	0.750	1.000	0.500	0.750	1.000
16	0.500	0.750	1.000	0.750	1.000	1.000	0.500	0.750	1.000
17	0.250	0.500	0.750	0.750	1.000	1.000	0.750	1.000	1.000
18	0.500	0.750	1.000	0.500	0.750	1.000	0.500	0.750	1.000
19	0.500	0.750	1.000	0.500	0.750	1.000	0.500	0.750	1.000
20	0.500	0.750	1.000	0.500	0.750	1.000	0.750	1.000	1.000
21	0.500	0.750	1.000	0.500	0.750	1.000	0.500	0.750	1.000
Average	**0.345**	**0.595**	**0.833**	**0.381**	**0.631**	**0.845**	**0.381**	**0.631**	**0.833**
BNP		**0.591**			**0.619**			**0.615**	

The formula for calculating BNP is $((a_2-a_1) + (a_m-a_1))/3 + a_1$

In the above example, BNP for PO is ((0.833-0.345) +(0.595-0.0.345))/3+0.345 = 0.591

Similarly, BNP is calculated for SIC and SIT. These values are input into the fuzzy model to obtain FIC and FIT.

APPENDIX-C

Typical calculation for a Sampled Bridge

Typical Calculation for Sampled Bridge Number-17

Details of Bridge

90 m three span prestressed concrete girder with open foundation in Mustang District

Contract Date: 6/25/2015, Initial Expected Date of Completion: 6/24/2016 (730 days / 2 years from Agreement)

Estimate Amount: 5,20,98,825.45 (not Including VAT) Contract Amount: 4,19,36,343.72 (19.51% below)

Date of completion: 7/7/2019 (Total Extension of 1108 days)

Assessment of time-delay in bridge

S.No.	Causes for time extension	Total Time Considered in days
1.	Very Low Temperature and Snowfall	90
2.	Earthquake	75
3.	Material Shortage due to strike	131
4.	Aggregate and Sand Shortage	6
5.	Public Disturbance at site	249
6.	Snowfall causing delay in construction	240
7.	Elections	60
8.	Monsson/Difficult Access to site	202
	Total Time Extension	1053

Classification of Various Risk Factors resulting in time delay

Risk Factor Number	Risk Factor	Number of days	Weightage of individual factor = $\frac{number\ of\ days}{Initial\ contract\ duration}$
RF 6	Unscientific Contract Duration	90+240 = 330	$\frac{330}{730} = 0.452$
RF 10	Social Issues at Site	249	$\frac{249}{730} = 0.341$
RF 11	Regional Geography and Access to Site	202	$\frac{202}{730} = 0.277$
RF 23	Improper Financial Management/ Misuse of Mobilization (Liquidated Damage Applicable)	55	$\frac{55}{730} = 0.075$
RF 27	Political Instability	60	$\frac{60}{730} = 0.082$
RF 28	Force Majeure (Earthquake)	75	$\frac{75}{730} = 0.102$
RF 30	Non-availability of construction material	131+6 = 137	$\frac{137}{730} = 0.188$
	Total	1108	$\frac{1108}{730} = 1.517$

Variation Order-1, Amount : 57,76,387.36 (not including VAT)

Total Contract Price Adjustment (CPA) : 72,31,565.94

Assessment of cost-overrun in bridge

S.No.	Causes of Variation	Cost Associated with Variation
1.	Change in Design Carriageway width of Bridge caused by change in scope of the project. (Upgradation of non-SRN road into SRN road)	39,81,191.48
2.	Additional Gabion Protection Works	17,95,195.88

Classification of Various Factors causing cost-overrun in the form of Variation Order (VO)

Risk Factor Number	Risk Factor	Amount	Weightage of individual factor = $\frac{Variation\ Amount}{Initial\ contract\ Amount}$
RF 5	Inappropriate Project Selection	39,81,191.48	$\frac{3981191.48}{41936343.72} = 0.095$
RF 11	Regional Topography and Access to Site	17,95,195.88	$\frac{1795195.88}{41936343.72} = 0.043$

Contract Price Adjustment Cost overrun Assessment

Price Adjustment Coefficient at the end of initial contract period = 1.196

Average value of Price adjustment coefficient = (1.196-1)/2 = 0.098

CPA without EOT = Average Price Adjustment Coefficient x Mobilization deduction coefficient x Contract Amount

