Cost Overrun Assessment Model in Highway Construction Projects Using Fuzzy Uncertainty Analysis

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Abstract: - **The aim of this paper is to propose a model for predicting cost overrun in highway construction projects using fuzzy logic. Model provides a decision support tool for contractors and project managers before bidding stage to quantify the probability of cost overrun. A list containing 52 factors responsible for cost overrun is prepared through vast literature review and negotiating with experts in highway construction industry. Total of 28 experts were asked to rank the identified factors on a five point likert scale. Identified factors are arranged in descending order using relative importance index method (RII). Top five factors are shortlisted for cost overrun assessment model development using fuzzy toolbox of MATLAB program software. Developed model shows graphs of variation of cost overrun for different combination of cost overrun factors. Finally, model validation is done using a case study.**

Keywords: - Construction industry, Cost overrun, Fuzzy logic, Relative importance index

I. INTRODUCTION

Construction industry is considered as one of the most dynamic and risky industrial sector. Many construction projects do not attain all their desired goals due to the presence of risks and uncertainties intrinsic in the project. One of the main duties of the construction project manager is to ensure that the project does not exceed its allotted cost & time frames despite claims. Due to different uncertainties such as Client characteristics, Consultant and design parameters, Contractor attributes, Project characteristics, Contract procedures and procurement methods, External factors and market conditions etc., the actual cost of project is not certainly known for the managers in advance. Therefore, total cost of project may differ significantly because of these uncertainties. In the construction market, most construction companies are willing to undertake infrastructure projects such as highway in order to maximize their profitability. In order to be awarded a contract in highly competitive construction market, companies should excel in choosing the most attractive markets and prepare winning bids for the selected construction projects in those markets. While preparing bids, the major concern of companies is to offer an optimum price that will enable them to earn enough profits and win the contract at the same time, where profit making ability is strongly correlated with proper estimation of a risk premium that is added onto the estimated cost of the project. Therefore a good forecasting approach is needed at the time of planning itself.

II. LITERATURE REVIEW

Garry D. Creedy, Martin Skitmore and Johnny K.W.Wong (2010) addressed the problem of why highway projects overrun their predicted costs. It identified the owner risk variables that contribute to significant cost overrun and then used factor analysis, expert elicitations, and nominal group technique to establish groups of importance ranked owner risks. Stepwise multivariate regression analysis is also used to investigate any correlation of the percentage of cost overrun with risks, together with attributes such as highway project type, indexed cost, geographic location and project delivery method.

Murat Gunduz, Yasemin Nielsen and Mustafa Ozdemir (2014) propose a decision support tool for contractors before the bidding stage to quantify the probability of delay in construction projects in Turkey by using the relative importance index (RII) method incorporated into fuzzy logic. For this purpose, 83 delay factors were identified, categorized into 9 major groups through a detailed literature review process as well as interviews with experts from the construction industry. The assessment model was developed using a commercial software product. The proposed methodology was tested in a real case study. Finally, some recommendations were made in order to minimize and control delays in construction projects.
YehielRosenfield (2013) examined the cost overrun phenomenon as a worldwide problem, identified its root causes, ranked them (on a local basis), and analysed them. Through expand focus principle, 146 potential causes gathered from the international professional literature as well as from prominent local experts. Through two cycles of expand–focus, they were filtered and merged into merely 15 independent universal root causes.

IIIRESEARCH METHODOLOGY

- Deciding cost overrun factors through a detailed literature and preparation of questionnaire for rating

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factors by expertise from highway construction field according to their severity level on a suitable scale.

- Selecting top five cost overrun factors by ranking them using Relative Importance Index (RII) method.
- Applying fuzzy logic technique for the development of cost overrun assessment model using fuzzy toolbox of MATLAB program software.
- Validation of model by applying it to a case study.

