Fuzzy Cognitive Map based Approach for Software Quality Risk Analysis

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ABSTRACT
This paper presents a software risk prediction tool for risk analysis during the development of a software product. The term "Risk" refers to a problem that can threaten the success of the software project but has not happened yet. Risks are uncertain. The main objective of each organization is to provide very high quality software to their customers. The term "Quality" is a value to the person. But there is a long list of software risks that can have adverse impact on the quality of the software. It is necessary to address all the risks; otherwise, they may lead to undesireable results. Fuzzy Cognitive Maps (FCMs) describe different concepts with different aspects of the behaviour of complex systems. A software tool based upon FCM has been developed for assessing software risks. This paper describes the reasoning behind the focus on risk management during the software development process and its importance in delivering high quality software by assessing software risks during the development process using fuzzy cognitive maps.

Categories and Subject Descriptors
D.2.9 [**Software Engineering**]: *Software quality assurance, Software management.*

General Terms
Management, Measurement, Performance, Reliability.

Keywords
Risk, Fuzzy Logic, Fuzzy Cognitive Maps, Risk Management.

1. INTRODUCTION
Software Engineering is a profession having the objective of providing high quality software to the customers within budget and schedule. It is a systematic approach to analysis, design, and implementation of the software withmany risks involved in creating high quality software. The term "Quality" refers to the degree to which a system meets specified requirements of a particular customer [1]. In other words, "Quality" means a value to someone.Quality consists of all the features to provide product satisfaction [2]. But, it is not always possible to fulfill all thecustomer's requirements by a particular system. Risks may arise during the development process and can have adverse affects on the quality of the software [3]. So, there is a need to control all the possible risks. Although controlling risks has a cost, if the risks are not addressed in a timely manner, they may result in undesireable results. There is no magic solution that overcomes software risks [4]. Risks occur due to errors made by software programmers. The causes of software errors can be due to faulty requirements, communication gap between clients and developers, deliberate deviations from software requirements, logical design errors, wrong documentation, shortcoming in testing process and procedure errors. Risks are always uncertain. Risks do not have any exact value. There is a long list of risks that always reduce software quality. Fuzzy logic can be used for risk analysis since it is a tool capable of modeling data that is complex and uncertain [6]. It provides mathematical tools for solving and working out approximate reasoning processes when having to deal with imprecise, uncertain, and vague data. This logic is perfect for dealing with the uncertainty risk plays in a project development [7]. A Fuzzy Cognitive approach is used as it is capable of dealing with complex systems through its features of simplicity, adaptability and capability of approximating abstractive structures [8].

1.1 Risk Management
The activity of risk management provides the mechanisms to reduce the probability of future uncertain events. Risk Management includes the four activities [9].

1. Risk Identification
2. Risk Analysis and Prioritization
3. Risk Planning
4. Risk Monitoring

The following figure 1 shows the risk management activities.

Figure 1. Different Risk Activities.

Risk Management is mainly concerned with the development process, not with the final product.

1.2 Study of Risk Factors
Risk analysis is the process of gathering all the risks and focusings on all the risks individually [10]. Risk analysis evaluates all the risks and the impact of each risk on software's success. Risks can be categorized as "Very Low Risk", "Low Risk", "Medium Risk", "High Risk", "Very High Risk"[11].

Software risks were addressed by Boehm [5] who gave the approaches to risk management. Boehm provides a list of major 10 risk factors, which are:

DOI: 10.1145/2047414.2047422 http://doi.acm.org/10.1145/2047414.2047422

- Personal Shortfalls
- Unrealistic time & cost estimates
- Developing the wrong software functions
- Developing the wrong user interface
- Gold Plating
- Late changes to requirements
- Shortfalls in externally supplied components
- Shortfalls in externally performed tasks
- Real time performance shortfalls
- Straining Computer Science Capabilities.