CPA without EOT (RF 29) = 0.098 x 0.8 x 4,19,36,343.72 = 32,87,809.35

Additional CPA because of EOT = 72,31,565.94 – 32,87,809.35 = 39,43,756.59

The additional CPA is now distributed according the weightage of time extension factors

Risk Factor Number	Risk Factor	Number of days	Weightage of individual factor = $\frac{number\ of\ days}{Total\ Time\ Extension} \times \frac{Additional\ CPA}{Initial\ Contract\ Amount}$
RF 6	Unscientific Contract Duration	330	$\frac{330}{1108} \times \frac{39{,}43{,}756.59}{4{,}19{,}36{,}343.72} = 0.028$
RF 10	Social Issues at Site	249	$\frac{249}{1108} \times \frac{39{,}43{,}756.59}{4{,}19{,}36{,}343.72} = 0.021$
RF 11	Regional Geography and Access to Site	202	$\frac{202}{1108} \times \frac{39{,}43{,}756.59}{4{,}19{,}36{,}343.72} = 0.0171$
RF 23	Improper Financial Management/ Misuse of Mobilization (Liquidated Damage Applicable)	55	$\frac{55}{1108} \times \frac{39{,}43{,}756.59}{4{,}19{,}36{,}343.72} = 0.005$
RF 27	Political Instability	60	$\frac{60}{1108} \times \frac{39{,}43{,}756.59}{4{,}19{,}36{,}343.72} = 0.005$
RF 28	Force Majeure (Earthquake)	75	$\frac{75}{1108} \times \frac{39{,}43{,}756.59}{4{,}19{,}36{,}343.72} = 0.005$
RF 30	Non-availability of construction material	137	$\frac{137}{1108} \times \frac{39{,}43{,}756.59}{4{,}19{,}36{,}343.72} = 0.012$

APPENDIX-D

Sampled Bridge Details

Bridge No.	Contract Date	Expected Date of Completion	Actual Completion Date	Initial Time	Time Taken	Additional Time	Contracted Amount	Total Expenditure	Cost overrun
1	4/1/2019	3/31/2020	3/24/2021	365	723	358	7,96,64,043	7,18,25,370	(78,38,673)
2	4/8/2015	10/11/2016	7/16/2018	552	1195	643	73,67,318	1,77,98,000	1,04,30,682
3	4/14/2016	10/13/2018	12/6/2020	912	1697	785	8,45,37,059	9,47,60,082	1,02,23,023
4	4/30/2015	4/30/2016	7/15/2017	366	807	441	2,95,94,000	3,23,59,000	27,65,000
5	1/6/2019	7/7/2020	10/1/2021	548	999	451	5,40,89,226	7,11,27,332	1,70,38,106
6	7/16/2012	7/16/2014	7/15/2018	730	2190	1460	1,71,49,370	2,06,26,000	34,76,630
7	2/6/2019	2/6/2020	7/14/2020	365	524	159	1,36,61,182	1,52,32,407	15,71,224
8	7/5/2014	7/6/2016	7/15/2017	732	1106	374	2,53,61,016	2,53,61,016	-
9	2/6/2019	2/6/2020	7/14/2020	365	524	159	2,04,91,774	2,28,48,610	23,56,837
10	3/31/2014	3/30/2016	6/28/2017	730	1185	455	4,31,00,354	4,52,48,768	21,48,414
11	7/2/2015	7/1/2018	10/6/2020	1095	1923	828	10,05,84,975	10,67,45,717	61,60,742
12	9/29/2016	9/28/2018	2/24/2019	729	878	149	3,55,14,942	3,55,14,942	-
13	7/9/2018	1/6/2021	12/23/2020	912	898	-14	7,32,45,696	8,47,01,881	1,14,56,185
14	8/27/2014	4/20/2015	12/31/2018	236	1587	1351	4,91,64,682	5,32,03,828	40,39,146
15	7/8/2018	7/7/2020	7/2/2020	730	725	-5	7,43,64,988	8,18,14,660	74,49,673
16	10/30/2014	1/15/2018	2/28/2018	1173	1217	44	5,62,76,250	5,84,82,714	22,06,464
17	6/25/2014	6/24/2016	7/7/2019	730	1838	1108	4,19,36,344	4,42,55,795	23,19,451
18	3/27/2014	2/3/2015	7/17/2015	313	477	164	6,00,12,673	6,28,58,043	28,45,371
19	7/27/2011	2/12/2014	7/14/2018	931	2544	1613	3,50,44,805	3,50,44,805	-
20	4/29/2016	10/28/2017	10/15/2019	547	1264	717	2,30,36,000	2,36,29,000	5,93,000
21	6/6/2011	2/12/2014	7/16/2019	982	2962	1980	1,52,20,227	1,52,20,227	-
22	4/12/2014	12/16/2015	6/15/2017	613	1160	547	7,50,24,373	7,75,50,000	25,25,627
23	6/23/2014	6/22/2016	12/25/2020	730	2377	1647	2,60,43,942	2,13,49,518	(46,94,424)
24	6/13/2010	6/13/2012	7/9/2013	731	1122	391	3,89,83,035	4,18,55,448	28,72,413
25	6/19/2014	6/18/2016	7/13/2018	730	1485	755	2,69,71,931	2,85,86,730	16,14,799
26	12/29/2016	6/13/2018	7/15/2019	531	928	397	91,25,000	95,44,000	4,19,000
27	6/19/2014	6/18/2016	7/13/2018	730	1485	755	2,82,15,215	2,99,51,677	17,36,462
28	1/14/2016	7/15/2017	7/15/2018	548	913	365	3,07,47,750	3,69,50,054	62,02,304
29	7/2/2014	7/1/2017	12/31/2018	1095	1643	548	8,82,99,012	10,03,66,806	1,20,67,794
30	2/27/2015	2/27/2016	4/16/2016	365	414	49	19,43,359	35,00,000	15,56,641
31	6/25/2014	6/24/2016	7/9/2018	730	1475	745	2,34,60,867	2,88,51,219	53,90,352
32	7/9/2013	6/29/2016	4/12/2017	1086	1373	287	1,61,45,000	1,77,98,000	16,53,000
33	7/10/2010	9/27/2012	7/15/2017	810	2562	1752	6,03,87,048	6,97,52,358	93,65,310
34	3/28/2016	6/28/2017	7/15/2018	457	839	382	1,78,29,000	2,04,77,295	26,48,295
35	5/2/2013	5/2/2015	4/13/2019	730	2172	1442	6,57,69,243	6,90,78,190	33,08,947
36	6/4/2012	7/15/2015	4/17/2016	1136	1413	277	1,29,69,352	1,48,51,000	18,81,648
37	7/2/2014	7/2/2017	3/25/2017	1096	997	-99	9,20,87,385	9,93,76,941	72,89,556
38	3/3/2017	3/3/2018	3/3/2018	365	365	0	81,69,621	87,67,912	5,98,291

