Risk Factors Assessment for Software Development Project Based on Fuzzy Decision Making

Shih-Tong Lu and Shih-Heng Yu

***Abstract*—This study investigates and identifies the assessment factors in software development project risk through literature reviews. Based on the identified assessment factors, a hierarchical structure of five dimensions and twenty-two factors is constructed, and two systematic approaches, fuzzy multiple criteria decision making (FMCDM) and consistent fuzzy preference relations (CFPR), were employed to assess the absolute and relative importance rates and then determine priorities of these factors. Among the identified dimensions, "Organization Function Risk" was considered as the most important dimension to influence the software development project performance.**

***Index Terms*—Fuzzy multiple criteria decision making, fuzzy preference relations, risk assessment, software development project.**

I. INTRODUCTION

With the rapid economic growth and innovation of information technology (IT), software developments and applications have been very important to enterprises' operations. Software development project is a highly professional work, with complicated, professional, technical and other features. However, software development projects have a dismal track-record of cost and schedule overruns and quality and usability problems [1]. Most software development projects often used more resources than planned, took more time to be completed, delivered in less functionality and less quality than expected was pointed out [2]. Those problems were caused because software development process faces tons of uncertainties or risk factors. Therefore, an effective risk assessment model not only can be used to facilitate identifying and measuring critical risk factors, but also can help to achieve a software development project's goals.

Risk-based project management has been a popular issue in many types of practical projects and associated academic studies. Because there are numerous software development risks, the proposed assessment procedure was designed using the multiple criteria decision making (MCDM) approach. Moreover, the risk associated evaluation is often determined by experts subjectively. Therefore, this study applies FMCDM, proposed by [3], and consistent fuzzy preference relations (CFPR) approach, proposed by [4], to dealing with the absolute and relative level of importance of software development risk factors. The results assessed based on FMCDM and CFPR were compared and risk management strategies were proposed in advance of implementing a software development project.

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II. RISK FACTORS IN SOFTWARE DEVELOPMENT

When software development projects were performed, many difficult problems will be encountered no matter executed by oneself or by outsourcing. To reduce project failure rate, various risk factors affecting project outcome should be identified by software engineering and information systems researchers. Risk assessment identifies sources of risk as they exist and emerge; that is, it identifies potential risk factors or risk items. Sources of risk in software development projects were investigated by several past attempts [5]–[9]. Frequently identified types of risk factors for software development projects, listed in Table I.

TABLE I: LIST OF RELATED REFERENCES REVIEWED FOR RISK FACTORS.

Author(s)	Risk factors
Boehm [5]	1.personnel shortfalls, 2.unrealistic schedules and budgets, 3.developing the wrong functions and properties, 4.developing the wrong user interface, 5.adding more functionality/features, 6.continuing stream of requirements changes, 7.shortfalls in externally furnished components, 8.shortfalls in externally performed tasks, 9.real-time performance shortfalls, 10.straining computer-science capabilities
Lee [6]	1.personnel shortfalls, key person(s) quit, 2.requirement ambiguity, 3.developing the wrong software function, 4.developing the wrong user interface, 5.continuing stream requirement changes, 6.schedule not accurate, 7.budget not sufficient, 8.gold plating, 9.skill levels inadequate, 10.straining hardware, 11.straining software, 12.shortfalls in externally furnished components, 13.shortfalls in externally performed tasks, 14.real-time performance shortfalls
Buyukozkan and Ruan [7]	1.Product engineering risks: requirements, design, code and unit test, integration and testing, engineering specialist. 2.Development environment risks: include development process, development system, management process, management methods, work environment. 3.Program constraints related risks: resources, contract, program interfaces.

TABLE I: LIST OF RELATED REFERENCES REVIEWED FOR RISK FACTORS (CONTINUE).

Author(s)	Risk factors
Jiang and Klein [8]	1.technological acquisition, 2.project size, 3.lack of team's general expertise, 4.lack of team's expertise with the task, 5.lack of team's development expertise, 6.lack of user support, 7.intensity of conflicts, 8.extent of changes brought, 9.resources insufficient, 10.lack of clarity of role definitions, 11.application complexity, 12.lack of user experience
Houston, Mackulak, and Collofello [9]	1.creeping user requirements, 2.lack of staff commitment, 3.low morale, 4.instability 5.lack of continuity in project staffing, 6.inaccurate cost estimation, 7.excessive schedule pressure, 8.lack of senior management commitment

From these reviews of past literatures, the software development risk factors were further screened and synthesized for this study. Twenty two risk assessment factors divided into five dimensions were finalized. Five risk dimensions include organization function, developing technology, personnel system, resources integration, and system requirement. The hierarchical structure of risk factors is shown as Fig. 1.