1) Identification and Ranking of cost overrun Factors

In this research, 52 factors responsible for cost overrun in highway construction projects are identified through vast literature survey. A Questionnaire form which is consisting of two parts A and B has been developed. In Part A personal Information of the respondents (for e.g. work experience, organization, average cost overrun of a project) was asked. Part B was aimed to obtain information about causes of cost overrun in highway construction industry. It was asked to rate those initially identified 52 factors according to their severity level on the given scale i.e. 1-Very low importance 2-Low importance 3-Medium importance

4-High importance 5-Very high importance

The relative importance index (RII) is calculated by using the relation given below:

$$\text{RII} = \frac{\text{W}}{\text{AXN}}$$

Where

W is the weighting given to each factor by the respondent (ranging from1 to 5),

A is the highest weight and N is the total number of respondent.

e.g. Considering factor Escalation of material prices,

$$\text{RII} = 123/5X28 = 0.8785$$

Relative importance index for all 52 factors are calculated and tabulated in descending order of RII. Table1 shows the causes rearranged in descending order according to their corresponding RII. Then, the causes are ranked according to their RII such that the cause received the highest RII is assigned rank equal to 1.Though all factors may be responsible for the cost overrun, it is very difficult to handle all the factors simultaneously. So to resolve this problem, we will consider only five top most ranked factors for further analysis. It is beneficial so that handling five factors is possible and as they are most affecting factors to cost overrun, we may predict or assess cost overrun related to highway construction project.

Table 1: List of identified cost overrun factors with RII and Rank

Sr. No.	COST OVERRUN FACTORS	RII	RANK
1.	Escalation of material prices	0.8785	1
2.	Right of way acquisition (Land acquisition)	0.8642	2
3.	Incorrect planning and scheduling by contractor	0.8500	3
4.	Improper construction methods	0.8357	4
5.	Contract failure-new contract establishment cost	0.8285	5
6.	Payments delay	0.8214	6
7.	Inaccurate investigation of construction site	0.7928	7
8.	Frequent change of subcontractors	0.7928	8
9.	Delay in reviewing and approving design documents during construction by consultant	0.7857	9
10.	Frequent equipment breakdown	0.7714	10
11.	Specification change	0.7642	11
12.	Poor communication between construction parties	0.7642	12
13.	Inadequate labour productivity	0.7642	13
14.	Encroachment problems	0.7571	14
15.	Contract tender price higher than the original cost estimate	0.7500	15
16.	Poor quality of project management	0.7428	16
17.	Latent conditions such as rock, and soil suitability, terrain conditions, ground conditions etc	0.7428	17
18.	Constructability under traffic	0.7357	18
19.	Experience in contracts	0.7285	19
20.	Frequent design changes	0.7285	20
21.	Lack of qualified project manager	0.7000	21
22.	Weather	0.6928	22
23.	Incomplete Drawings	0.6928	23
24.	Rework due to error by contractor	0.6857	24
25.	Lack of skilled labour	0.6785	25
26.	Rehabilitation of affected people	0.6642	26
27.	Ineffective delay penalties	0.6642	27
28.	Low efficiency of equipment	0.6571	28
29.	Late delivery of material	0.6500	29
30.	Political situation	0.6357	30
31.	Slow mobilization of equipment	0.6285	31
32.	Mistakes in design	0.6285	32
33.	Natural disasters such as earthquake, floods, hurricane etc	0.6071	33
34.	Remote location cost	0.5928	34
35.	Shortage of equipment	0.5928	35
36.	Poor financial control	0.5928	36
37.	Experience in the line of work	0.5857	37
38.	Changes in government regulations and laws	0.5857	38
39.	Unclear arbitration process for legal disputes between construction parties	0.5714	39

