International Journal of Security and Its Applications
Vol.9, No.11 (2015), pp.145-154
http://dx.doi.org/10.14257/ijsia.2015.9.11.15

Identification of Software NFR based on the Fuzzy-QFD Model

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Abstract

NFR determination of the software products is an important link in the requirement development. Considering the correlation and inter-dependence between FR and NFR of software, this paper puts forward a NFR system identification method of the software products based on the fuzzy-QFD model through constructing the FR-NFR correlation matrix of software. The model express correlation evaluation with the 7-level natural language, build the software FR-NFR correlation matrix, fuzzy the matrix vector by the trapezoidal fuzzy number, then calculate the relative importance and absolute importance of NFR, at last get the importance NFR by the NFR screening algorithm.

***Keywords**: software requirement；NFR；QFD; trapezoidal fuzzy number*

1. Introduction

Functional requirement (FR) and non-functional requirement (NFR) are two core parts of software requirement. FR defines the functions that the software product must implement. Users use those functions to accomplish the specific tasks and business requirements. NFR is the quality description of the software product, including the constraints of software quality in different aspects, so as to ensure reliable operation of the software product as expected. In fact, software NFR decides the architecture design of development [1] which FR should also abide. Thus, clarifying the NFR of a software product is the problem of primary importance in the software requirement development as well as the basis for ensuring its reliability in the later stage.

The existing studies on software requirement mostly focus on FR acquisition and recognition, such as domain-based model [2], ontology description [3], manual [4], opinion [5], scene [6-7], requirement identification [8-11], ethnography-based cognition engineering and other methods [12-13], but little has been carried out on NFR. In addition, the existing studies are mainly based on the influence of NFR on software architecture design [14], definition of NFR classification [15-20] and evaluation of NFR importance [21-25]. Identifying NFR of the software product accurately is an important link in the requirement development [26]. QFD can overcome some problems appearing in the requirement analysis [27], effectively recognize users' requirements, convert them into a series of detailed design specifications, and identify the relative importance of different NFR attributes of the software product [28-29]. Moreover, the effectiveness of QFD in the software requirement development has been recognized [30-33], so the research is also based on QFD model.

Considering the correlation and interdependence between FR and NFR, this paper puts forwards a NFR determination method containing six steps through constructing the fuzzy-QFD model based on the FR-NFR correlation matrix of the software product. Chapter 1 summarizes the possible software NFRs according to the existing literature. Chapter 2 introduces the software NFR determination process based on the fuzzy QFD in details.[1]

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2. Software NFR Determination Process Based on the Fuzzy-QFD Model

The NFR determination method based on the fuzzy-QFD model proposed in the paper is shown in Figure 1.

