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DEVELOPING SOME FUZZY MODULES FOR FINDING RISK PROBABILITIES IN INDIAN PPP PROJECTS

P Baruah[a*] and M Kakati[b]

[a]Executive at IIIT Guwahati
[b]Former Dean, Faculty of Management, Gauhati University

Abstract

During last two decades a large number of transport sector projects have been executed through the Public Private Partnership (PPP) mode in India. Since the period of execution and operations of these infrastructure projects are usually long enough, their intricacies are also much more. This is more so in a country like India where culture of PPP projects had just started in late 1990s. The vague nature of criticalities associated with these projects compound with inexperienced project management has compelled many researchers to go for finding better path of managing these projects by applying methods like AHP, Fuzzy logic and neural networks. In this paper five simple representative fuzzy logic modules have been framed for determining probabilities of some critical events, results from which have been further refined with the Delphi process. For convergence of crisp value in Delphi process '10% ± Mode value' has been considered as the criteria. Validation of the developed modules have been done with data collected through questionnaires survey as part of the research. Analysis of data from some surveyed case study projects through our developed modules shows that in India managing the "O & M risk" is most vulnerable as of now.

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Keywords: Public Private Partnership (PPP), Infrastructure, Fuzzy, Delphi, Risk

1.1. Background

A large number of transport sector infrastructure projects have been undertaken through Public Private Partnership (PPP) model during last two decades in India. However, finding of a better path towards managing these PPP infrastructure projects has always been on the primary agenda for researchers in India and abroad. Many researchers intended for developing a risk assessment & management model involving some of the identified critical risks of PPP field. Development of risk assessment models using methods like AHP, Neural Network, Monte Carlo simulations (*Yang W. & Tian C., 2012*) and Fuzzy logic (*Ho and Wang; Campbell, 2008; Thomas, 2002;* Yuanzhi Xing, 2017) have also established that classical models cannot be easily applied to practical problems that are ill- defined and require subjective evaluations. System specific scenario modelling is more suitable for such situations. It was also concluded that most classical/ conventional approaches for project risk assessment do not adequately capture the intricacies of all risk factors and their inter relations. However, empirical experience plays a major role in risk assessment. (*Thomas, 2002*).

Simulation and sensitivity analysis were also used for technical and financial risk assessment in most of the PPP projects in earlier decades (*Woodward, 1995; Malini, 1997; Lam and Tam, 1998; Ye and Tiong, 2000; INFRISK- WBI, 1999*). However, the use of simulation is often constrained by the absence of reliable probability density functions for many input variables and their inter-relationships. In addition, non-availability of past data from similar projects often leads to inadequate modelling of important risk factors while applying such methods in PPP projects. The life cycle of PPP projects are usually long enough and project risk assessment must therefore involve long-term forecasting. Various risks and their corresponding cause factors can be country and sector specific. Therefore, there are certain amount of uncertainty emanating from a project itself or its external factors would always be present. These needs to be captured in risks assessment models along with concepts of long-term forecasting based on subjective information provided by project experts in case of a survey based research.

1.2. Framework for Risk Modelling with Fuzzy logic:

The Fuzzy Logic tool was introduced in 1965 by *Lotfi Zadeh*, and is a mathematical tool for dealing with uncertainty. It offers a tool for a soft computing partnership and the important concept of computing with words'. It provides a technique to deal with imprecision and information granularity. The fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. On the contrary, the traditional binary set theory describes crisp events only, which only explains that 'either do or do not occur' situations. Fuzzy uses probability theory to explain if an event will occur, measuring the chance with which a given event is expected to occur. The theory of fuzzy logic is thus, based upon the notion of relative graded membership and so are the functions of mentation and cognitive processes. Thus, utility of fuzzy sets in their ability to model uncertain or ambiguous data is often found in applied field of science. Fig 1.1 shows a simplified logic of fuzzy real life system (*Sivanandam. S.N. et al., 2007*)

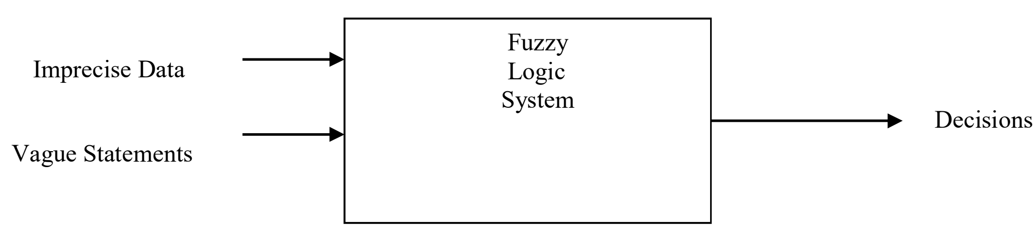


Fig 1.1: Simple Fuzzy Logic System in Real Life *(Source, Springer: 2007)*

Risk assessment is a process for estimating the probability of occurrence of events and the magnitude of their adversity based on expert judgments collected through survey. A scale of "likelihood" enables different risks to be compared without needing a full quantitative analysis. Thus, in a risk assessment process the estimation of the probability of occurrence of the risk event is the primary task for the estimator, based on which further calculations for the risk criticality can be carried out. However, The uncertainty in determining the probabilities for the risk events of a PPP projects are so large and complex that even experts becomes ambiguous in their opinions towards most of these aspects.

In real life situations to deal with complexities of risk evaluations like in a PPP projects, one has to take into account number of possibilities in a single event itself. Further, the possibility theory focuses primarily on imprecision, which is intrinsic to natural language which again is assumed to be probabilistic.

The authors intended for developing few representative modules for finding out probabilities of critical risk of Indian PPP projects and were primarily relying on all India questionnaire surveys conducted by them during 2010-13.

In order to define a possibility distribution, a notion of fuzzy restriction is introduced in solution to our problem. So, taking $\tilde{F}$ to be a fuzzy set of the set of the universe U characterized by a membership function $\mu_{\tilde{F}}(x)$, where $\tilde{F}$ is a fuzzy restriction on the variable X (here, probability of occurrence of an event). $\tilde{F}$,acts as elastic constraints on values those may be assigned to X in the sense that the assignment of the values x to X have the form

$X = x: \mu_{\tilde{F}}(x)$---------------------------- (A)

$\mu_{\tilde{F}}(x)$is the degree to which the constraint represented by $\tilde{F}$ is satisfied when x is assigned to X. In our proposed model, the fuzzy restrictions assumed are EL, VL, L, M, H, VH and EH (Table 1.1) and is used as the measuring scale of the variables for expert opinions. This notation was followed by Thomas A. V. (*2002*). A similar scale (except VVL in place of EL) was used by Tah and Carr (*2000*). The membership functions of various fuzzy subsets of probability are defined with 0 and 1 as extreme values. The subsets are divided into seven groups. A straight-line variation between "Extremely Low" and "Extremely High" is assumed. Triangular fuzzy sets are used to define these 7 membership functions.

Table 1.1 Classification of Fuzzy Probability Sets

Fuzzy Sets	**Linguistic Explanation**
EL	Extremely Low
VL	Very Low
L	Low
M	Medium
H	High
VH	Very High
EH	Extremely High

Triangular fuzzy sets are very common in fuzzy applications and proposed software to be used namely 'MATLAB' has inbuilt triangular membership function creator modules 'trimf' and are shown in Fig 1.2.

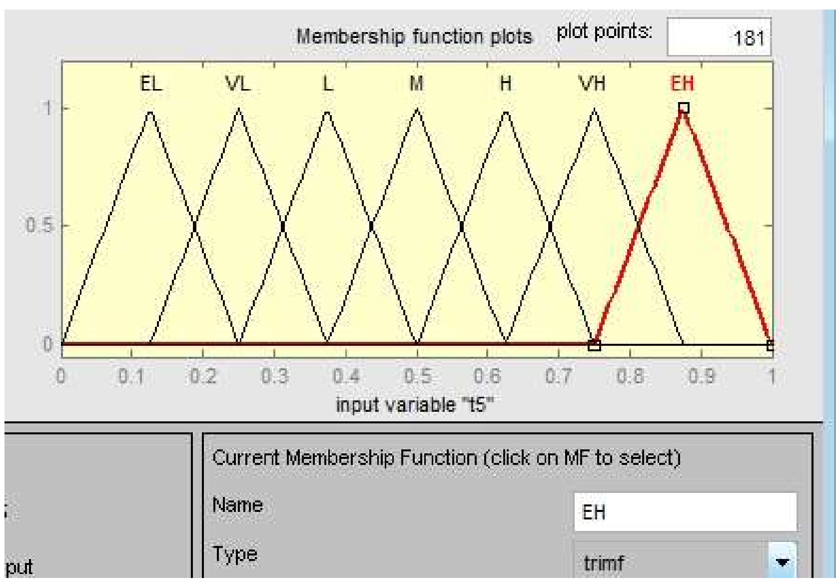


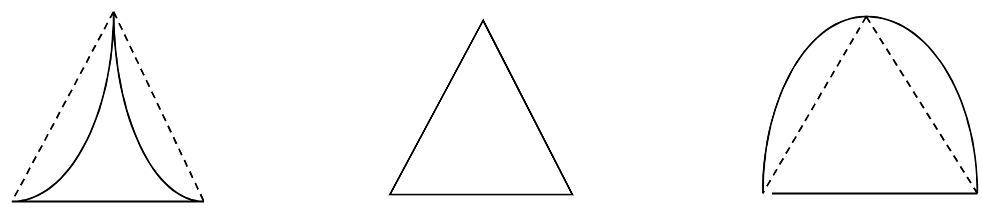
Fig 1.2: Triangular Membership functions 'trimf' in MATLAB

1.2.1. Linguistic Modifiers:

A linguistic modifier based on the confidence level of the opinion/judgment of experts is used to modify the membership function of the fuzzy set proposed by the experts. Three levels of confidence level of the experts with respect to their judgments are: 'High', 'Medium and' Low'. The initial triangular fuzzy set is modified to 'contracting' or 'dilating' by modifying function $\mu (x)$ as given in the Table 1.2.