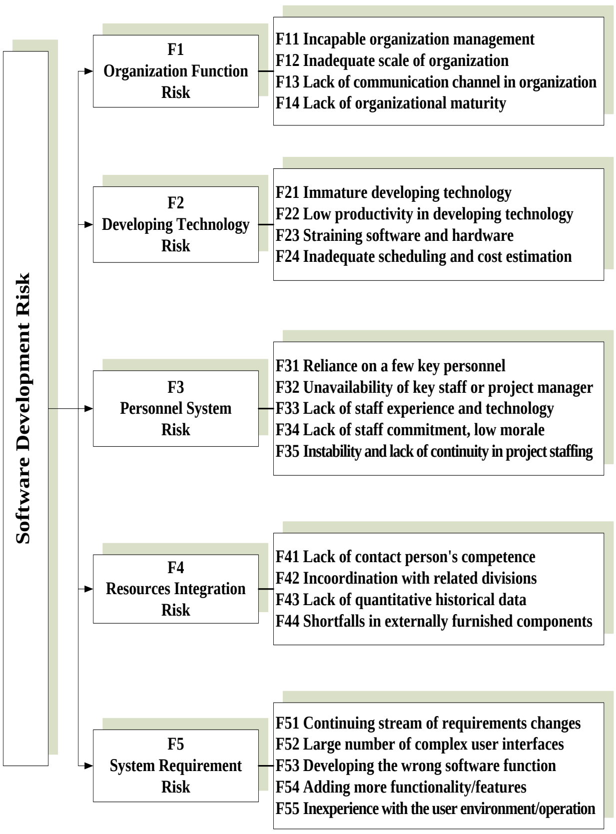

Fig. 1. Hierarchical structure of software development project risks.

III. RESEARCH METHOD

This study measures level of importance of risk factors using an integrated measure of magnitude of unintentional events on project success. Assuming the different project risk factors equally affect project success is impractical. To better manage project risks and increase chances of project success, level of importance of risk factors on project success should be carefully evaluated and further used as the fundamental information for the control, response and management of project risks. That is, the varying effects of project risk factors on project success provide valuable information needed to allocate software development project resources.

Multiple criteria decision making (MCDM) was used to deal with the complexity and diversity of the analyses of multiple risk factors. When level of importance of risk factors was evaluated, most decision-makers or project managers were accustomed to measure those factors as linguistic values, e.g., very high, high, fair, low, very low for a subjective judgment. Therefore, FMCDM was applied to the analysis of this study [3]. FMCDM approach in this study was used to determine the absolute level of importance of risk factors by concept of simple additive weight (SAW). This study adopted CFPR [4] to determine the relative grade of importance of risk factors by concept of preference relations. Some concepts and operations of FMCDM and CFPR used in this study are briefly described as the followings.

A. FMCDM

1) Linguistic Variables:

Zadeh [10] mentioned that as it is difficult to have a logic expression in a fuzzy or vagueness environment by using a conventional quantifying approach. A linguistic variable essentially represents the variable using a word or a sentence in human languages. This study employed the seven semantic scales, revised from [3], to assess level of importance for software development project and their corresponding triangular fuzzy numbers (TFN) are listed in Table II.

TABLE II: FUZZY LINGUISTIC ASSESSMENT VARIABLES.

Semantic Scale	Corresponding TFN
Absolutely high (AH)	(0.9, 1.0, 1.0)
Very high (VH)	(0.7, 0.9, 1.0)
High (H)	(0.5, 0.7, 0.9)
Fair (F)	(0.3, 0.5, 0.7)
Low (L)	(0.1, 0.3, 0.5)
Very low (VL)	(0.0, 0.1, 0.3)
Absolutely low (AL)	(0.0, 0.0, 0.1)

2) The Matrix of Level of Importance:

The matrix $\tilde{X}$ for the level of importance of each of the risk factors $(F_j, j=1, 2, ..., n)$ was displayed as (1). The evaluators $(E^i, i=1, 2, ..., m)$ input their subjective judgments of the level of importance for each risk factor by using the semantic variable listed in Table II.