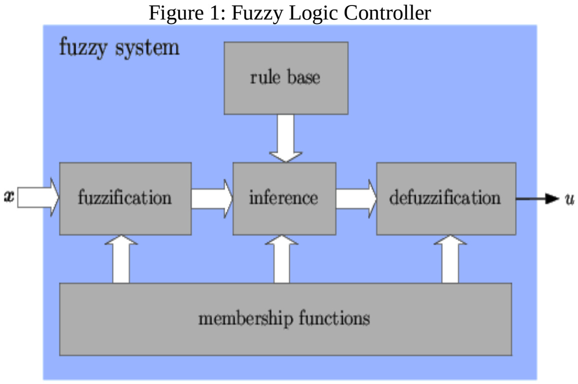
40.	Inflation	0.5642	40
41.	Unreliable supplier of material	0.5571	41
42.	Monopoly of material suppliers	0.5500	42
43.	Obsolete technology	0.5500	43
44.	Absenteeism of labour	0.5285	44
45.	Deficient documentation	0.5214	45
46.	Period of contract	0.5142	46
47.	Difficulties in importing equipments and materials	0.5000	47
48.	Size of contract	0.4928	48
49.	Cultural heritage issue	0.4857	49
50.	Personal conflicts among labour	0.4571	50
51.	Social and cultural impacts	0.4500	51
52.	Changing of bankers policy for loans	0.4428	52

Table 2: List of top five important factors

Sr. No.	COST OVERRUN FACTORS	RII	RANK
1.	Escalation of material prices	0.8785	1
2.	Right of way acquisition (Land acquisition)	0.8642	2
3.	Incorrect planning and scheduling by contractor	0.8500	3
4.	Improper construction methods	0.8357	4
5.	Contract failure-new contract establishment cost	0.8285	5

2) Fuzzy Logic Controller

Figure 1: Fuzzy Logic Controller



The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true". A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data. A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier. These components and the general architecture of a FLS is shown in Figure 1. Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification.

a) Membership Functions

A membership function is a curve in which input space is sometimes referred to as the universe of discourse, defining how each point in the input space is mapped to a membership value between 0 and 1. Membership functions are used in the fuzzification and defuzzification steps of a FLS, to map the non-fuzzy input values to fuzzy linguistic terms and vice versa. There are different shapes of membership functions, viz, triangular, trapezoidal, Gaussian, bell-shaped etc. Triangular membership functions are used in this study as they are widely used

b) Fuzzy Rules

In a FLS, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. The actual meaning of the if.... and... then rules is

If x is A i and y is B j then z is C k

c) Defuzzification

Defuzzification is the process in which outcomes of control models in the form of fuzzy numbers can be converted to precise output numbers. Fuzzy outcomes of fuzzy control model, including effects of all input variables of problem, and considering integrated effects of them by accessing various cost overrun phenomenon by fuzzy rules, are undergone fuzzy removing process and cost overrun is determined as an interval of zero to one.

3) Analysis steps for the model development using fuzzy toolbox of MATLAB software

To develop the model, following steps are performed on fuzzy logic tool box of MATLAB.

(i) Construct a five input, one output system in the FIS editor. The identified cost overrun factors and "cost overrun" are entered as input members and output member respectively.

(ii) Membership functions of all of the input and output variables are defined in membership function editor.

(iii) In order to perform fuzzy inference, rules which connect input variables to output variables are defined. For the present model 210 rules are constructed in the form of IF-THEN

(iv) The relative importance indices (RII"s) of cost overrun factors are assigned as weight to the fuzzy rules to develop the assessment model to estimate the probability of cost overrun.

4) Cost Overrun Prediction Model using Fuzzy toolbox of MATLAB software

Development of cost overrun assessment model in fuzzy inference system involves steps such as FIS editor, membership function editor, Formation of rules (Rules editor), Weighing of rules and defuzzification. Following table 3 shows linguistic variables used in model and their membershipfunction.