Table 1.2 Confidence Level of Expert's Judgment

Symbol	Confidence Level	Modification of Membership
H	High	$\mu(x) = [\mu(x)]^2$
M	Medium	$\mu(x) = [\mu(x)]$
L	Low	$\mu(x) = [\mu(x)]^{1/2}$



High Medium Low

Fig 1.3: Modified Possibility Distributions

For this purpose, function module developed by Olaf Wolkenhauer, Control Systems Centre at UMIST, Manchester M60 1QD, UK, FSTB - Fuzzy Systems Toolbox for MATLAB, 1994 has been used. MATLAB version 7.9.0(R2009b) and Simulink (registered trade mark of MathWorks.Inc) are the primary application packages used in the model development.

1.3. Detail Scenario modelling:

All India questionnaire surveys (in three stages during 2010 to 2013) were conducted among four major stake holders/participants (Government representatives, promoters/developers, lenders and consultants) of Indian PPP projects for finding critical risk factors. An 'Other' category of participants consisting of Academician, Students, Journalist and common users, who had knowledge of PPP projects, was also included in the survey. The survey responses were statistically analysed for quantifying the results for qualitative analysis. A detailed case study analysis of 30 infrastructure projects was also carried out and survey findings have been validated through case study comparison. The primary intension of the first and second stage of survey were to find out critical risk factors as stated above and their probable impact on the projects. However, the 3rd stage survey was intended to collect some project specific expert data and project specific event ratings, which could be eventually used in formulating some of our fuzzy modules' events.

Accordingly, in third stage of survey project specific performance/risk management parameters had been sent to the respondents for ratings. At the same time, as per discussions as mentioned above five risk management parameters were so selected that they represent management of overall critical Project risks events involved in Indian PPP projects. Thus, the following representative risk managing parameters were chosen:

- **Low O & M** (Which involves managing for risk events like demand revenue generation, Quality & services, Safety, Environmental issues)
- **Low Time Overrun** (Which involves managing for risk events like Construction stage delays involving land acquisitions & others, as well operational stage delays arising from malpractices to public resistances)
- **Low Cost Overrun** (Which involves managing for risk events like design & technology fault, changing scenario at site)
- **Financial Compatibility** (Which involves managing of risk like Selection of competent agencies to risk of adopting right kind of financial structure)
- **Effective Project Management** (Which involves risk of managing technological aspects, socio-political aspects, organizational aspects)

1.3.1. Modelling of Risks with the Fault Tree Approach:

The author took help of 'fault tree approach', which is one of the promising methods of risk analysis and practiced in system reliability studies, environmental risk analysis, etc. It is presently being followed in wide range of engineering decision making applications. A fault tree is a logical diagram, which reflects a relation between a specific undesirable Risk events falling under a specific category of risk and having an impact on the project objective and failures of the component of the system. An undesirable event is first defined and casual relationships of the failures leading to that event are then identified (*Aven, 1992; Wang and Roush, 2000; Bedford and Cooke, 2001, Thomas, 2002*). In fault tree analysis, attempts are made to develop a deterministic description of the occurrence of the top event in terms of the occurrence (or non-occurrence) of their lower order events. For the purpose of our research, the fault tree approach was used to model the five (above stated) identified representative parameters of risks in Indian PPP projects. Each risk (risk category) is decomposed into a suitable number of component (C1, C2…) risk events (second level). The second level component events are further decomposed into tertiary (3^{rd} level) risk factors or can be further drilled down if scope exist. The risk factors, which lead to the occurrence of component risk events (T1, T2….) in the fault tree, for which further decomposition is not possible are treated as terminal events. In the risks modelling process, component risk events are considered as decision variables (output) and terminal events (T1, T2….) are considered as state variables (input).

It is to be mentioned that the module that have been developed are of representative in nature and thus may not be exact. However, efforts were made to put into as much possible factors as can be on basis of the scope and objectives of the research work.

Fig1.7 to 1.11 presents the developed fault tree models for this research purpose, representing the five identified risk management parameters already stated. The basic assumption considered in constructing these fault trees was that for managing a upper level or for the top level risk, the probabilities of occurrences of next or lower level risks needs to be controlled. So, the determination of probabilities of the terminal events are of paramount importance's for undertaking any risk management strategy.

As already mentioned, MATLAB (R2009b) has been used for developing the necessary modules, 'fuzzy inference engine' a inbuilt module in MATLAB is used to combine two terminal events as per 'defined set of rules' at a time and thereby to move on to the top of the tree. Similar approach was adopted by researchers like Boloş. M. I.*et. al.*,(2015), Yuanzhi Xing *et al.* (2017).

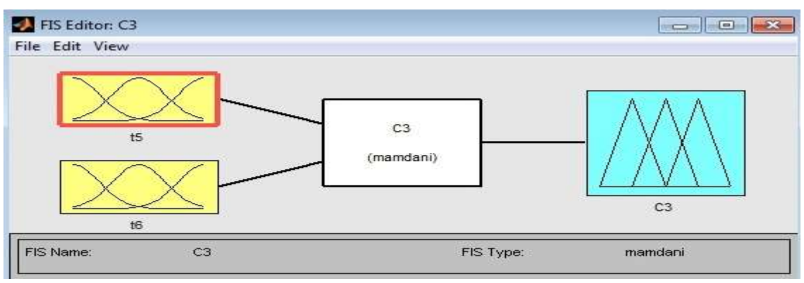


Fig 1.4: In built Fuzzy Engine editor setup in MATALAB

The 'defined set of rules', as stated in the preceding paragraph has been worked out by risk matrix evaluation. For the purpose of this study, a probability impact risk matrix given by Akintoye*et al* (2003) at Fig1.5 is taken into consideration for framing the matrix at Fig 1.6.

High	***	****	*****
Medium	**	***	****
Low	*	**	***
	Low	Medium	High

Risk Criticality

Fig1.5: Risk Matrix given by Akintoye*et. al.(*2003)

EH	****	****	*****	*****	******	******	*******
VH	***	****	****	*****	*****	******	******
H	***	***	****	****	*****	*****	******
M	**	***	***	****	****	*****	*****
L	**	**	***	***	****	****	*****
VL	*	**	**	***	***	****	****
EL	*	*	**	**	***	***	****
	EL	VL	L	M	H	VH	EH

Risk Criticality

Fig1.6: Risk evaluation matrix framed for the purpose of this study.

1.3.2. Constructing the models in Simulink:

MATLAB (R2009b) with associated 'Simulink' gives a strong, yet easy platform to construct real time models. By constructing models using Simulink, one can verify the 'step by step' approach of model development & validity with real time display of results or for that matter any debugging procedures. The Simulink module provides with enough component materials to construct a model with logical view points and to see that the results at various critical points / steps are accurately displayed on the screen alongside. The researcher thus took the advantage of Simulink with an objective to check the validity of results at various critical points (here the probabilities of next higher level component events) before getting to be assured about the result of final stage (the top risk level event's probability). Thus, the following five Smulink models presented at Fig 1.12 to 1.16 have been prepared before the final code preparations of the five risk probability assessment modules.