Table 1. Applications of Fuzzy Cognitive Maps

Sr. No.	Applications of Fuzzy Cognitive Maps	Reference
1.	Diagnosis of Diseases	R. Taber [27]
2.	Analysis of Electrical Signals	M.A. Styblinski, B.D. Meyer. [28]
3.	Modelling Decision Support Systems	E.I. Papageorgiou et al. [29], R M. Axelrod et al. [24], M. Laukkanen [30 - 32], B. Kosko [33] ,Stylios [34]
4.	In Banking Industry for Customer Satisfaction	S.M.R. Nasserzadeh et al. [35]
5.	Process Industry	C.E. Pelaez et al. [36]
6.	Analysis of Failure Mode Effects	C.E. Pelaez et al. [37]
7.	Fault Management in Distributed Environment	T.D. Ndousse et al. [38]
8.	Analysis of Business Performance Indicators	G. Mentzas [39]
9.	Cotton Yield Farming in Precision Farming	E.I. Papageorgiou et al. [40]
10.	Decision Making in Radiation Therapy Planning Systems	C.D. Stylios et al. [41]
11.	Diagnosis of Specific Language Impartment	V.C. Georgopoulos et al. [42]
12.	Intelligent Database Processing	R. Satur et al. [43]
13	Modelling of Supervisory Systems	C.D. Stylios et al. [44]
14.	Modelling of Plant Growth	K. Gotoh et al. [45]
15.	Modelling of Virtual Worlds	J. Dickerson et al. [46]
16.	Modelling of Political Affairs in South Africa	M. Khan et al.[47]
17.	Protein Sequence Analysis	W. Stach et al. [48]
18.	Modelling Software Project Management	W. Stach et al. [49, 50]
19.	Modelling Metabolic and Regulatory Networks	J. Dickerson et al. [51]
20.	Modelling and Stimulating High Level Behaviour	D.E. Koulouriotis et al. [52]
21.	Web Mining Interference Amplification	K.C. Lee et al. [53]
22.	Design of Electronic Data Interchange Control	S. Lee et al. [54]
23.	Geographic Information Systems	R. Satur et al. [55]
24.	Relationship Management in Airlines Services	I. Kang et al. [56]
25.	Simulate Information Systems Strategic Planning Process	D. Kardaras et al. [57]

Depending upon the nature of software, some risks may arise and some risks may hide during the development process. A list of six risk dimensions is provided which is better than Boehm's original list of risks [12]. Riskit method has features of its sound theoretical foundations and it focus on qualitative understanding of risks [7]. Priors are applied to small and large projects which require detailed information of the organization to develop a set of risk factors [13]. A cost effective framework, specifically targeted at Indian software Small-to-Medium-sized Enterprises (SMEs) focuses on organizations that have no experience in software process improvement (SPI) programs. The results of the study can be used by organizations to achieve the CMMI standards to build up high quality software [14]. The Software Engineering Institute (SEI) has done work in identifying risk factors [15, 16, 17]. The taxonomy contains 194 "questions" to study knowledge of project and can be used for risk management activities. Artificial Intelligence software for risk analysis model named Fuzzy Fault Tree (FFT) employs "Fuzzy Weibull" membership functions and basically designed to accomplish cost analysis, Identify uncertainties and find out the account for vagueness [18]. For better risk analysis data can also be collected through the medium of questionnaires. Rapid application development was used to construct the software in efficient manner and mitigation steps each risks were defined [19]. Tools are available for the management of various kinds of risks [9]. There is need to manage the process of software in terms of cost. A tool for cost overrun is proposed [20]. Fuzzy logic approach was used to identify threats to computer systems [21]. A FCM based technique was used for risk assessment in health care institution [22]. FCM technique was used to do transaction based risk analysis for security management [23].

1.3 Fuzzy Cognitive Maps

Cognitive maps were initially introduced in 1976 by Robert Axelrod and were applied in political scienc [24]. Fuzzy Cognitive Maps (FCMs) were first introduced by Bart Kosko in 1986 as an extension of cognitive maps [25]. A Fuzzy cognitive map is a cognitive map within which the relations can be used to compute the "strength of impact" of various elements. The construction of an FCM requires human experience in the form of inputs and knowledge on the system under consideration [8]. Thus, FCMs integrate the accumulated experience and knowledge concerning the underlying causal relationships among different factors [26]. Fuzzy Cognitive Maps are represented by graphs. FCMs models can be represented by a square matrix called Connection Matrix. Matrix is the combination of row and column in the table. Each cell in connection matrix stores the value of corresponding relationship.

2. RELATED WORK ON FCMs

Table 1 shows various applications proposed by researchers in recent literature.