$$\tilde{X} = \begin{array}{c} \\ F_1 \\ F_2 \\ F_3 \\ \vdots \\ F_n \end{array} \begin{array}{c} \begin{array}{ccccc} E^1 & E^2 & E^3 & \cdots & E^m \end{array} \\ \begin{bmatrix} \tilde{x}_1^1 & \tilde{x}_1^2 & \tilde{x}_1^3 & \cdots & \tilde{x}_1^m \\ \tilde{x}_2^1 & \tilde{x}_2^2 & \tilde{x}_2^3 & \cdots & \tilde{x}_2^m \\ \tilde{x}_3^1 & \tilde{x}_3^2 & \tilde{x}_3^3 & \cdots & \tilde{x}_3^m \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_n^1 & \tilde{x}_n^2 & \tilde{x}_n^3 & \cdots & \tilde{x}_n^m \end{bmatrix} \end{array}, \quad \begin{array}{l} i=1,2,3,\cdots,m \\ j=1,2,3,\cdots,n \end{array} \tag{1}$$

where m denotes the number of evaluators, and n is the number of risk factors, and $\tilde{x}_j^i = (Lx_j^i, Mx_j^i, Ux_j^i)$ indicates the fuzzy level of importance assessed by the i^{th} evaluator for the j^{th} risk factor.

3) The Synthesized Level of Importance of Factors:

Each of the evaluators independently performed his/her assessments based on his/her experience, intuition and knowledge. An average score computation, displayed as (2). , is then employed to synthesize the TFNs of m evaluators, which explored a synthesized fuzzy level of importance value for each of the risk factors.

$$\tilde{w}_j = \frac{1}{m}\left[\sum_{i=1}^{m} \tilde{x}_j^i\right] \tag{2}$$

where $\tilde{w}_j = (Lw_j, Mw_j, Uw_j)$ represents the synthesized fuzzy level of importance of the j^{th} risk factor.

4) The Defuzzification:

The synthesized results of the fuzzy risk assessment are still in fuzzy numbers format. Therefore, it is necessary to further conduct defuzzification approach to transfer fuzzy numbers to crisp numbers. The aggregated triangular fuzzy numbers ($\tilde{w}_j$) was then defuzzified to best non-fuzzy performance (BNP) values (W_j), which is displayed as (3).

$$W_j = \frac{[(Uw_j - Lw_j) + (Mw_j - Lw_j)]}{3} + Lw_j \tag{3}$$

where W_j is the grade of importance of the jth risk factor in crisp numbers format. Finally, the normalized grade of importance of the jth risk factor was computed according to (4).

$$R_j = W_j \Big/ \textstyle\sum_{j=1}^{n} W_j, \quad \sum_{j=1}^{n} R_j = 1 \tag{4}$$

B. CFPR

Another approach used in this study would like to assess the relative importance of risk factors of software development project for enterprises. Thus, this study further applies the consistent fuzzy preference relations (CFPR) approach, proposed by Herrera-Viedma et al.[4], for constructing the decision matrices of pairwise comparisons based on additive transitivity property. The CFPR not only enables a decision-maker to give values for a set of factors with the least judgments, but also avoids checking the consistency in decision-making process. The following provides a brief introduction on the definitions and steps of the proposed method.

1) Multiplicative Preference Relations:

Matrix $\boldsymbol{A} \subset \boldsymbol{X} \times \boldsymbol{X}$ shows the multiplicative preference relations of $\boldsymbol{X}$ factor centers on $\boldsymbol{A}$, where $\boldsymbol{A} = [a_{ij}]$, a_{ij} is the preference intensity ratio of factor x_i to factor x_j. Saaty [11] suggested a_{ij} to be scaled from 1 to 9. Herein, $a_{ij} = 1$ represents the existence of indifference between criterion x_i and x_j, $a_{ij} = 9$ manifests that x_i is absolutely important than x_j. In this case, the preference relation is typically assumed to be a multiplicative reciprocal:

$$a_{ij} \cdot a_{ji} = 1 \quad \forall i, j \in \{1, \cdots, n\} \tag{5}$$

2) Fuzzy Preference Relations:

The fuzzy preference relation $\boldsymbol{P}$ on a set of factors $\boldsymbol{X}$ is a fuzzy set of the product $X \times X$ with membership function $\mu_p : X \times X \to [0,1]$. The preference relation is represented by the matrix $\boldsymbol{P} = [p_{ij}]$, where $p_{ij} = \mu_p(x_i, x_j)$. Herein, p_{ij} is interpreted as the grade of importance ratio of criterion x_i over x_j. If $p_{ij} = 1/2$, it means that x_i and x_j are equally important (i.e. $x_i \sim x_j$); $p_{ij} = 1$ indicates that x_i is absolutely important to x_j; $p_{ij} > 1/2$ shows that x_i is more important to x_j, i.e. $x_i \succ x_j$. In this case, the preference matrix, $\boldsymbol{P}$, is usually assumed additive reciprocal, i.e.