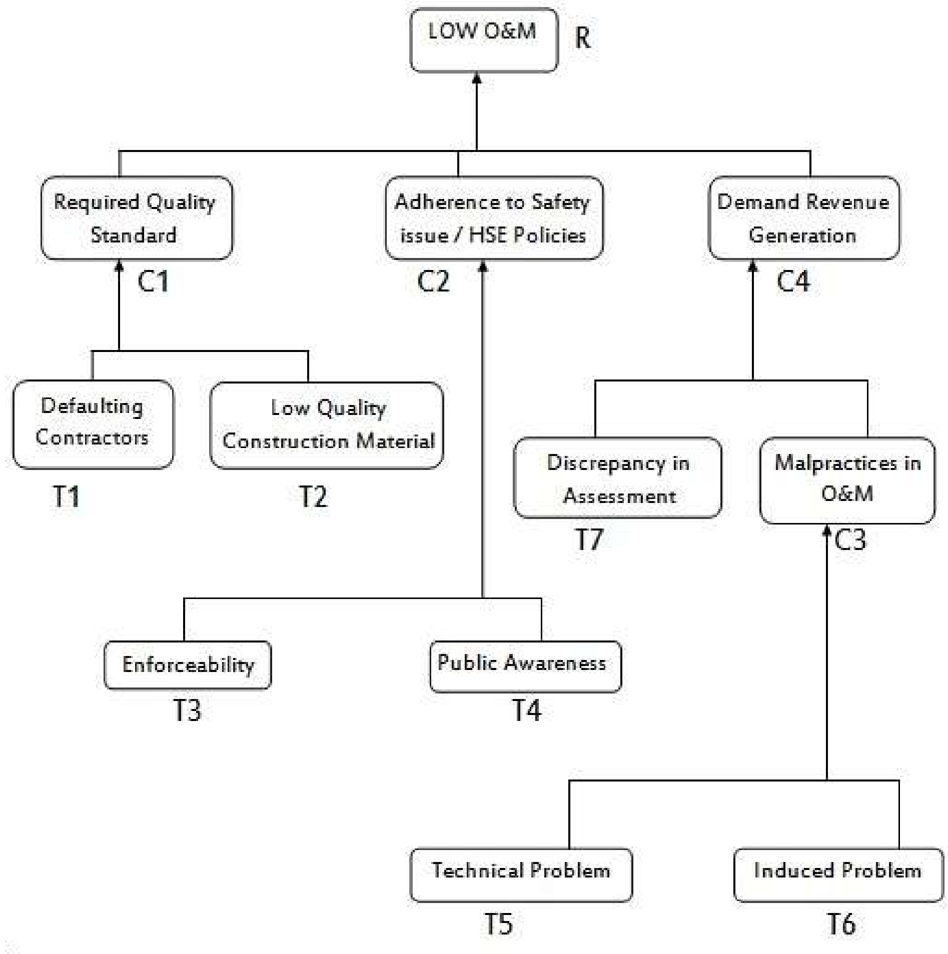


Fig 1.7: Fault Tree for LOW O & M Risk probability determination

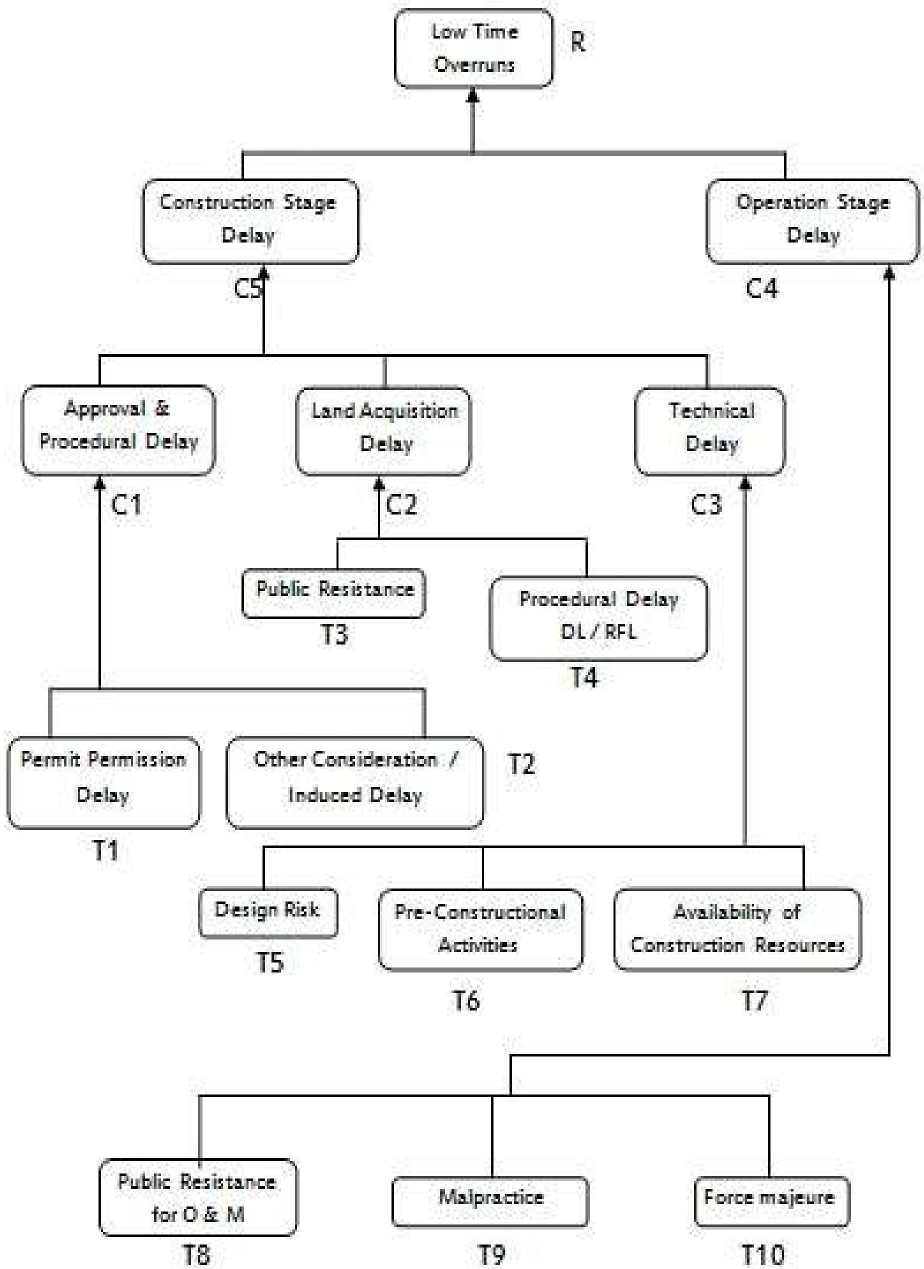


Fig1.8: Fault Tree for LOW TIME Risk probability determination

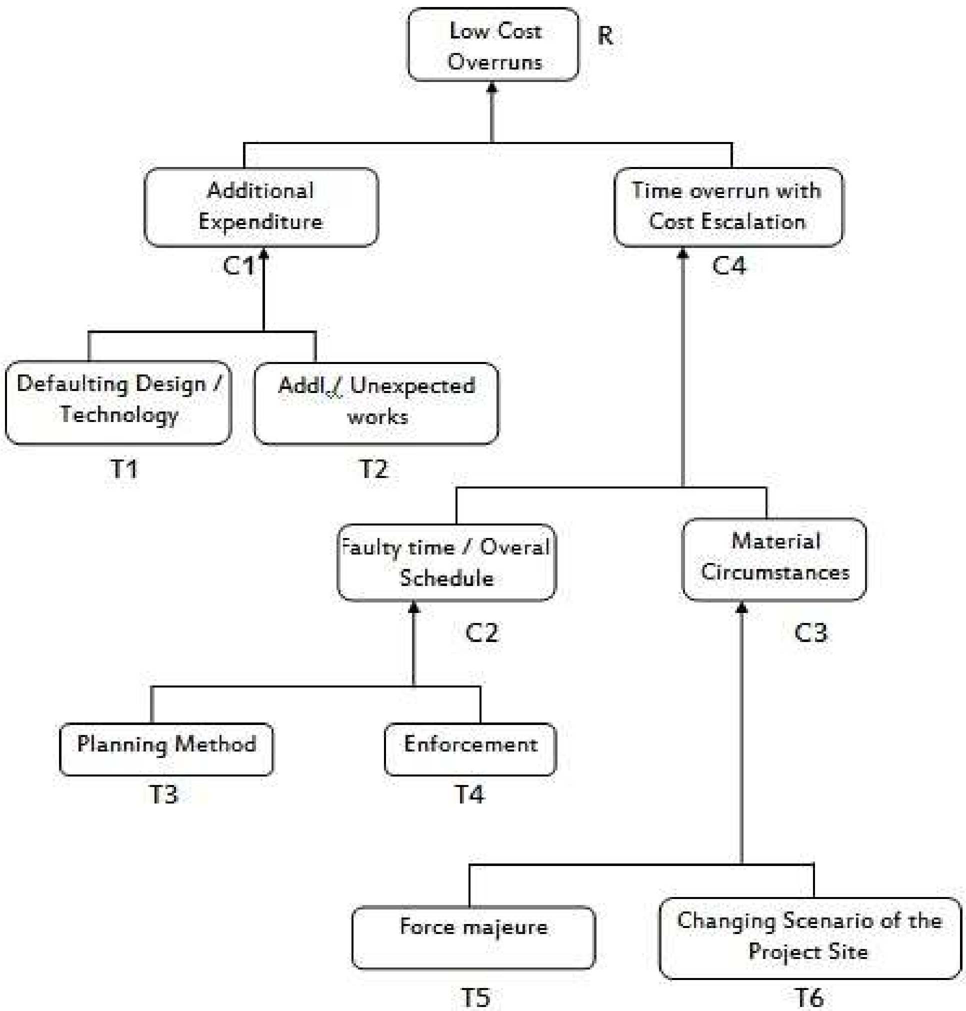