Table 2. Input Risk Factors

Risk Factors
Poor Management
Shortfalls in Externally Supplied Components
Market Competition
Environmental Failure
Change in Customer's Requirements

DOI: 10.1145/2047414.2047422 http://doi.acm.org/10.1145/2047414.2047422

Deadline Pressure
Lack of Staff Commitment
Adding Unnecessary Features
Developing Wrong Software Functions
Wrong Documents
Lack of User Support
Incorrect Metrics
Developing Wrong User Interface
Straining Computer Science Capabilities
Lack of Training/Experience

3. PROPOSED WORK

For the analysis of results, we have proposed a fuzzy cognitive maps based tool for software risk analysis. As per the literature survey [57]. We have found that there is a long list of risks that can have adverse effect on the software quality and finally all these risks can have direct or indirect impact on the project failure. Although the impact of various risk parameters can vary according to the organization. Table 4 in Appendix A shows all the factors related to software risks and their interdependices. The weigths of all the dependent factors is calculated using FIS rule viewer where neutral input parameter of all the risk factors is 0.5, considered as the default value.The weights are calculated by considering input value as 1. Similarly, all the weight of the dependent components are computed. Here, finally we have selected 15 factors that can have direct or indirect impact on the project failure. The 15 risk factors were considered to check their impact on 4 factors. Table 2 contains the list of input risk factors. Table 3 contains the list of output factors which can be adversely affected if the above factors arise. Although, impact level of various parameters can be set or change according to the organizations moreover parameters can also be changed according to the requirements of the different organizations. We have constructed rule base using 31 rules as per the given opinion by the experts .The data used for constructing rule base is shown in Appendix A.

Table 3. Output Factors

Output Panels
Chances of Personnel Shortfalls
Chances of Technical Failure
Chances of Poor S/W Quality
Chances of Project Failure.

Using MATLAB, a GUI based tool is developed according to the 31 different added rules as shown in figure 2. The comprehensive FCM containing all the concepts and the weights is shown in figure 3.

4. DESIGN METHODOLOGY

In order to find out the impact of risk factors, the opinion of 4 experts has been considered. The impact of risks was provided five categories. They are listed as: “VL”, “L”, “M”, “H”, “VH”.