$$p_{ij} + p_{ji} = 1, \forall i, j \in \{1, \cdots, n\} \tag{6}$$

3) Consistent Fuzzy Preference Relations:

A set of factors $\boldsymbol{x} = \{x_1, \cdots, x_n\}$ and $\boldsymbol{x} \in X$ is associated with a reciprocal multiplicative preference relations $\boldsymbol{A} = [a_{ij}]$ for $a_{ij} \in [1/9, 9]$. Then a_{ij} can use (7) to obtain the corresponding reciprocal fuzzy preference relation $\boldsymbol{P} = [p_{ij}]$ for $p_{ij} \in [0,1]$ associated with $\boldsymbol{A}$:

$$p_{ij} = g(a_{ij}) = \frac{1}{2}(1 + \log_9 a_{ij}) \tag{7}$$

Herein, $\log_9 a_{ij}$ is considered because a_{ij} is between $1/9$ and 9. When the reciprocal fuzzy preference relation $\boldsymbol{P} = [p_{ij}]$ is additive consistency, there exist the relationships as (8) and (9):

$$p_{ij} + p_{jk} + p_{ki} = \frac{3}{2} \quad \forall i < j < k \tag{8}$$

$$p_{i(i+1)} + p_{(i+1)(i+2)} + \cdots + p_{(j-1)j} + p_{ji} = (j - i + 1)/2, \forall i < j \tag{9}$$

4) The Relative Level of Importance of Factors:

When we obtain the $n-1$ preference intensity ratio $\{a_{12}, a_{23}, \cdots, a_{n-1,n}\}$ of factors $\boldsymbol{x} = \{x_1, \cdots, x_n \mid n \geq 2\}$ from experts' judgments, (7) can be used to construct a fuzzy preference relation for the set of n–1 values $\{p_{12}, p_{23}, \cdots, p_{n-1,n}\}$. Then the other preference relations values of the decision matrix $\boldsymbol{P}$, $\boldsymbol{B} = \{p_{ij} \mid \wedge_{i<j} p_{ij} \notin \{p_{12}, p_{23}, \cdots, p_{n-1,n}\}\}$, will be obtained by the (6), (8) and (9). However, after this calculation, all the necessary elements in the decision matrix $\boldsymbol{P}$ may really not all lie within [0, 1] but will lie within $[-a, 1+a]$, where

$a = \left|\min\{\boldsymbol{B} \cup \{p_{12}, p_{23}, \cdots, p_{n-1n}\}\}\right|$. Therefore, it can be obtained the consistent reciprocal fuzzy preference relation matrix $\boldsymbol{P}'$ by the transformation function $\boldsymbol{P}' = f(p)$. This process can make the decision matrix maintaining reciprocity and additive consistency. The transformation function is as following:

$$f : [-a, 1+a] \to [0,1],\ f(x) = (x+a)/(1+2a) \qquad (10)$$

The obtained assessment decision matrix, $\boldsymbol{P}' = (p'_{ij})$, shows the consistent reciprocal relation. It can apply the equation (11) to determine the corresponding relative grade of importance for each factor:

$$A_i = \sqrt[n]{\prod_{i=1}^{n} p'_{ij}}, \quad w_i = A_i \big/ \sum_{i=1}^{n} A_i \qquad (11)$$

Finally, this assessment results can be used to determine the priority of risk factors for software development projects. In addition, decision makers can use the results to draw up appropriate risk management strategies to treat to the significant risk factors which were ranked top priority.

IV. Case Results

Five experts with many years' experience on information management division of medium scale technology enterprise were invited to provide response to the questionnaire survey. They were asked to provide the inputs of absolute importance of each risk factor and relative importance of pair risk factors which identified in this study on software development projects. Table III shows the grade of importance and ranking of risk dimensions and factors by FMCDM approach. Then, Table IV shows the same contents, but the results were computed by CFPR approach.

Among the identified five dimensions, "Organization Function Risk" was found as the most important risk dimension to influence the software development performance and success no matter evaluated by CFPR or FMCDM. "Developing Technology Risk" and "Resources Integration Risk" are respectively the second and third important dimensions to affect software development project performance when evaluated by CFPR, but the third and second when evaluated by FMCDM. "Personnel System Risk" and "System Requirement Risk" are the last two dimensions in sequence on absolute and relative importance affecting performance and success of development project.