Fig1.9: Fault Tree for LOW COST Risk probability determination

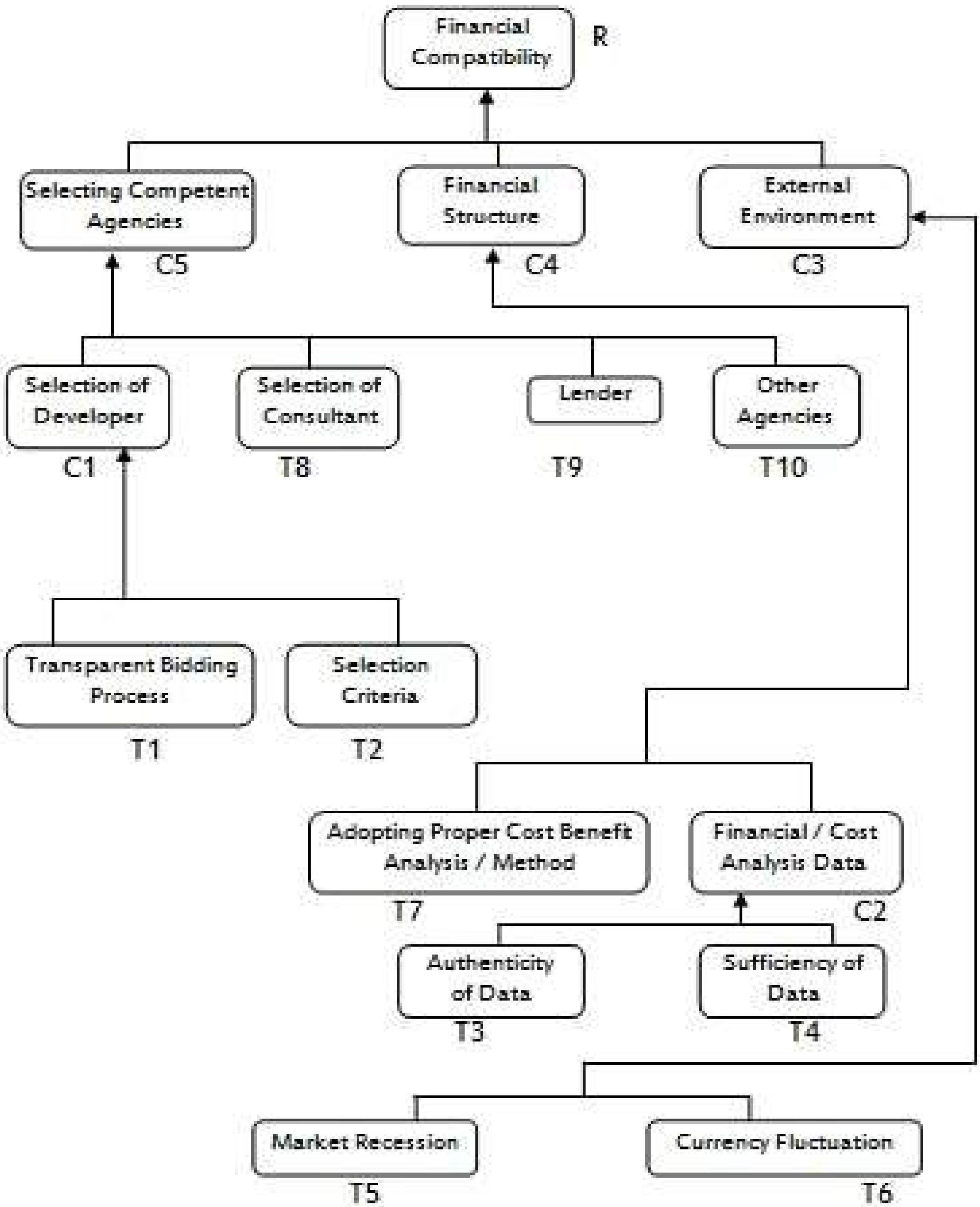


Fig1.10: Fault Tree for Financial Compatibility Risk probability determination

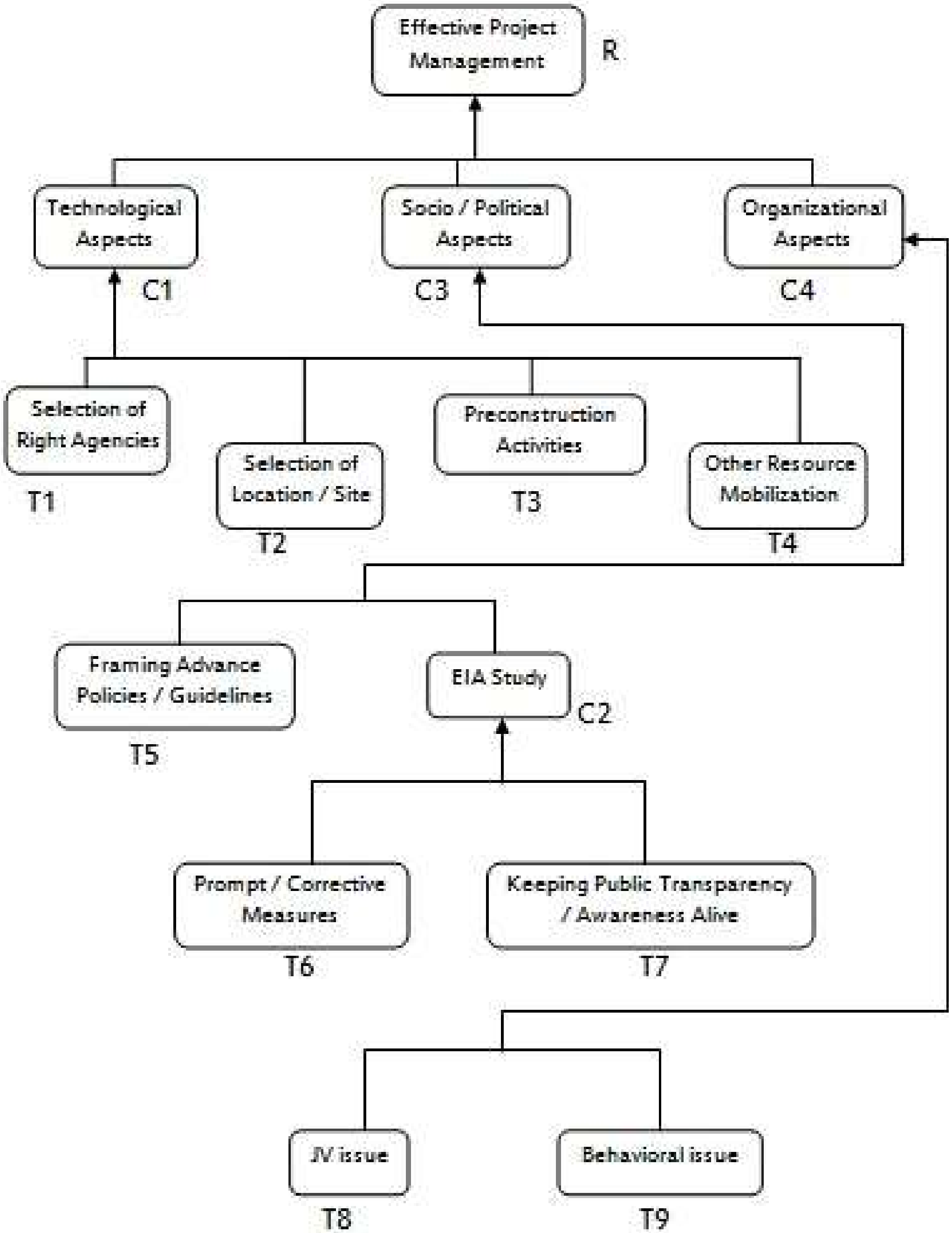


Fig1.11: Fault Tree for Effective Project Management Risk probability Determination