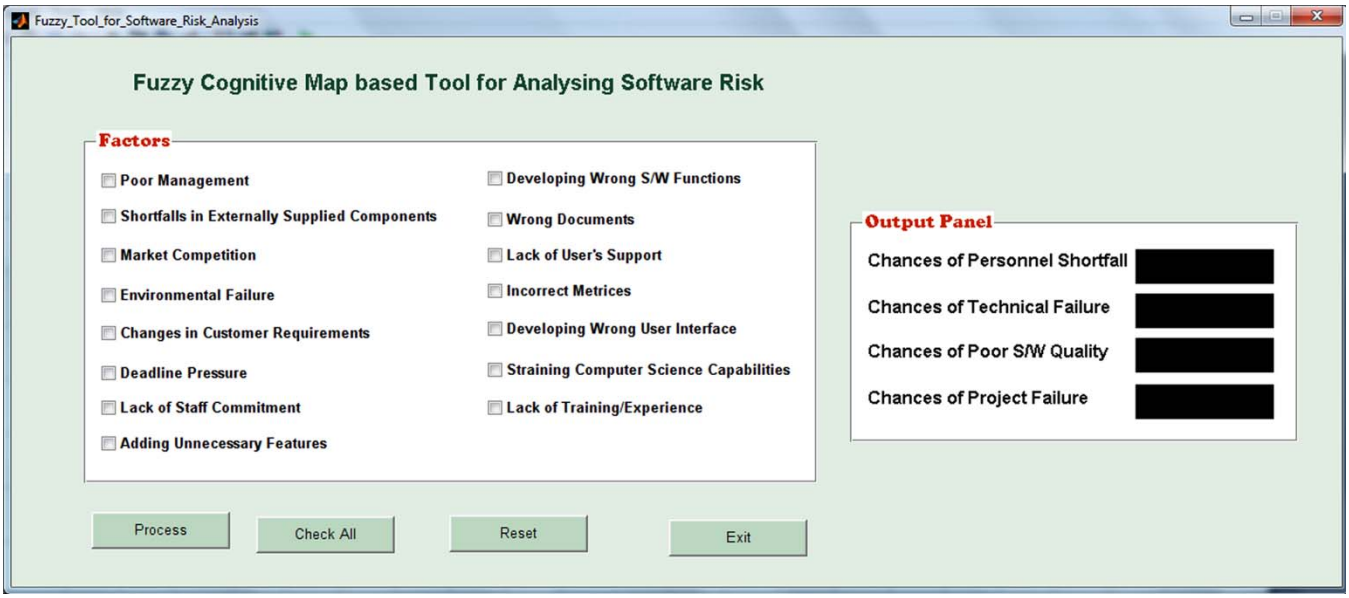

Figure 2. GUI Tool of the Proposed Technique

Membership functions have been used for designing the fuzzy inference system in MATLAB. Figure 4 shows membership functions used for variable *S/W Quality* with five linguistic values {VL, L, M, H, VH}. For input factors, Z-shaped and S-shaped built-in membership functions have been used. For output factors, triangular-shaped and trapezoidal-shaped membership functions have been used.The Z-shaped membership function used is given in Eq. 1.

$$f(x;0,1)=\begin{cases}1, x\le 0\\ 1-2\left(\dfrac{x-0}{1-0}\right)^2, 0\le x\le \dfrac{0+1}{2}\\ 2\left(\dfrac{x-1}{1-0}\right)^2, \dfrac{0+1}{2}\le x\le 1\\ 0, x\ge 1\end{cases} \quad (1)$$

DOI: 10.1145/2047414.2047422 http://doi.acm.org/10.1145/2047414.2047422

The trapezoidal-shaped membership function is given in Eq. 2.

$$f(x;0.669,0.892,0.9,1)=\begin{cases}0, x\le 0.669\\ \dfrac{x-0.669}{0.892-0.669}, 0.669\le x\le 0.892\\ 1, 0.892\le x\le 0.9\\ \dfrac{1-x}{1-0.9}, 0.9\le x\le 1\\ 0, 1\le x\end{cases} \quad (2)$$

The relationships among the factors have been defined in the form of IF-THEN rules of fuzzy logic. Rules are formulated after representation of inputs and outputs of fuzzy sets in membership functions. As in the case of *Adding Unnecessary Features* can have adverse effect on the *S/W Quality*. Its rule are as given below.