Bridge No.	Contract Date	Expected Date of Completion	Actual Completion Date	Initial Time	Time Taken	Additional Time	Contracted Amount	Total Expenditure	Cost overrun
39	6/18/2014	6/7/2017	6/7/2017	1085	1085	0	6,67,91,821	7,45,34,693	77,42,872
40	7/4/2014	10/6/2015	4/2/2017	459	1003	544	2,31,95,256	2,31,95,256	-
41	8/27/2012	12/15/2014	6/29/2016	840	1402	562	2,76,12,993	2,71,74,043	(4,38,950)
42	2/5/2011	5/4/2012	7/15/2013	454	891	437	91,01,463	91,77,792	76,329
43	4/19/2011	9/21/2013	6/14/2015	886	1517	631	4,85,83,801	5,45,82,524	59,98,723
44	7/7/2015	1/5/2017	8/5/2017	548	760	212	4,41,55,699	4,45,17,882	3,62,183
45	6/19/2014	6/18/2016	12/20/2016	730	915	185	3,31,05,719	3,50,66,003	19,60,284
46	2/22/2013	5/20/2014	5/20/2014	452	452	0	2,02,09,778	2,02,09,778	-
47	7/9/2015	7/8/2018	6/4/2020	1095	1792	697	11,12,69,962	14,47,16,097	3,34,46,136
48	2/1/2013	2/27/2015	2/26/2016	756	1120	364	1,83,74,627	1,83,74,627	-
49	3/16/2014	9/15/2015	6/15/2017	548	1187	639	2,61,58,990	2,86,44,094	24,85,104
50	6/24/2016	9/27/2017	6/6/2018	460	712	252	1,45,49,000	1,46,06,000	57,000
51	4/27/2016	5/13/2018	10/26/2018	746	912	166	2,63,69,869	2,69,99,197	6,29,328
52	5/13/2014	5/12/2016	5/14/2017	730	1097	367	3,29,80,245	3,63,40,059	33,59,815
53	7/12/2017	7/12/2019	7/12/2019	730	730	0	3,99,61,991	4,22,79,720	23,17,728
54	3/5/2015	7/7/2015	7/12/2015	124	129	5	23,24,832	23,29,845	5,013
55	11/4/2015	11/3/2016	2/15/2017	365	469	104	3,56,37,103	3,71,75,976	15,38,873
56	3/10/2019	3/9/2020	7/15/2020	365	493	128	1,18,69,093	1,28,69,000	9,99,907
57	3/10/2019	3/9/2020	7/15/2020	365	493	128	99,79,023	1,08,23,001	8,43,978