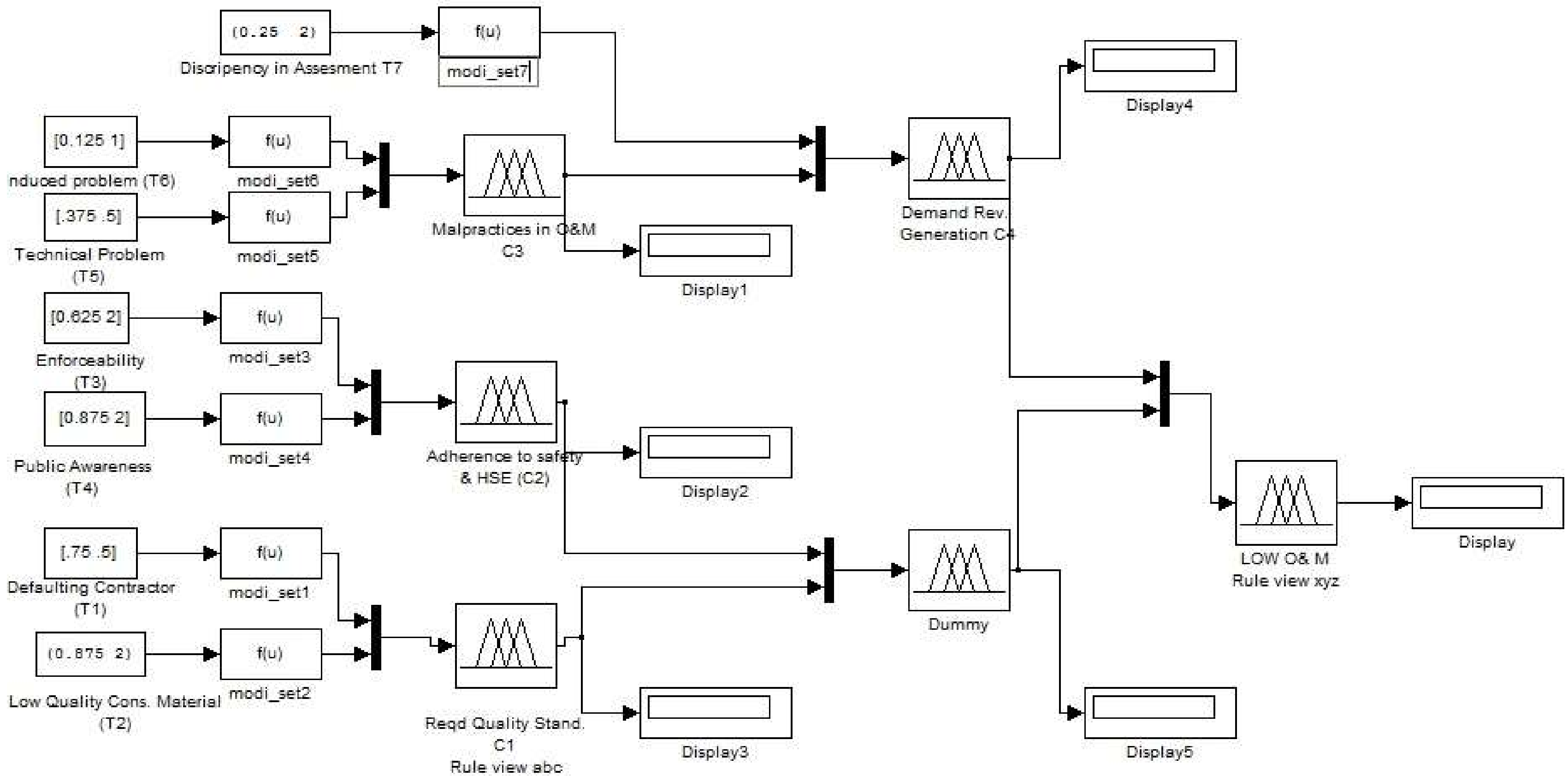


Fig 1.12: Simulink model development for Low-O & M module

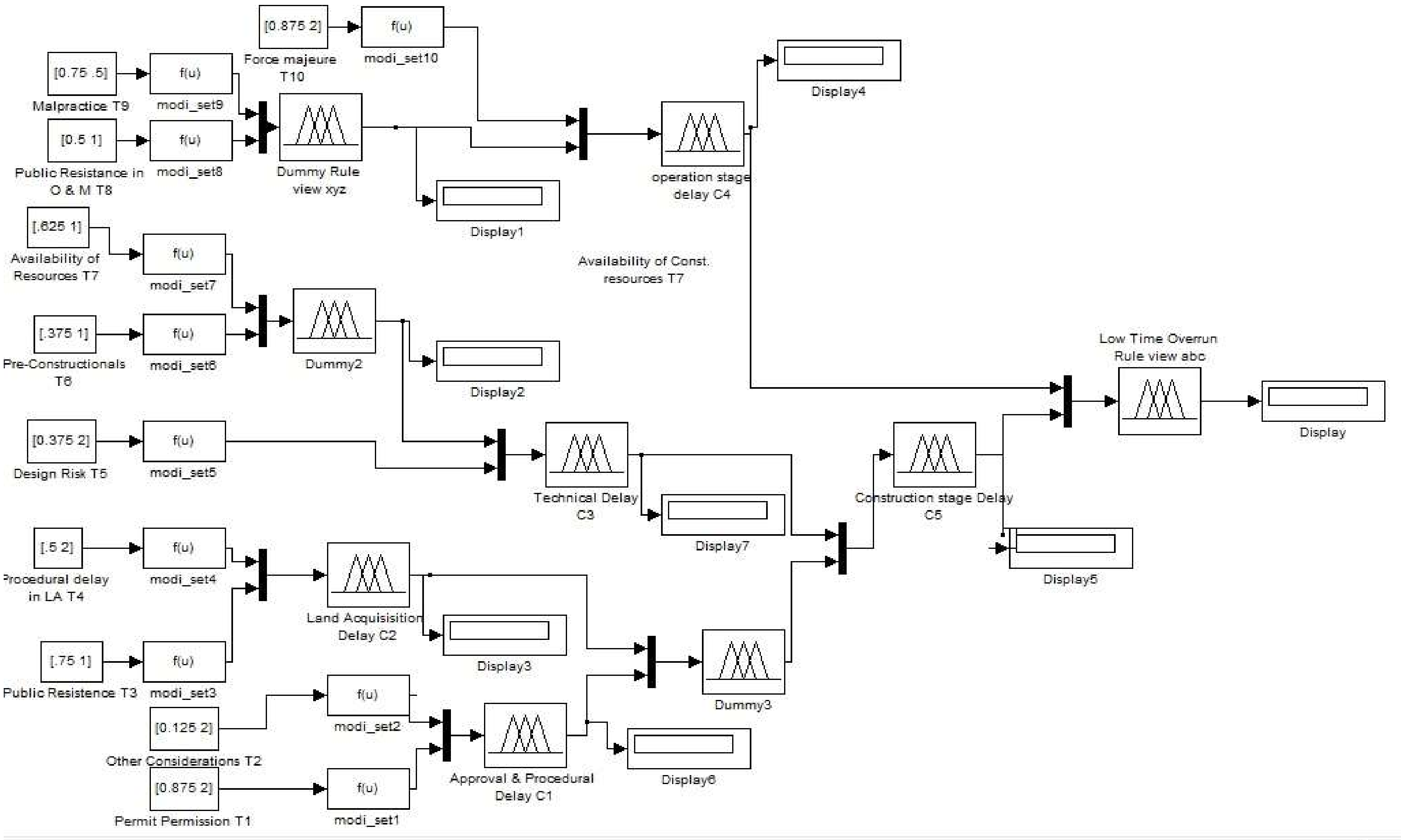


Fig 1.13: Simulink model development for Low-Time overrun module

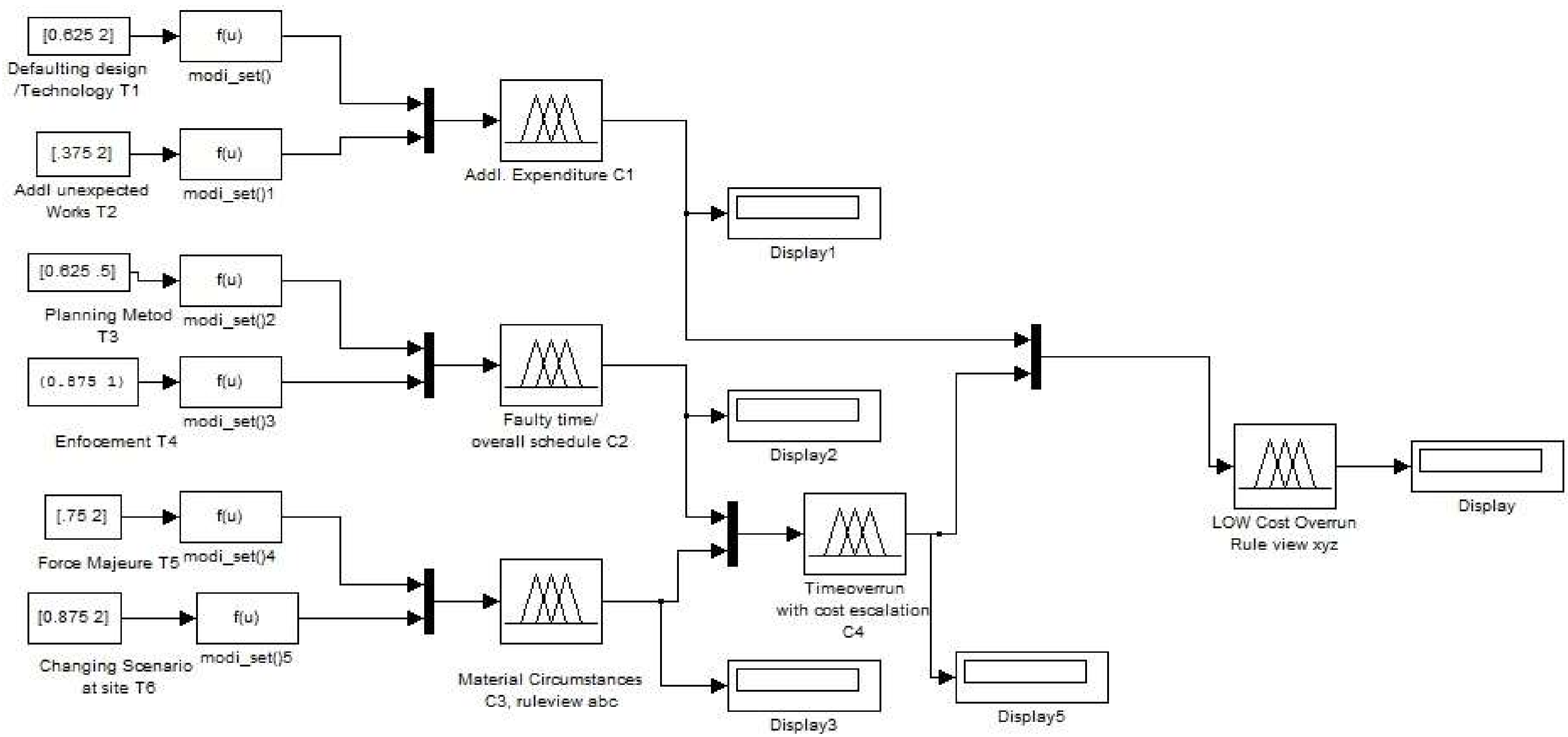


Fig1.14: Simulink model development for Low-Cost Overrun module

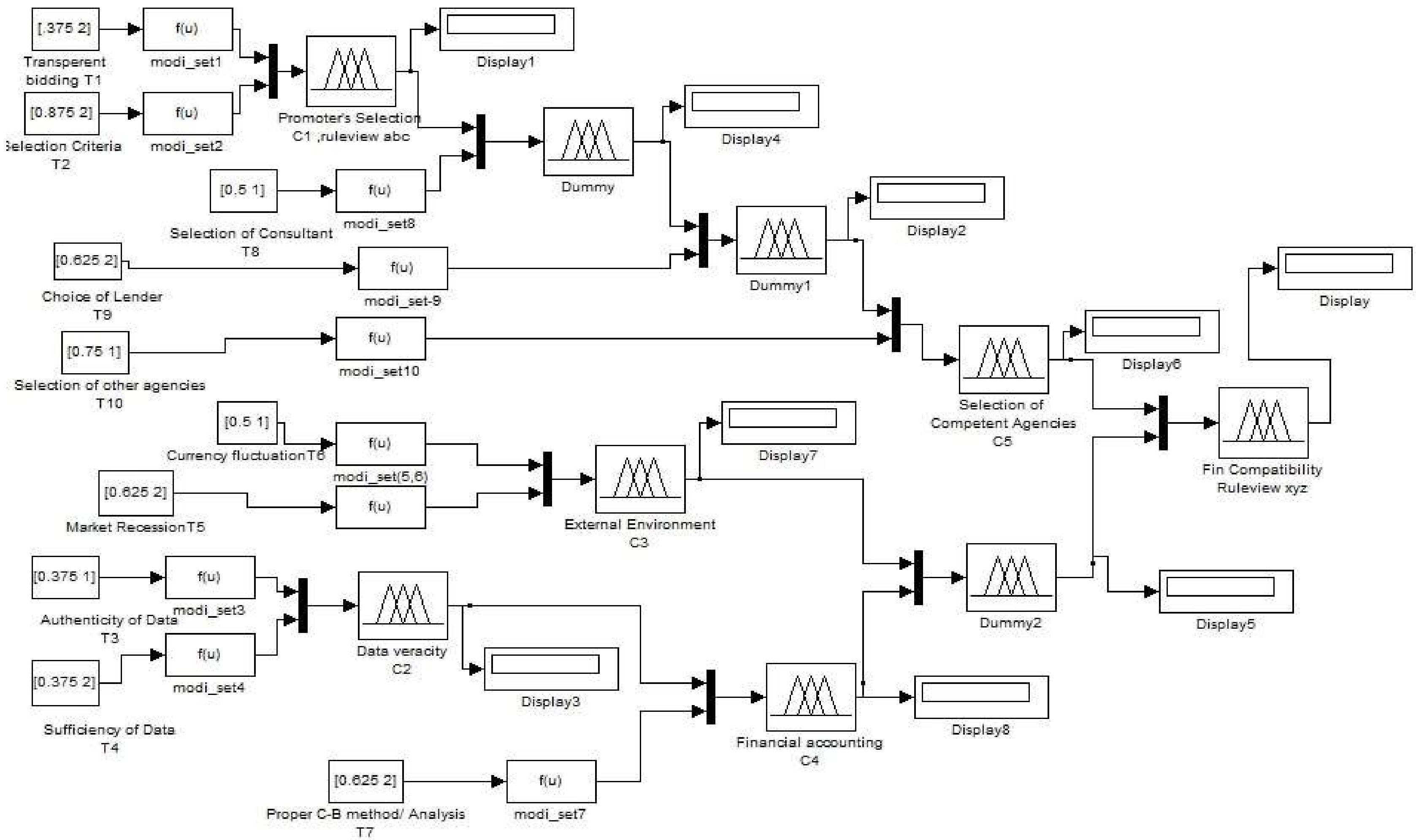


Fig1.15: Simulink model development for Financial Compatibility module

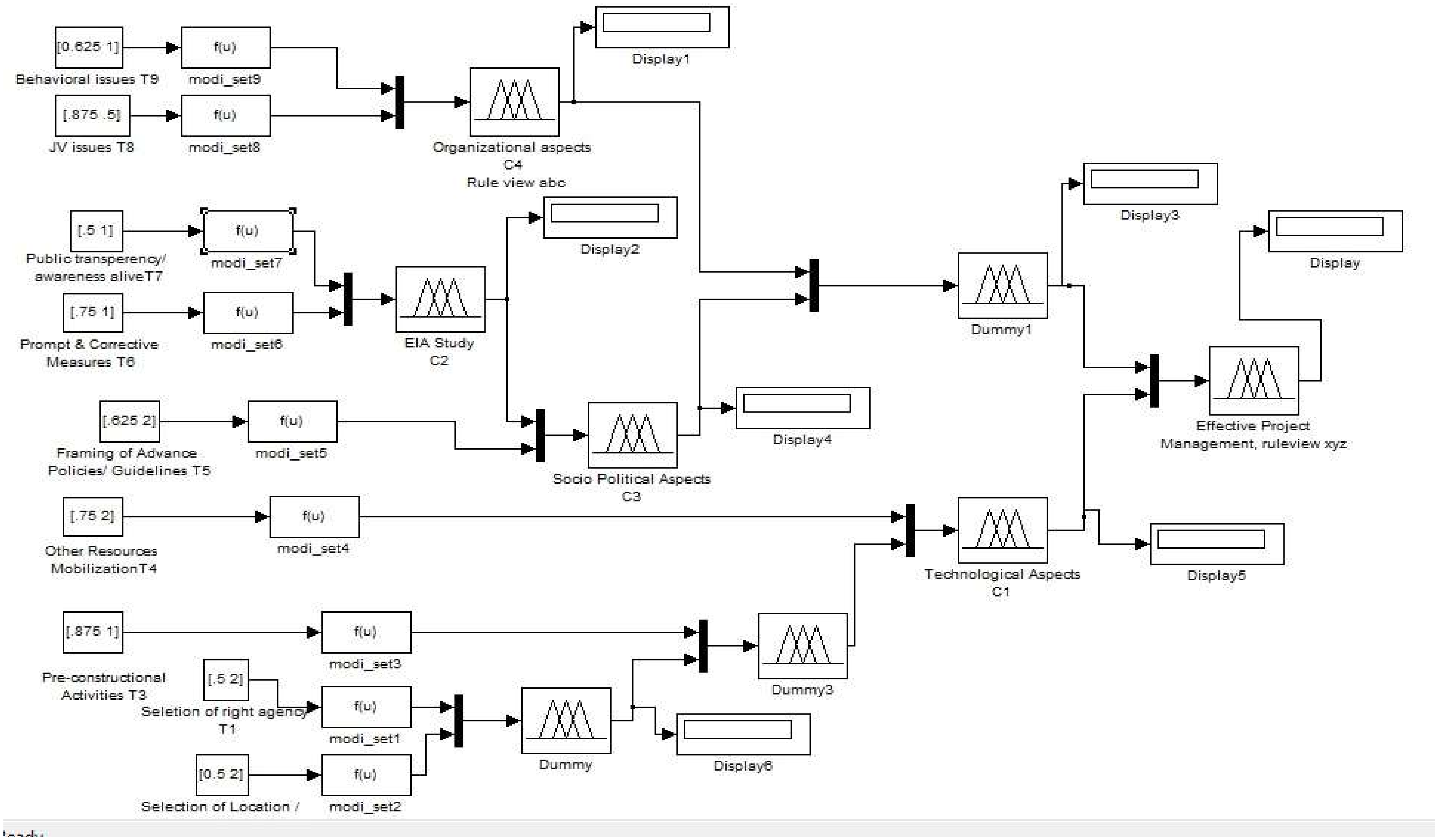


Fig 1.16: Simulink model development for Effective Project Management module

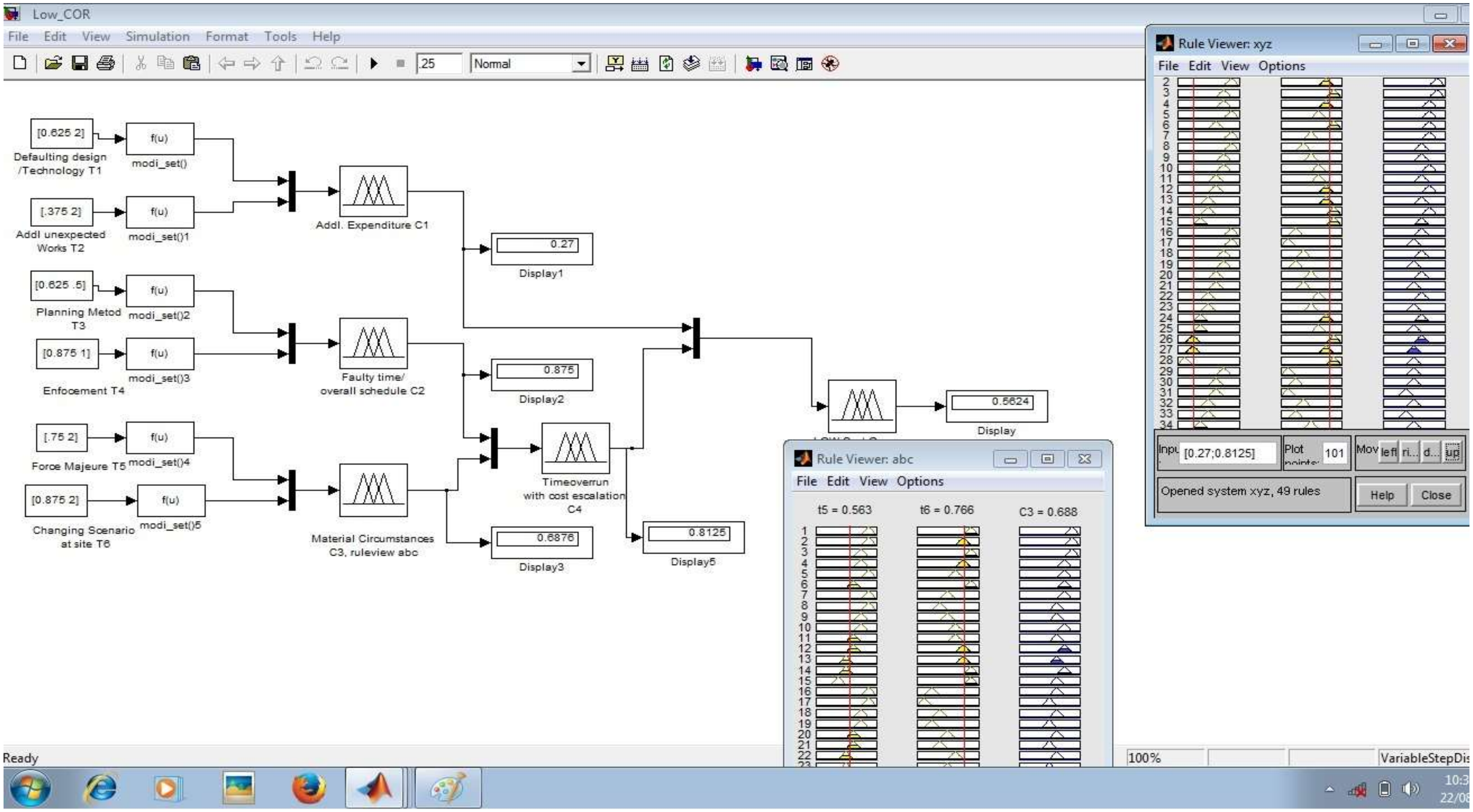


Fig 1.17: A Simulink model testing under process during the course of study

1.4. Delphi Process:

The Fuzzy Delphi Method is an analytical process based on the Delphi Method that draws on the ideas of the Fuzzy Theory. The Delphi Method is a type of collective decision-making method (*Linstone &Turoff, 2002*), with several rounds of anonymous written questionnaire surveys conducted to ask for experts' opinion. It requires multiple repetitions when asking experts for their opinion. The process continues until all the experts arrive at a consensus. Requirement of multiple passes to get a consensus is the inherent weakness of this process (*Ho and Chen, 2007*). Many researchers in the past have therefore, adopted the Fuzzy Delphi method (*Thomas, A.V., 2002; Ho& Wang, 2008*). Thomas A. V. (*2002*) conducted a day's workshop attended by six experts to give their opinion and to modify it at the end of first & second round of Delphi iterations then & there itself. However, Ho& Wang has mentioned about sorting out of variables by taking 25% above and below median value. Considering the scope of their research, the researcher however proposed to go for sorting out of the first round values (got after defuzzification carried out with 'centroid' method) by taking 10% above and below the 'Mode' values, so as to converge the results, after input of a modified set of values by the experts who have been excluded after first round based on above specified criteria.

Thus, the steps involved in our modules for risk probability determination are summarized as follows:

- Get input data from the experts (12 experts in this study)
- Fuzzify the inputs
- Transform the input either contracting or dilating depending on the expert's opinion is high or low. (Use of modi_set( ))
- Pass the value to simulink (if used) or simply run the module developed to get the defuzzified terminal event's values and Probability of the Risk event R (crisp value) after first round of evaluation.
- Find out the mode value of R and check who the experts are falling outside 10% above and below the mode value range.
- Screen them out and modify their second round of input values with recalculated terminal event value.
- For rest of experts falling within 10% range of mode value, run for second round to get next round of crisp value of R as well as terminal events values.

- Again check with 10% mode value criteria, if all values are within the range, get the final value of R.