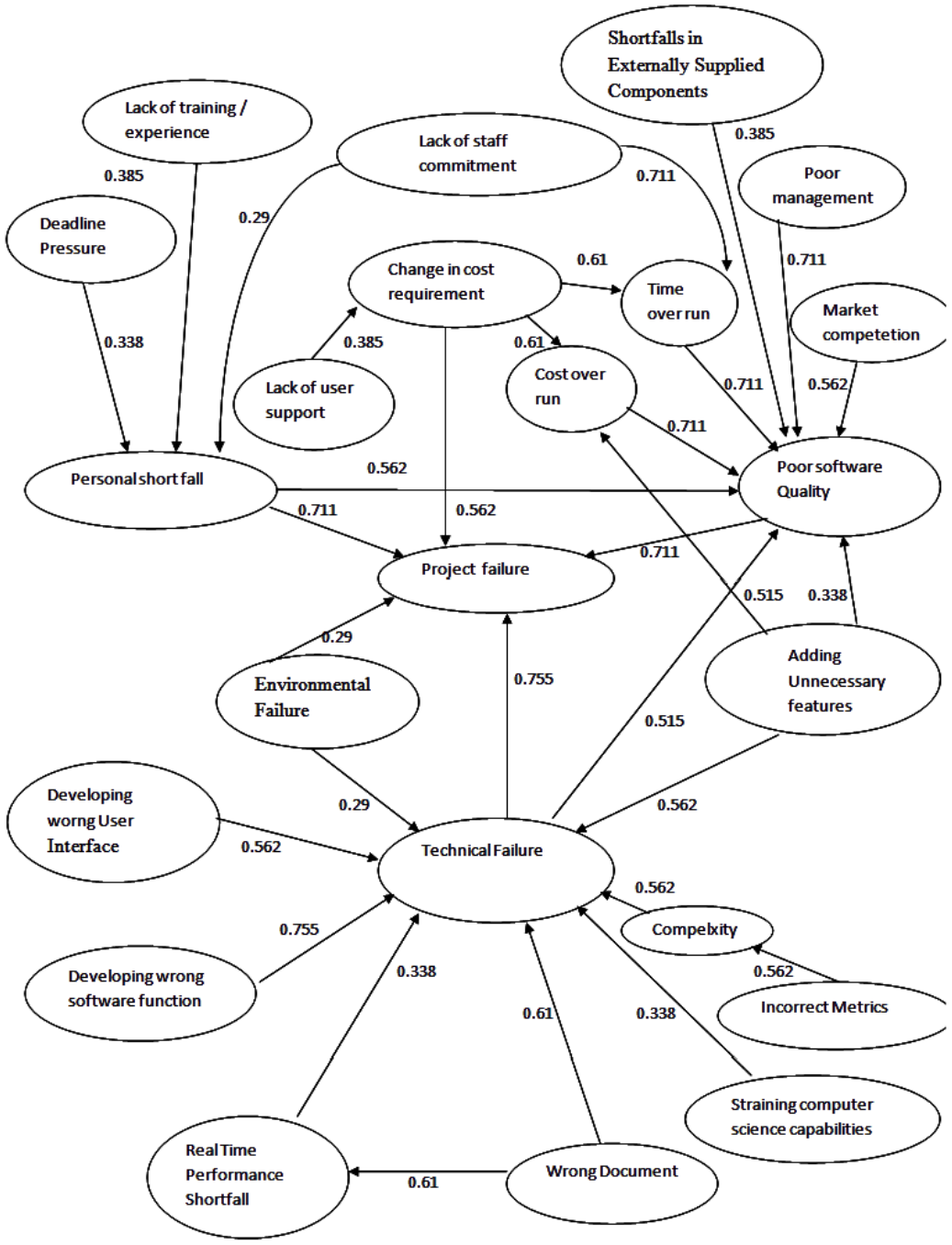

Figure 3. FCM containing all concepts alongwith corresponding weights.

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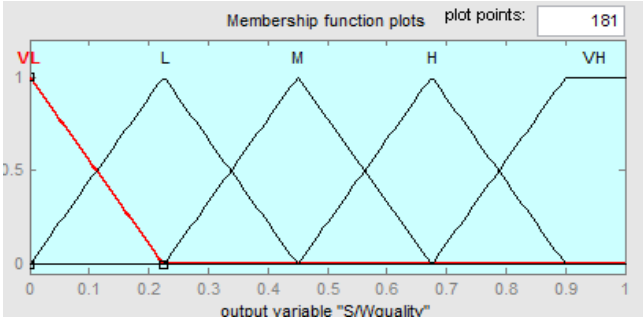

Figure 4. Membership Function for Output factor S/W Quality.

If (*AddUnnecessaryFeature* is *Yes*) **then** (*S/Wquality* is **L**) (0.5)
If (*AddUnnecessaryFeactures* is *Yes*) **then** (*S/Wquality* is **M**) (0.5)
The first rule has been multiplied with a rule coefficient 0.5 because this reflects the opinion of two experts out of four. Similarly, second rule is multiplied by 0.5.
If (*GoldPlating* is *Yes*) **then** (*Cost* is **M**) (0.75)
If (*GoldPlating* is *Yes*) **then** (*Cost* is **H**) (0.25)
The above rules have been multiplied with rule cofficients 0.75 and 0.25, respectively. Because in the opinion of three experts the effect of *GoldPlating* on *Cost* is Medium and one expert opine that the effect is High. Simple approach is applied to find out the weights of a particular input factor on the output factor if an adverse condition occurs.
Figure 5 shows the weight calculated by considering input value as 1 and resulting weight shows the dependency of *Adding Unnecessary Features* upon *Technical Failure* is 0.562. Similarly, 31 weights have been computed taking different input and output risk factors.

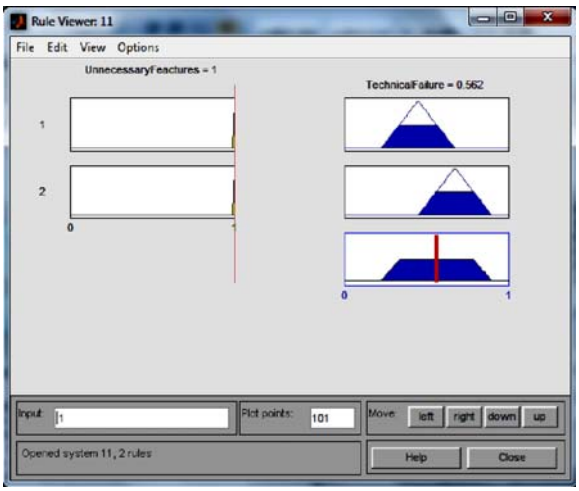

Figure 5. Weight of Dependency of Risk Factor.