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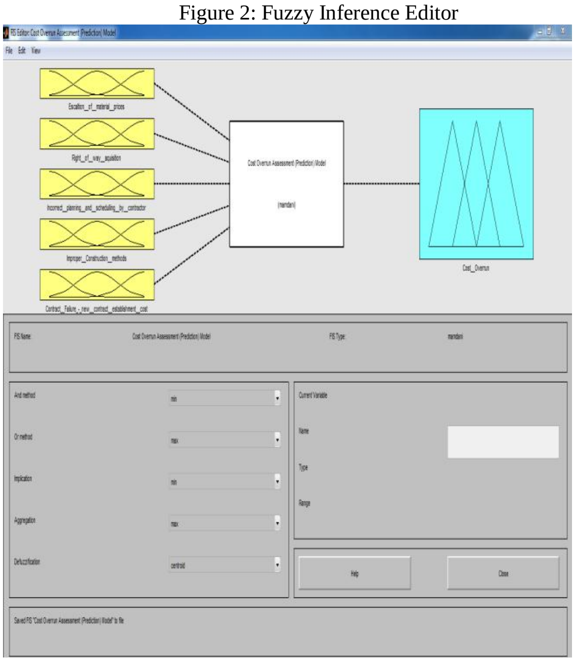
Table 3: Linguistic variables used for model development and their membership functions

Variables	Range	MFs	No of MFs	Name of the parameters
Escalation of material prices	[0-1]	trimf	5	1.very low 2.low 3.medium 4.high 5.very high
Right of way/Land acquisition	[0-1]	trimf	5	1.very low 2.low 3.medium 4.high 5.very high
Incorrect planning and scheduling by manager	[0-1]	trimf	5	1.very low 2.low 3.medium 4.high 5.very high
Improper construction methods	[0-1]	trimf	5	1.very low 2.low 3.medium 4.high 5.very high
Contract failure-new contract establishment cost	[0-1]	trimf	5	1.very low 2.low 3.medium 4.high 5.very high

a) Fuzzy Inference Editor

The FIS Editor displays general information about a fuzzy inference system. In this step, input and output parameters are fixed. We have considered five input and one output system. So from edit option, five inputs are added. Editing and nomenclature of each of five inputs and single output is done. Thereafter, file is saved by exporting it to workspace. In this way, FIS editing is completed. Mamdani and sugeno are two types of inference systems used. Mamdani type of inference system is used here. FIS editor from fuzzy toolbox is shown in the figure 2.

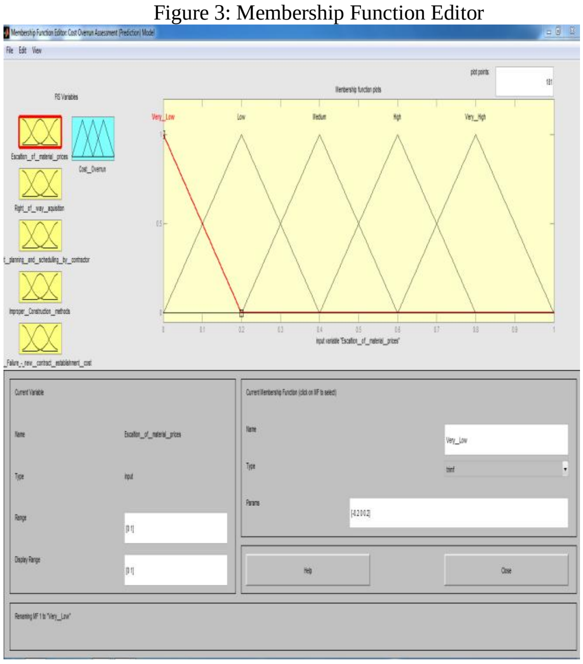
Figure 2: Fuzzy Inference Editor



b) Membership Function Editor

The Membership Function Editor is the tool that lets you display and edit all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system. Membership function editor from fuzzy toolbox is shown in the figure 3.

Figure 3: Membership Function Editor



c) Rule Editor

At this point, the fuzzy inference system has been completely defined, in that the variables, membership functions, and the rules necessary to analyze cost overrun are in place. Total 210 rules are created using all five input