TABLE III: Important and Ranking of Risk Factors by FMCDM.

Dimensions /factors	Local weights	Ranks	Global weights	Ranks
F1	**0.223**	**1**		
F11	0.3028	1	0.0677	1
F12	0.2068	4	0.0462	12
F13	0.2580	2	0.0577	4
F14	0.2324	3	0.0519	8
F2	**0.207**	**3**		
F21	0.2793	1	0.0579	2
F22	0.2196	4	0.0455	13
F23	0.2345	3	0.0486	10
F24	0.2665	2	0.0553	5
F3	**0.166**	**5**		
F31	0.1669	5	0.0276	22
F32	0.2298	1	0.0380	15
F33	0.1785	4	0.0296	21
F34	0.2264	2	0.0375	16
F35	0.1983	3	0.0328	18
F4	**0.214**	**2**		
F41	0.2525	2	0.0540	6
F42	0.2707	1	0.0579	3
F43	0.2465	3	0.0527	7
F44	0.2303	4	0.0492	9
F5	**0.190**	**4**		
F51	0.2514	1	0.0477	11
F52	0.1839	3	0.0349	17
F53	0.2214	2	0.0420	14
F54	0.1726	4	0.0327	19
F55	0.1707	5	0.0324	20

TABLE IV: Important and Ranking of Risk Factors by CFPR.

Dimensions /factors	Local weights	Ranks	Global weights	Ranks
F1	**0.255**	**1**		
F11	0.3562	1	0.0907	2
F12	0.1730	3	0.0440	10
F13	0.3024	2	0.0770	3
F14	0.1684	4	0.0429	12
F2	**0.244**	**2**		
F21	0.3782	1	0.0924	1
F22	0.1843	3	0.0450	9
F23	0.1343	4	0.0328	17
F24	0.3032	2	0.0741	4
F3	**0.169**	**4**		
F31	0.1051	5	0.0177	21
F32	0.2482	2	0.0419	13
F33	0.1499	4	0.0253	19
F34	0.2684	1	0.0453	8
F35	0.2284	3	0.0385	14
F4	**0.181**	**3**		
F41	0.2406	3	0.0436	11
F42	0.3022	1	0.0548	6
F43	0.2691	2	0.0488	7
F44	0.1882	4	0.0341	16
F5	**0.151**	**5**		
F51	0.3743	1	0.0566	5
F52	0.1991	3	0.0301	18
F53	0.2410	2	0.0364	15
F54	0.1205	4	0.0182	20
F55	0.0651	5	0.0098	22

For each dimension, among the first dimension (F1), incapable organization management (F11) was both considered as the most important risk factor by using the proposed two approaches, and it is also the most important factor for global aspect by FMCDM. Among the second, fourth and fifth dimension (i.e. F2, F4 and F5), immature developing technology (F21), in-coordination with related divisions (F42) and continuing stream of requirements changes (F51) were all found as the most important risk factors to influence the software development project success when evaluated by the two approaches. Unavailability of key staff or project manager (F32) and lack of staff commitment, low morale (F34) respectively is the most important risk factor to harm software development project success when evaluated by the proposed two approaches.

For global aspect, the ranking of lack of communication channel in organization (F13) and inadequate scheduling and cost estimation (F24) are very close and more important among other factors when evaluated by the two approaches. Furthermore, reliance on a few key personnel (F31), lack of staff experience and technology (F33), adding more functionality/features (F54) and inexperience with the user environment/operation (F55) are more and less important factors among other factors when evaluated by the two approaches.

V. Conclusion

Risk is an inherent component of software development projects. However, more preparation in advance will be less loss on operation. Thus, in this study, five risk dimensions and associated twenty-two risk factors were investigated. It can help the project managers to overview the global picture of risk. Then, we adopt two simple and systemic models to assess project risks for a software development. The questionnaires making and computation processes are easy to conduct whatever approach was used. The case results by FMCDM and by CFPR are similar in more important factors. It implied that the grade of importance of risk dimensions or factors are close whatever intuitional judgments by FMCDM and comparative judgments by CFPR.

Based on the results investigated following the built models to perform the risk management or plan response strategies for software development projects. These models can benefit the stakeholders of software development project to recognize what risk factors they face and to facilitate risk assessment and furthermore complete project risk management plan to allocate resources adequately.

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