5. EXPERIMENTAL RESULTS

We supposed that if during the development process some risk arise what would be the percentage of possibility of risk occurrence. In figure 6, we considered that IF poor management, shortfalls in externally supplied components DeadlinePressure, Wrong Documents, Straining ComputerScience Capabilities are on. The tool predicts the output based upon the weights assign to each factor.The following diagram shows the different ON factors and the output panels shows the chances of Personnel shortfalls will be 11.0218%, chances of technical failure would be 23.9378%, chances of Poor S/W quality would be 28.612% and finally the chances of project failure would be 28.6187%.

In Second case, *Enviornmental Failure ,Changes in customer requirements*, *Developning wrong software functions ,incorrect metrics and lack of training/experience* are considered to be present. Figure 7 shows present factors and the output panel shows that the chances of *Personnel shortfalls* will be 11.4282%, chances of *Technical Failure* would be 22.018%, chances of *Poor S/W quality* would be 30.3059% and finally the chances of *Project Failure* would be 35.3941%.

In another case, figure8 shows the different present factors and the output panel shows that the chances of *Personnel shortfalls* will be 11.4282%, chances of *Technical Failure* would be 27.3339%, chances of *Poor S/W quality* would be 35.7713% and finally, the chances of *Project Failure* would be 29.2052%.

DOI: 10.1145/2047414.2047422 http://doi.acm.org/10.1145/2047414.2047422

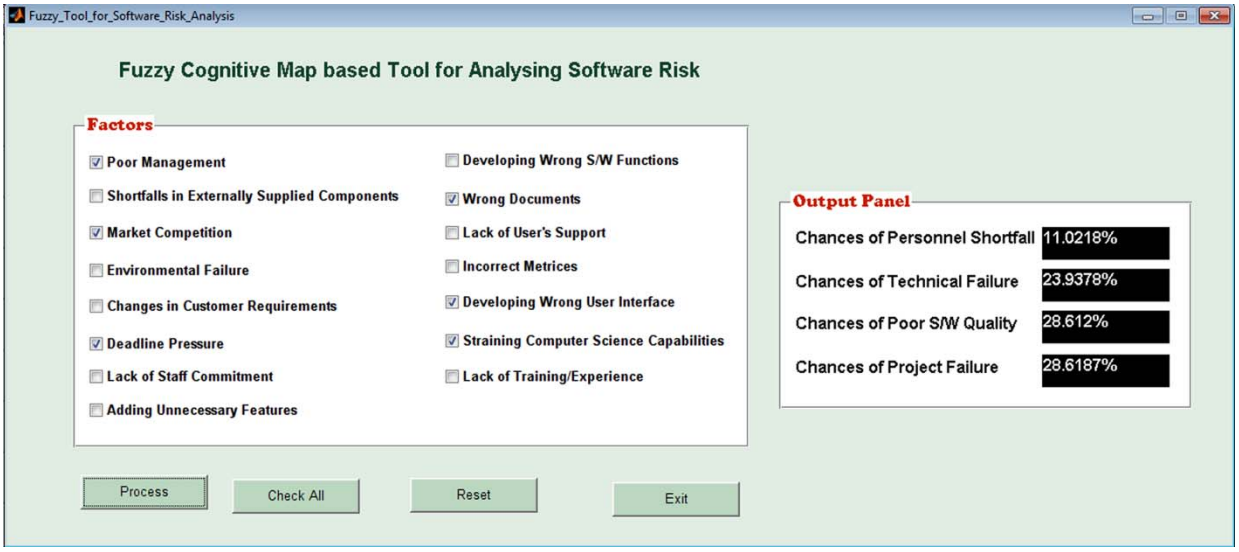

Figure 6. Software Risk Analysis in Case 1.