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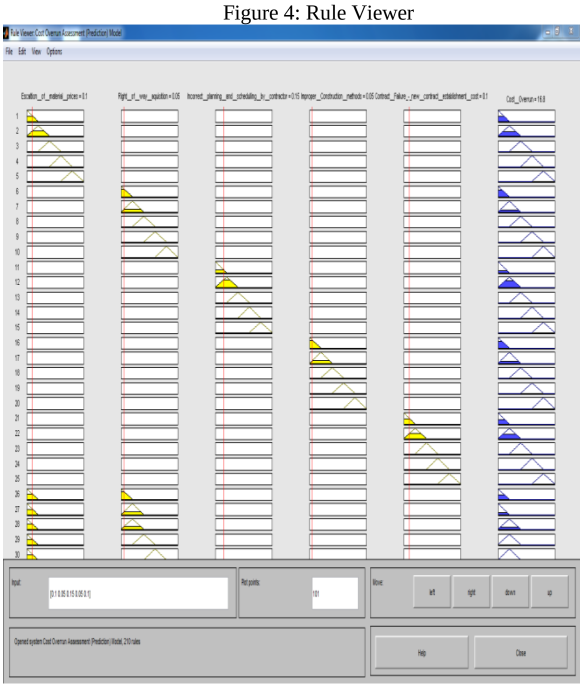
variable factors and one output variable. While creating rules, as maximum as possible possibilities and combinations of input variable factors are taken as uncertainty involved is maximum. While inserting rules by combination of two input variable factors, assign weight as average of relative importance index of both the factors. Sample rules are given below:

1. If Escalation of material prices is Very Low then Cost overrun is Very Low (0.8785)
2. If Escalation of material prices is Low then Cost overrun is Low (0.8785)
3. If Escalation of material prices is Medium then Cost overrun is Medium (0.8785)
4. If Escalation of material prices is Medium then Cost overrun is Medium (0.8785)
5. If Escalation of material prices is Very High then Cost overrun is Very High (0.8785)
6. If Right of way aquisition is Very Low then Cost overrun is Very Low (0.8642)
7. If Escalation of material prices is Very Low and Right of way acquisition is Very Low then Cost overrun is Very Low (0.8713)

d) Rule Viewer

The Rule Viewer displays a roadmap of the whole fuzzy inference process. It is based on the fuzzy inference diagram described in the previous section. The Rule Viewer allows you to interpret the entire fuzzy inference process at once. The Rule Viewer also shows how the shape of certain membership functions influences the overall result.

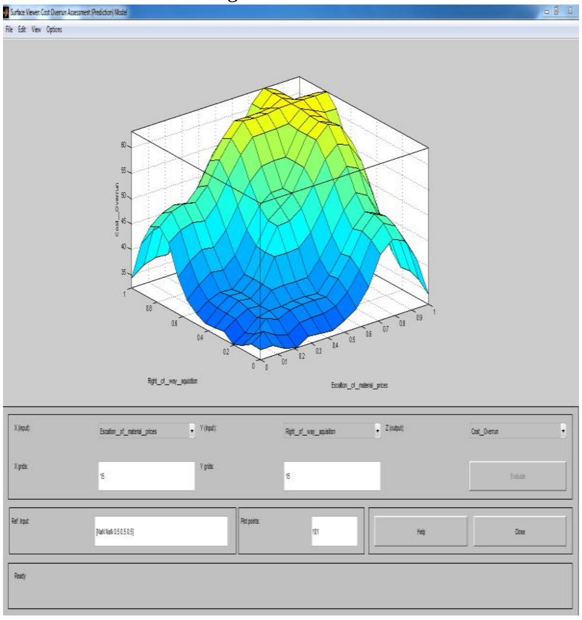
Figure 4: Rule Viewer



e) Surface Viewer

In surface viewer, we can see variation of any two cost overrun factors acting in combination with respect to cost overrun.