1.5. Details of Input data arrangements and running of modules:

During the third stage of survey of this research 12 experts have been selected to give their opinion on the terminal events of the five risks which have been chosen for developing the identified risk management modules. Thus these five modules were:

- Low O & M
- Low Time Overrun
- Low Cost Overrun
- Financial Compatibility
- Effective Project Management

Accordingly, data were sought in a 7-point Linguistic scale of 'EH' to 'EL' for opinion on the terminal events' possibilities. At the same time, confidence level (with which the experts are predicting) were also sought from the experts in a 3-point Linguistic scale of High, Medium and Low.

MATLAB programs were written for each one of the above five modules. On running a specific module, say 'Low O&M', it prompts for the Terminal event number T1 and on entering that value it will ask for the corresponding confidence level. On entering, the desired confidence level, it will ask for the next terminal event and then for its confidence level again. This way, the input session will continue till the data for last terminal events of that specific module is not entered upon. On entering all the input values the crisp number for the upper most risk event is calculated out by the programming module based on step by step upward movement in the fault tree; based on rules/risk matrix framed for the purpose. The output of a lower level combination of two events combine either to a separate output emanating from another two combinations or to a 3rd direct input, depending on the fault tree structure / model developed. Further, it has been programmed to show on the screen the Crisp Value of R (defuzzified with cetroid method) and the terminal values of all the events for next round (defuzzified values of previous round).

1.6. Results of Analysis of Data through the developed modules:

The results of analysis of data as received from the 12 experts at 3rd stage of survey (Appedix-A) are analysed through the developed modules and are presented in Table 1.3 and 1.4.At the end of first round, it was found that for the module of 'Low O&M' opinions of Expert No. 1,2,4 & 8 are falling outside the set out criterion of 10% $\pm$ range of Mode values. Similarly, for the module of Effective Project Management, opinion of Expert No.7 is falling outside this range. Hence, the next round iteration was made with the median/mode values for all other modules except the above two. For the above two modules, 'Mode' values are taken as input data for all other Experts, whereas for the differing Experts average of the Mode value and the Expert's individual values has been taken as input. On end of second round, the crisp value are seen to be converging on 10% $\pm$ 'Mode' value criteria. Finally, in order of risk probability following sequence has emerged:

(1) Low O & M
(2) Low Time Overrun
(3) Effective Project Management
(4) Low Cost Overrun
(5) Financial compatibility

1.7. Validation of the developed models:

The validation of the developed models is unavoidable aspect and therefore was planed at the time of obtaining the expert opinions. Direct preferential rating on the five risk management/success categories were obtained from the experts apart from their opinion on possibilities of terminal events. It may be mentioned that the experts were unaware of the probable outcome of analysis of their rating of individual terminal events and at the same time they did not know the opinions of their other counter parts. Thus the results were totally unknown either to the experts or the researcher at that time.

For validation purpose results obtained (analysed) through our developed module are compared with the direct preferential ranking by these 12 Experts. The direct preferential ranking obtained from the experts also showed 'Low O & M' as the first preference. However, 'Effective Project Management' got the second ranking in direct preferential rating followed by 'Low time overrun', 'Low cost overrun' and 'Financial Compatibility' respectively (Appendix-B).

The results obtained through our framed modules have shown the same risk possibilities' order, except the differences in ranking of Low Time overrun and Effective Project Management. This may be due to co linearity of the variables / factors considered for the module's model development as well as fault in minute decomposition in the fault tree level.

However, our evaluated ranking of the topmost possible risk i.e. 'O&M' in Indian PPP projects has been substantiated by a very strong argument put forward in the '*Business Standard'*. As per the argument the country has already entered an inflexion point in PPP where it is moving from asset creation to operation of projects, as because a substantial number of projects awarded in the early years of PPP's initiations have now entered into the most critical O & M phase (*Singh S. P., 2013*).

1.8. Concluding remarks:

As stated in section 1.3 of this article the developed risk management modules are representative in nature and may not be exact. One of the basic intentions of this research was to establish that an effective risk assessment framework can be easily framed by applying techniques like Fuzzy Delphi and with the development of these five modules, the researcher remained successful in proving that. The 'fuzzy logic' itself stands on the principles of approximations and as Dr. V. K. Raina commented, *"It is more meaningful to have an approximate solution to an exact problem than an exact solution to an approximate problem"*. There may be scopes for further refinement of the modules like making them more user friendly or even considerations of more numbers of component/terminal events in the fault tree, incorporating more than two terminal events in a fuzzy control structure with associated increase in the rule set. Nevertheless, with the faming of these modules, the researcher was able to establish that complex risk forecasting like in a PPP environments of India could be undertaken by developing simple basic modules like the ones developed by the researcher.

(Acknowledgement: The authors like to acknowledge the help of Mr. N. Bhagawati, IASST Guwahati for the soft computing)

Table 1.3: **Crisp Values after first round**

Risk Mgnt Criteria	Events	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Exp9	Exp10	Exp11	Exp12	Mode
Low O&M	**R**	**0.655**	**0.610**	**0.735**	**0.666**	**0.745**	**0.745**	**0.745**	**0.653**	**0.745**	**0.711**	**0.699**	**0.722**	**0.745**
	T1	0.652	0.610	0.720	0.660	0.726	0.721	0.726	0.618	0.726	0.696	0.692	0.679	0.726
	T2	0.653	0.623	0.719	0.658	0.724	0.725	0.726	0.627	0.722	0.698	0.690	0.677	0.694
	T3	0.651	0.615	0.715	0.659	0.722	0.722	0.722	0.621	0.722	0.697	0.688	0.669	0.722
	T4	0.650	0.620	0.718	0.658	0.725	0.725	0.725	0.625	0.725	0.699	0.690	0.675	0.725
	T5	0.653	0.617	0.712	0.661	0.727	0.727	0.727	0.625	0.727	0.701	0.690	0.661	0.727
	T6	0.649	0.615	0.719	0.657	0.726	0.726	0.726	0.627	0.726	0.700	0.691	0.679	0.726
	T7	0.651	0.610	0.715	0.659	0.722	0.722	0.722	0.621	0.722	0.697	0.688	0.669	0.722
Low time overrun	**R**	**0.687**	**0.678**	**0.673**	**0.687**	**0.693**	**0.727**	**0.727**	**0.687**	**0.687**	**0.687**	**0.727**	**0.687**	**0.687**
	T1	0.699	0.680	0.683	0.699	0.704	0.729	0.729	0.699	0.699	0.699	0.729	0.699	0.699
	T2	0.682	0.676	0.664	0.682	0.686	0.727	0.727	0.682	0.682	0.682	0.727	0.682	0.682
	T3	0.699	0.689	0.683	0.699	0.704	0.737	0.737	0.699	0.699	0.699	0.737	0.699	0.699
	T4	0.695	0.678	0.679	0.695	0.704	0.735	0.735	0.695	0.695	0.695	0.735	0.695	0.695
	T5	0.688	0.681	0.671	0.688	0.693	0.731	0.731	0.688	0.688	0.688	0.731	0.688	0.688
	T6	0.699	0.698	0.683	0.699	0.704	0.737	0.737	0.699	0.699	0.699	0.737	0.699	0.699
	T7	0.699	0.689	0.683	0.699	0.704	0.737	0.737	0.699	0.699	0.699	0.737	0.699	0.699
	T8	0.680	0.681	0.689	0.680	0.684	0.725	0.725	0.680	0.680	0.680	0.725	0.680	0.680
	T9	0.682	0.677	0.664	0.682	0.686	0.727	0.727	0.682	0.682	0.682	0.727	0.682	0.682
	T10	0.704	0.693	0.689	0.704	0.710	0.740	0.740	0.704	0.704	0.704	0.740	0.704	0.704
Low cost overrun	**R**	**0.682**	**0.686**	**0.682**	**0.682**	**0.682**	**0.625**	**0.682**	**0.682**	**0.672**	**0.682**	**0.683**	**0.682**	**0.682**
	T1	0.675	0.678	0.675	0.675	0.675	0.635	0.675	0.675	0.667	0.675	0.675	0.675	0.675
	T2	0.674	0.677	0.674	0.674	0.674	0.638	0.674	0.674	0.666	0.674	0.675	0.674	0.674
	T3	0.675	0.678	0.675	0.675	0.675	0.623	0.675	0.675	0.666	0.675	0.674	0.675	0.675
	T4	0.674	0.677	0.674	0.674	0.674	0.632	0.674	0.674	0.666	0.674	0.675	0.674	0.674
	T5	0.675	0.678	0.675	0.675	0.675	0.630	0.675	0.675	0.667	0.675	0.675	0.675	0.675

	T6	0.675	0.678	0.674	0.675	0.675	0.627	0.675	0.675	0.667	0.675	0.675	0.675	0.675
Fin comp	**R**	**0.687**	**0.681**	**0.752**	**0.686**	**0.679**	**0.687**	**0.726**	**0.687**	**0.687**	**0.726**	**0.686**	**0.680**	**0.687**
	T1	0.688	0.682	0.755	0.687	0.680	0.688	0.730	0.688	0.688	0.730	0.687	0.674	0.688
	T2	0.686	0.678	0.762	0.684	0.677	0.686	0.729	0.686	0.686	0.729	0.684	0.675	0.686
	T3	0.695	0.689	0.751	0.697	0.687	0.695	0.734	0.695	0.695	0.734	0.697	0.672	0.695
	T4	0.695	0.680	0.751	0.693	0.687	0.695	0.734	0.695	0.695	0.734	0.693	0.674	0.695
	T5	0.699	0.692	0.762	0.697	0.690	0.699	0.736	0.699	0.699	0.736	0.697	0.672	0.699
	T6	0.686	0.682	0.753	0.684	0.690	0.686	0.725	0.686	0.686	0.725	0.684	0.675	0.686
	T7	0.704	0.692	0.766	0.702	0.696	0.704	0.739	0.704	0.704	0.739	0.702	0.671	0.704
	T8	0.699	0.692	0.748	0.697	0.690	0.699	0.736	0.699	0.699	0.736	0.697	0.672	0.699
	T9	0.695	0.689	0.760	0.693	0.687	0.695	0.734	0.695	0.695	0.734	0.693	0.672	0.695
	T10	0.699	0.692	0.749	0.697	0.690	0.699	0.736	0.699	0.699	0.736	0.697	0.672	0.699
Eff PM	**R**	**0.654**	**0.652**	**0.662**	**0.653**	**0.652**	**0.653**	**0.725**	**0.654**	**0.652**	**0.629**	**0.671**	**0.652**	**0.652**
	T1	0.661	0.659	0.657	0.668	0.647	0.668	0.752	0.665	0.641	0.627	0.679	0.647	0.668
	T2	0.661	0.647	0.656	0.659	0.659	0.659	0.729	0.661	0.659	0.631	0.679	0.659	0.659
	T3	0.665	0.662	0.658	0.663	0.662	0.663	0.734	0.665	0.662	0.631	0.682	0.662	0.662
	T4	0.670	0.652	0.658	0.668	0.668	0.668	0.742	0.670	0.668	0.632	0.686	0.668	0.668
	T5	0.651	0.652	0.657	0.650	0.649	0.650	0.715	0.651	0.649	0.629	0.671	0.649	0.649
	T6	0.661	0.659	0.657	0.659	0.659	0.659	0.729	0.661	0.659	0.631	0.679	0.659	0.659
	T7	0.665	0.668	0.658	0.650	0.662	0.659	0.715	0.665	0.662	0.631	0.671	0.641	0.665
	T8	0.665	0.662	0.656	0.663	0.662	0.663	0.734	0.665	0.662	0.631	0.671	0.662	0.662
	T9	0.670	0.668	0.658	0.668	0.668	0.668	0.715	0.670	0.668	0.631	0.686	0.668	0.668