Time Delay Risk Factors of 57 Sampled Bridges

Bridge Number	RF 1	RF 2	RF 3	RF 4	RF 5	RF 6	RF 7	RF 8	RF 9	RF 10	RF 11
1											
2									0.395		
3	0.430										0.100
4											0.344
5	0.42										
6									1.164		
7											0.135
8		0.123	0.163								
9											0.135
10	0.164										
11										0.221	
12	0.204										
13		0.132								0.197	
14									0.975		
15		0.055						0.164			
16											

Bridge Number	RF 1	RF 2	RF 3	RF 4	RF 5	RF 6	RF 7	RF 8	RF 9	RF 10	RF 11
17						0.452				0.341	0.277
18					0.239						
19									0.505		0.53
20		0.329									0.366
21									1.085		0.244
22											
23											
24	0.274			0.261							
25											0.348
26							0.377				
27											0.538
28	0.301					0.365					
29	0.164										
30											
31	0.349										0.123
32											
33	0.111	0.296			0.41				0.111		0.185
34											
35											0.61
36											
37											
38											
39											
40											
41		0.071	0.169	0.107							0.071
42	0.434			0.132							
43											
44											0.113
45	0.103										0.068
46											
47	0.548	0.089									
48											0.263
49											0.217
50									0.548		
51					0.102						
52					0.194						
53											
54											
55											
56							0.241				
57											
Total	**3.502**	**1.095**	**0.332**	**0.5**	**0.945**	**0.817**	**0.618**	**0.164**	**4.783**	**0.759**	**4.667**

Bridge Number	RF 12	RF 13	RF 14	RF 15	RF 16	RF 17	RF 18	RF 19	RF 20	RF 21
1								0.608		
2		0.063		0.395			0.163			
3										
4		0.096					0.164			
5								0.328		
6		0.048					0.123			
7										
8		0.048					0.123			
9										
10		0.048					0.151			
11										
12										
13										
14		0.148					0.254			
15										
16										
17										
18										
19										
20		0.329								
21				1.085						
22		0.367					0.261			
23						0.082				
24										
25										
26		0.371								
27										
28										
29					0.086		0.072			
30										
31					0.152					
32		0.032								
33					0.216	0.469				
34		0.394				0.442				
35						0.397	0.215	0.201		
36		0.198								
37										
38										
39										
40		0.771					0.196			
41										
42				0.396						
43										
44								0.274		
45					0.082					
46										
47										

Bridge Number	RF 12	RF 13	RF 14	RF 15	RF 16	RF 17	RF 18	RF 19	RF 20	RF 21
48										
49		0.411					0.21			
50				0.548						
51						0.121				
52		0.048					0.123			
53										
54							0.04			
55							0.285			
56		0.109								
57		0.247								
Total	**0**	**3.728**	**0**	**2.424**	**0.536**	**1.511**	**2.38**	**1.411**	**0**	**0**

Bridge Number	RF 22	RF 23	RF 24	RF 25	RF 26	RF 27	RF 28	RF 29	RF 30	RF 31
1							0.123	0.25		
2	0.362					0.109	0.072			
3				0.130			0.200			
4	0.246					0.164	0.109			0.082
5							0.073			
6				0.609			0.055			
7							0.08			
8							0.055			
9							0.08			
10					0.082		0.055		0.123	
11		0.247				0.055	0.233			
12										
13										
14	0.45	2.203			2.203	1.148	0.169			0.127
15										
16					0.038					
17		0.075				0.082	0.102		0.188	
18		0.284								
19			0.392				0.081		0.097	0.129
20										0.287
21						0.183	0.076		0.183	0.244
22						0.098	0.065		0.117	
23		1.248				0.164	0.103		0.536	0.123
24										
25					0.255	0.164	0.102		0.123	0.041
26										
27		0.064				0.164	0.103		0.123	0.041
28										
29							0.068		0.11	
30							0.134			
31		0.047				0.082	0.103		0.164	
32		0.057				0.055	0.037		0.083	