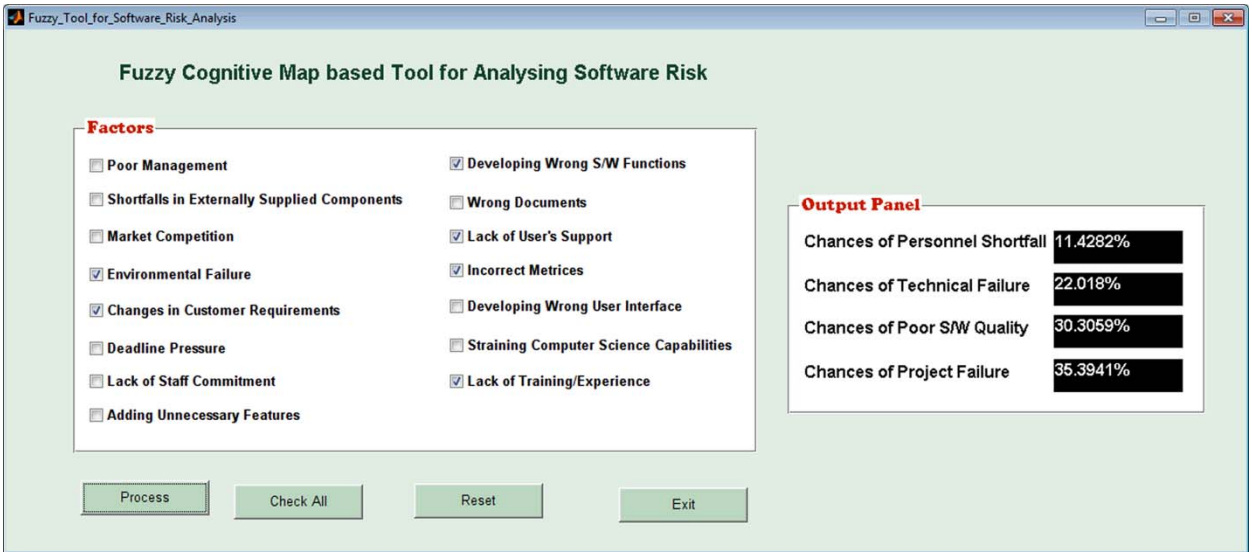

Figure 7. Software Risk Analysis in Case 2.

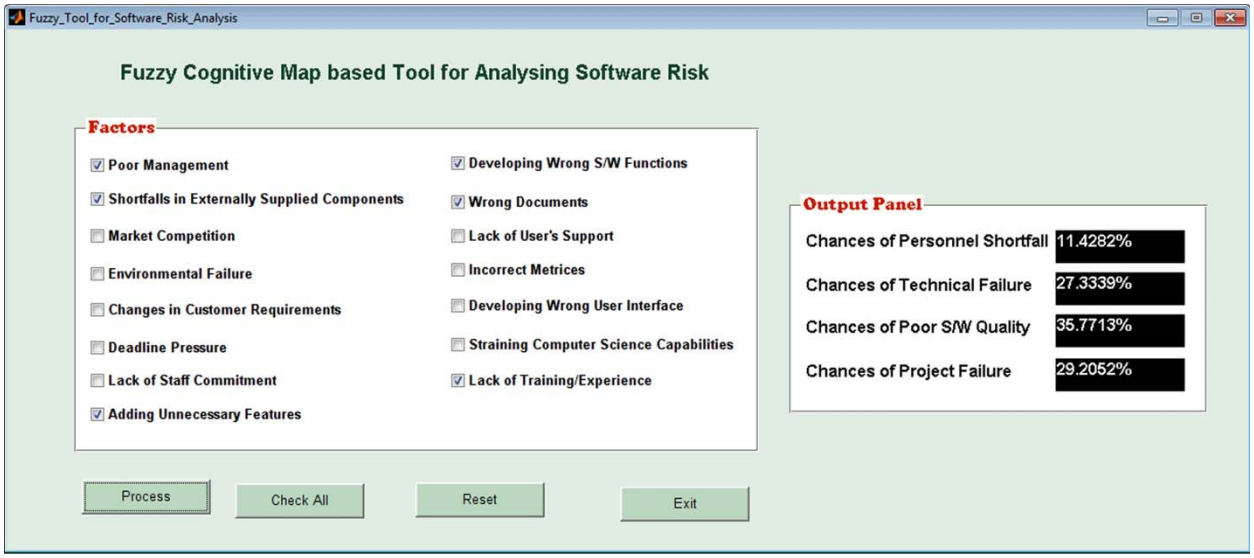

Figure 8. Software Risk Analysis in Case 3.