Figure 5: Surface Viewer



5) Model Validation

Model validity concerns the degree to which the variables, as measured by the research reflects the hypothesized construct. A detailed case study analysis of state highway construction project is carried out to validate the survey findings on most significant factors contributing to cost overrun. The completed state highway construction project Kapurhol-Purandar which is located in Pune district, Maharashtra. Following are the major factors due to which project suffered cost overrun with the percentage loss caused by each factor shown in table 4:

1) Specification change- 20.5%

2) Latent conditions such as rock and soil suitability, terrain and ground conditions etc- 19%

3) Delay in reviewing and approving design documents during construction by consultant-15.5%

4) Frequent change of subcontractors- 8%

5) Payments delay- 2.5%

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Table 4: List of major factors responsible for a cost overrun in a case study with RII

Sr. No.	FACTORS	RII
1.	Specification change	0.7642
2.	Right of way acquisition (Land acquisition) Latent conditions such as rock and soil suitability, terrain and ground conditions etc	0.7428
3.	Delay in reviewing and approving design documents during construction by consultant	0.7857
4.	Frequent change of subcontractors	0.7928
5.	Payments delay	0.8214

6) RESULTS AND DISCUSSIONS

Results obtained by implementing the developed model to a case study are tabulated in table 5. Results show that for different Percentage loss of each of the input variable i.e. factors responsible for cost overrun, the increase in estimated cost of the project (cost overrun) in percentage can be found out. This model gives us prediction about cost overrun due to worst activity of different factors. Considering first combination of different Percentage loss of factors, due to which Kapulhor-Purandar state highway suffered increase in estimated cost of project would have been predicted as 17.3%. Similarly, cost overrun can also be predicted for another different combination of percentage loss of factors as shown in table 5.

Table 5: Cost overrun for different % loss of factors-case study

Factors	Specification change (%loss)	Latent conditions such as rock and soil suitability, terrain and ground conditions etc (%loss)	Delay in reviewing and approving design documents during construction by consultant (%loss)	Frequent change of subcontractors (%loss)	Payments delay cost (%loss)	Cost overrun (%)
1.	20.5	19	15.5	8	2.5	17.3
2.	15	25	5	5	15	22.1
3.	20	15	10	10	5	17.2

In table 6, all the information regarding project such as estimated and final cost of the project, cost overrun estimated by the application of developed model to the mentioned state highway project and actual cost overrun is tabulated. Percentage error between estimated cost overrun and actual cost overrun is calculated as 8.09% which means model can give results with an accuracy of ±5-10%. As estimated cost overrun is less than and close to actual cost overrun, the proposed model holds good for prediction of cost overrun.

Table 6: Final results of a case study

Project details	
Type of Project	Highway Construction
Name of Project	Kapurhol-Puranadar/SH-63, Dist-Pune
Specification change	20.5 % loss
Latent conditions such as rock and soil suitability, terrain and ground conditions	19 % loss
Delay in reviewing and approving design documents during construction by consultant	15.5 % loss
Frequent change of subcontractors	8 % loss
Payments delay cost	2.5 % loss
Estimated cost of Project	Rs. 127500000
Final Cost of Project	Rs. 151350000
Cost Overrun (estimated)	17.3%
Cost overrun (actual)	18.7%
% error=[(Actual-Estimated)/Estimated]x100	8.09%

IV. CONCLUSION

Cost overrun phenomenon is very common in highway construction industry. Only some projects are completed within the budget. To avoid construction cost overrun, there is need to develop a cost overrun prediction/assessment model as a decision support tool for the project managers, cost estimators for the construction projects before bidding stage. The fuzzy logic has a great prediction capability given by many researchers; it has bright scope in civil engineering research (optimization). Some conclusions of the case study are enlisted below:

[1] Cost overrun can be estimated at the planning stage itself and suitable preventive measures can be adopted to overcome the situation and to avoid serious consequences.

[2] The factors that are responsible for increase in cost are identified in this report. The percentage of affectability of factors changes from project to project. So for different projects, this model can be applied effectively only by allocating value of RII corresponding to factors considered keeping all parameters same.

[3] The fuzzy logic handles the uncertainties which reside during construction projects and it can handle multiple inputs easily and quantify more realistically the classical problem analysis.

[4] Other approaches require accurate equations to model real-world behaviors, fuzzy logic can accommodate the ambiguities of human languages and logics.

[5] One of the shortcoming of this method is that as fuzzy rules are based on expert judgement and literature survey findings, it is clear that a completely different model may be proposed by other researchers based on different expert opinions.

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