Table 1.4:Crisp Values after second round

Risk Mgnt Criteria	Events	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Exp9	Exp10	Exp11	Exp12	Mode	Final converging values after all the rounds
Low O&M	**R**	**0.703**	**0.695**	**0.726**	**0.705**	**0.726**	**0.726**	**0.726**	**0.697**	**0.726**	**0.726**	**0.726**	**0.726**	**0.726**	**0.729**
	T1	0.7031	0.6949	0.726	0.705	0.726	0.726	0.726	0.6975	0.726	0.726	0.726	0.726	0.726	0.7291
	T2	0.7034	0.6951	0.7266	0.7054	0.7266	0.7266	0.7266	0.6977	0.7266	0.7266	0.7266	0.7266	0.7266	0.7291
	T3	0.7031	0.6948	0.726	0.705	0.726	0.726	0.726	0.6975	0.726	0.726	0.726	0.726	0.726	0.7291
	T4	0.7031	0.6948	0.726	0.705	0.726	0.726	0.726	0.6974	0.726	0.726	0.726	0.726	0.726	0.7291
	T5	0.7031	0.6948	0.7259	0.705	0.7259	0.7259	0.7259	0.6974	0.7259	0.7259	0.7259	0.7259	0.7259	0.7291
	T6	0.7031	0.6948	0.726	0.705	0.726	0.726	0.726	0.6973	0.726	0.726	0.726	0.726	0.726	0.7291
	T7	0.7031	0.6949	0.726	0.705	0.726	0.726	0.726	0.6975	0.726	0.726	0.726	0.726	0.726	0.7291
Low time overrun	**R**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.709**	**0.726**
	T1	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7266
	T2	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.726
	T3	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.726
	T4	0.709	0.709	0.709	0.709	0.709	0.709	0.709	0.709	0.709	0.709	0.709	0.709	0.709	0.7259
	T5	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.7092	0.726
	T6	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.726
	T7	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.7089	0.709
	T8	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7094	0.7089
	T9	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093	0.7093
	T10	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7088	0.7089
Low cost overrun	**R**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.696**	**0.709**

	T1	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.7092
	T2	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.7089
	T3	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.7089
	T4	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.7094
	T5	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.7093
	T6	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.6963	0.7088
Fin comp	**R**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.696**
	T1	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.6963
	T2	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.6963
	T3	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.6963
	T4	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.6963
	T5	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.6963
	T6	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.6963
	T7	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.708
	T8	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7081
	T9	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7081
	T10	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7079
Eff PM	**R**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.693**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.708**	**0.715**
	T1	0.7075	0.7075	0.7075	0.7075	0.7075	0.7075	0.6939	0.7075	0.7075	0.7075	0.7075	0.7075	0.7075	0.7147
	T2	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.6939	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7147
	T3	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.6938	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7147
	T4	0.7076	0.7076	0.7076	0.7076	0.7076	0.7076	0.6937	0.7076	0.7076	0.7076	0.7076	0.7076	0.7076	0.7147
	T5	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.6941	0.7081	0.7081	0.7081	0.7081	0.7081	0.7081	0.7147
	T6	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.6939	0.7078	0.7078	0.7078	0.7078	0.7078	0.7078	0.7147
	T7	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.6938	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7147
	T8	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.6938	0.7077	0.7077	0.7077	0.7077	0.7077	0.7077	0.7147
	T9	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.6937	0.7079	0.7079	0.7079	0.7079	0.7079	0.7079	0.7147

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Appendix-A

Input data received from 12 experts for fuzzy risk management/ probability prediction modules:

Sl. No.	Response by			Expert-I		Expert-II		Expert-III		Expert-VI		Expert-V		Expert-VI		Expert-VII		Expert-VIII		Expert-IX		Expert-X		Expert-XI		Expert-XII	
	Risk management/Success Category	Terminal Events	Terminal Event No.	Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event		Rating of lower most /Terminal Event	
				Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl	Importance	Conf. Levl
A	Low O & M Cost	Defaulting Contractors	T1	VH	H	EH	M	VH	L	VH	H	VH	M	VH	H	VH	M	VH	H	VH	M	VH	H	VH	L	EH	M
		Low quality construction materials	T2	L	M	L	H	VH	M	H	M	M	M	H	M	VH	M	EH	M	L	M	M	M	H	M	VH	M
		Enforceability	T3	EH	H	VH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H
		Public awareness	T4	H	M	M	H	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M
		Technical problem	T5	H	H	H	H	H	H	H	H	H	L	H	L	H	L	H	M	H	L	H	L	H	M	H	H
		Induced Problem	T6	EH	M	VH	H	EH	M	EH	M	EH	M	EH	M	EH	M	EH	M	EH	M	EH	M	EH	M	EH	M
		Discrepancy in assessment	T7	EH	H	EH	M	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H
B	Low Time Overruns	Permit permission delay	T1	VH	H	VH	M	VH	H	VH	H	VH	H	VH	M	VH	M	VH	H	VH	H	VH	H	VH	M	VH	H
		other consideration/induced delay	T2	M	L	H	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L
		Public resistance	T3	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H
		Procedural delay (DL/RFL)	T4	EH	H	EH	M	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H
		Design Risk	T5	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M
		Pre-constructional activities	T6	VH	H	M	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H
		Availability of constructional resources	T7	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H
		Public resistance in O & M phase	T8	H	L	H	M	H	H	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
		Malpractice	T9	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L
		Force majeure	T10	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
C	Low Cost Overruns	defaulting Design & Technology	T1	VH	M	EH	M	VH	M	VH	M	VH	M	VH	H	VH	M	VH	M	EH	M	VH	M	VH	M	VH	M
		Additional/unexpected works	T2	EH	H	VH	H	EH	H	EH	H	EH	H	H	H	EH	H	EH	H	VH	H	EH	H	EH	H	EH	H
		Planning method	T3	EH	M	VH	M	EH	M	EH	M	EH	M	EH	M	EH	M	EH	M	H	H	EH	M	H	H	EH	M
		Enforcement	T4	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H
		Force majeure	T5	M	M	M	L	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
		Changing scenario of the project area	T6	H	M	H	M	H	H	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M
D	Financial Compatibility	Transperent bidding process	T1	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M
		Selection criteria	T2	VH	M	EH	M	VH	H	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M	EH	L
		Authenticity of data	T3	EH	H	EH	H	EH	M	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	VH	H	EH	H
		Sufficiency of data	T4	EH	H	VH	M	EH	M	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	VH	M
		Market Recession	T5	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H
		Currency Fluctuations	T6	VH	M	H	M	VH	M	VH	M	VH	H	VH	M	VH	L	VH	M	VH	M	VH	L	VH	M	EH	L
		Adopting of proper Cost-benefit analysis method	T7	H	H	VH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
		Selection of consultant	T8	VH	H	VH	H	VH	L	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H
		Choosing Lenders	T9	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H
		Other agencies	T10	VH	H	VH	H	H	L	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H
E	Effective Project Management	Selection of right agencies	T1	EH	H	EH	H	EH	H	H	H	EH	M	H	H	M	H	VH	H	EH	L	H	L	EH	H	EH	M
		Selection of location/site	T2	EH	H	EH	M	EH	L	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H
		Pre-constructional activities	T3	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H
		other resource mobilisation	T4	H	H	H	M	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
		Framing of Adanced and appropriate policies/guidelines	T5	VH	M	H	M	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M	VH	M
		Prompt/Corrective measures	T6	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H	EH	H
		Keeping Public Transperancy/Awarness alive	T7	VH	H	H	H	VH	H	VH	M	VH	H	EH	H	VH	M	VH	H	VH	H	VH	H	VH	M	EH	L
		JV partnership issue	T8	VH	H	VH	H	EH	M	VH	H	VH	H	VH	H	VH	H	VH	H	VH	H	EH	H	VH	M	VH	H
		Behavioral issue	T9	H	H	H	H	H	H	H	H	H	H	H	H	VH	M	H	H	H	H	VH	H	H	H	H	H

Direct Preferential ratings by the experts for possibilities on risk management criteria:

Risk Management Categories		1st preference No. of experts	2nd preference No. of experts	3rd preference No. of experts	4th preference No. of experts	5th preference No. of experts	Final score	Rank
Sl. No.	Description							
A	Low O & M	4	3	2	2	1	43	1
B	Low Time Overrun	2	1	4	4	1	35	3
C	Low Cost Overrun	2	2	2	2	4	32	4
D	Financial Compatibility	1	4		2	5	30	5
E	Effective Project Management	3	2	4	2	1	40	2

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