DOI: 10.1145/2047414.2047422 http://doi.acm.org/10.1145/2047414.2047422

6. CONCLUSION

Researchers are working to get the more and knowledge of how risk factors can be measured and integrated into the project management process. So that negative impacts can be avoided or we can plan out how to tackle such kind of risks during the management of the development process. Risk analysis is a structured mechanism to provide the visibility of threats to project success. Researchers are concerned by sharing which risk factors does directly and which risk factors does not directly affect among multiple projects will help upcoming software projects to avoid reiterating the issues of the past. As researchers are working in the area of risk management and as more and more data is collected, the refined the models and techniques will become in the future. In reality, this is a practically impossible task, both from the amount of information required and the difficulty of extracting/ estimating the required probability information of risk occurrence. Still, we have proposed software tool for risk analysis with limited parameters. This model can be extended to analyze different factors of large scale projects in the coming future.

APPENDIX A

The experts provided us the recommended decisions in terms of impact levels “Very Low”, “Low”, “Medium”, “High” and “Very High”. The data used to develop fuzzy rules is shown in table 4.The weights calculated between the various factors are also shown.

Table 4. Relationship between various factors, opinions of experts and computed edge weights.

S.No.	Input Factor	Output Factor	Expert 1	Expert 2	Expert 3	Expert 4	Weight
1.	Deadline Pressure	Personnel Shortfalls	L	L	M	M	0.338
2.	Lack of Training/ Experience	Personnel Shortfalls	H	M	H	H	0.385
3.	Lack of Staff Commitment	Personnel Shortfalls	L	M	L	L	0.29
4.	Lack of Staff Commitment	Time Overrun	H	VH	H	H	0.711
5.	Lack of User Support	Change in Customer Requirements	H	H	H	M	0.385
6.	Change in Customer Requirements	Time Overrun	H	H	H	M	0.61
7.	Change in Customer Requirements	Cost Overrun	H	M	H	H	0.61
8.	Time Overrun	Poor S/W Quality	H	VH	H	H	0.711
9.	Cost Overrun	Poor S/W Quality	H	H	VH	H	0.711
10.	Shortfalls in Externally Supplied Components	Poor S/W Quality	M	H	H	H	0.385
11.	Poor Management	Poor S/W Quality	H	H	H	VH	0.711
12.	Market Competition	Poor S/W Quality	M	M	H	H	0.562
13.	Adding Unnecessary Features	Poor S/W Quality	M	L	L	M	0.338
14.	Personnel Shortfalls	Poor S/W Quality	H	M	M	H	0.562
15.	Technical Failure	Poor S/W Quality	M	M	M	H	0.515
16.	Adding Unnecessary Features	Technical Failure	M	H	M	H	0.562
17.	Developing Wrong User Interface	Technical Failure	M	H	H	M	0.562
18.	Developing Wrong S/W Functions	Technical Failure	VH	VH	H	H	0.755
19.	Straining Computer Science Capabilities	Technical Failure	L	M	M	L	0.338
20.	Enviornmental Failure	Technical Failure	L	L	M	L	0.29
21.	Complexity	Technical Failure	M	H	H	M	0.562
22.	Realtime Performance Shortfalls	Technical Failure	L	M	L	M	0.338
23.	Wrong Documents	Technical Failure	H	H	M	H	0.61
24.	Wrong Documents	Realtime Performance Shortfalls	H	H	M	H	0.61
25.	Adding Unnecessary Features	Cost Overrun	H	M	M	M	0.515
26.	Incorrect Metrics	Complexity	M	H	M	H	0.562
27.	Environmental Failure	Project Failure	L	L	M	L	0.29
28.	Poor S/W Quality	Project Failure	H	H	VH	H	0.711
29.	Personnel Shortfalls	Project Failure	H	H	H	VH	0.711
30.	Change in Customer’s Requirements	Project Failure	M	M	H	H	0.562
31.	Technical Failure	Project Failure	H	VH	H	VH	0.755

DOI: 10.1145/2047414.2047422 http://doi.acm.org/10.1145/2047414.2047422

7. ACKNOWLEDGMENTS

The authors are highly indebted to the experts team comprising of Mr. Arun Arora, InMobi solutions pvt ltd, Bangalore, India, Mr. Karanpal Kalsi, Amazon Development center pvt. ltd., Bangalore, India, Mr. Mohit Saini, Verizon, Hyderabad, India and Mr. Sandeep Nayak, InMobi solutions pvt ltd, Bangalore, India, for their invaluable support in designing and experimenting with this system.

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