Bridge Number	RF 22	RF 23	RF 24	RF 25	RF 26	RF 27	RF 28	RF 29	RF 30	RF 31
33						0.019			0.235	0.111
34										
35						0.11	0.041		0.155	0.247
36						0.053	0.035		0.079	0.046
37										
38										
39										
40						0.131	0.087			
41									0.179	0.071
42										
43										
44										
45										
46										
47										
48					0.218					
49						0.109	0.073		0.164	
50										
51										
52						0.082	0.055			
53										
54										
55										
56										
57					0.104					
Total	**1.058**	**4.225**	**0.392**	**0.739**	**2.9**	**2.972**	**2.569**	**0.25**	**2.659**	**1.549**

Cost Overrun Risk Factors of 57 Sampled Bridges

Bridge Number	RF 1	RF 2	RF 3	RF 4	RF 5	RF 6	RF 7	RF 8	RF 9	RF 10	RF 11
1											
2											
3	0.054										
4											0.093
5	0.210										
6									0.203		
7			0.137								
8											
9			0.137								
10	0.024										
11										0.073	
12											
13		0.037									0.082
14											
15		0.045									0.032

Bridge Number	RF 1	RF 2	RF 3	RF 4	RF 5	RF 6	RF 7	RF 8	RF 9	RF 10	RF 11
16											0.039
17					0.095	0.028				0.021	0.060
18					0.047						
19			0.093								0.042
20											0.026
21											
22											
23											
24	0.074										
25			0.052								0.043
26	0.046										
27			0.062								0.039
28	0.091					0.111					
29	0.123		0.051								0.015
30											
31	0.167		0.024								0.016
32											
33	0.012	0.188			0.045				0.012		0.021
34											
35			0.015								0.035
36											
37											0.079
38											0.073
39	0.022		0.007								0.086
40											
41			-0.016								
42											0.008
43											0.123
44	0.008										
45	0.016										
46											
47	0.148	0.072									
48											
49											0.095
50	0.004										
51					0.024						
52					0.102						
53	0.058										
54			0.002								
55	0.043										
56											
57											
Total	**1.100**	**0.342**	**0.564**	**0.000**	**0.313**	**0.139**	**0.000**	**0.000**	**0.215**	**0.094**	**1.007**

Bridge Number	RF 12	RF 13	RF 14	RF 15	RF 16	RF 17	RF 18	RF 19	RF 20	RF 21
1										
2		0.367								
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29					0.022		0.018			
30										
31					0.019					
32		0.016								
33					0.024	0.052				
34		0.149								
35										
36		0.093								
37										
38										
39										
40										
41										
42										
43	0.070									
44										
45										
46										

Bridge Number	RF 12	RF 13	RF 14	RF 15	RF 16	RF 17	RF 18	RF 19	RF 20	RF 21
47										
48										
49										
50										
51										
52										
53										
54										
55										
56		0.084								
57		0.085								
	0.070	**0.794**	**0.000**	**0.000**	**0.065**	**0.052**	**0.018**	**0.000**	**0.000**	**0.000**

Bridge Number	RF 22	RF 23	RF 24	RF 25	RF 26	RF 27	RF 28	RF 29	RF 30	RF 31
1										
2						0.629	0.419			
3				0.237				0.076		
4										
5								0.105		
6				0.203						
7										
8										
9										
10							0.008		0.020	
11							0.028	0.072		
12										
13								0.030		
14								0.082		
15								0.036		
16										
17						0.007	0.006		0.012	
18										
19										
20										
21										
22						0.012	0.008		0.014	
23										
24										
25					0.022	0.014	0.090		0.014	
26										
27		0.004				0.011	0.007		0.011	
28										
29							0.017	0.082	0.028	
30										
31		0.006				0.010	0.013	0.069	0.021	

Bridge Number	RF 22	RF 23	RF 24	RF 25	RF 26	RF 27	RF 28	RF 29	RF 30	RF 31
32						0.027	0.018		0.041	
33						0.002			0.026	0.012
34										
35										
36						0.013	0.009		0.020	0.011
37										
38										
39										
40										
41										
42										
43				0.070						
44										
45								0.043		
46										
47								0.081		
48										
49										
50										
51										
52										
53										
54										
55										
56										
57										
	0.000	**0.010**	**0.000**	**0.510**	**0.022**	**0.725**	**0.623**	**0.676**	**0.207**	**0.023**