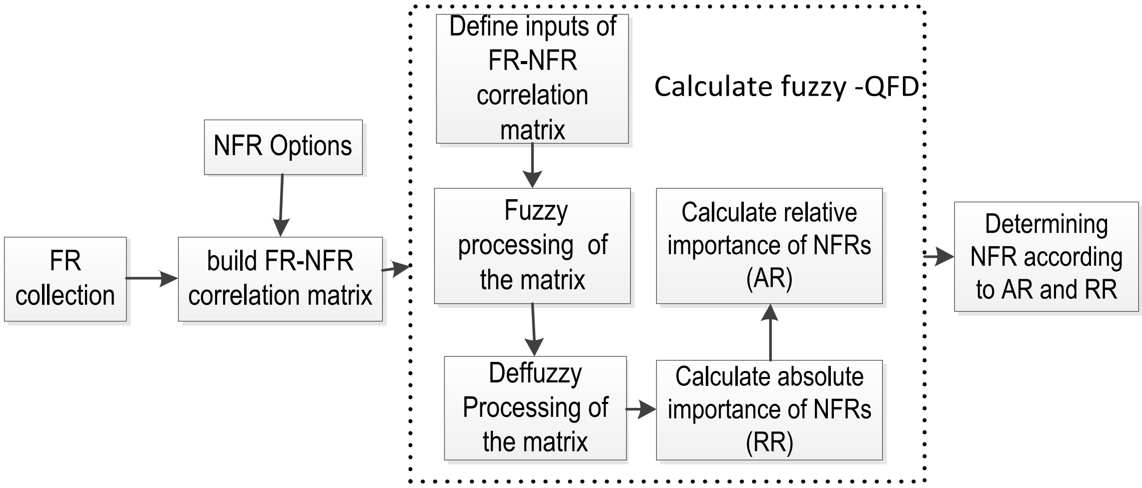

Figure 1. NFR Determination Method based on the Fuzzy-QFD Model

2.1 FR Collection

FR is the definition and specification of what the software system needs to do. It is the carrier of NFR. Thus, FR collection of the software product is the first step. At present, software FRs can be collected by the BPR process, GORA method, in-depth interview and requirement analysis of the original system. They are reflected by some basic user requirements and standards and functions, scenes or cases related to the business process and expressed in the set form after screening, decomposition, weighing and confirmation {FR1, FR2,…,FRn}.

2.2 Optional NFR

ISO/IEC 25010, which supersedes ISO/IEC 9126-1, was issued in March 2011. It has eight product quality characteristics (NFRs) and 31 sub-characteristics, but above NFRs focus only on the quality characteristics of software. For the information system development of an enterprise, however, many technical factors like architecture type, interface standard and version assessment and social and economic factors like legal permission, organization strategy, market orientation, technical training and support, reputation and ability of the developer should also be taken into account. Therefore, the domestic and foreign scholars [14-20] have added some other NFRs later.

This paper generalizes NFRs mentioned in above literature and proposes the NFR layered model as shown in Figure.2. NFRs in the model are reflected in three aspects: quality property, technical factor and socio-economic factor. Those three aspects are further subdivided into different primary and secondary sub-attributes. According to the definition of IEEE software engineering ISO/IEC 25010-2011, NFR is used to describe how a software system is designed to meet users' requirements. 43 sub-attributes in the

NFR layered model can reflect the implementation of a software system from different perspectives. Thus, this paper regards those 43 candidate NFRs of the software system as the column of the FR-NFR correlation matrix.

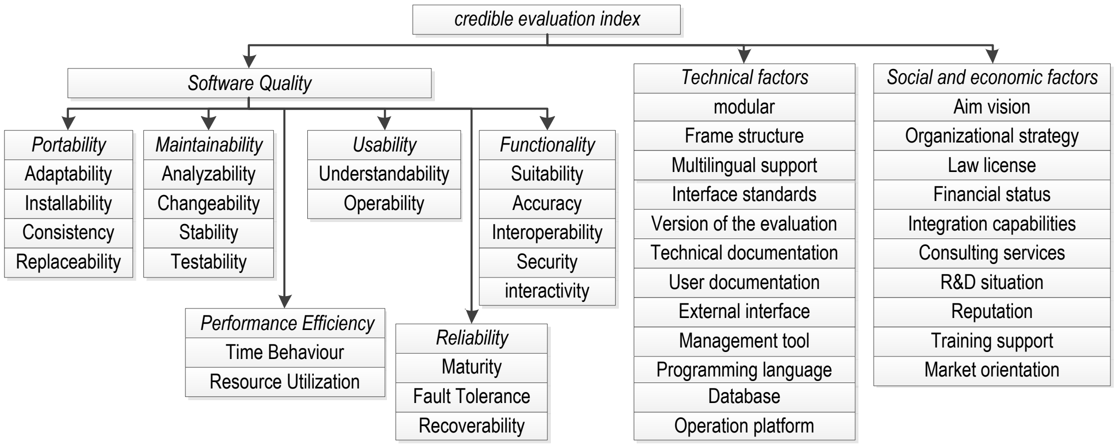

Figure 2. Credible Evaluation Index

2.3 FR-NFR Correlation Matrix

It is assumed that FR_n is FR of No. *n* and $\{FR_1, FR_2, ..., FR_n\}$ is the FR set of the software. For each FR_i, relevant participants need to give the correlation evaluation between FR_i and 44 NFRs $\{NFR_1, NFR_2, ..., NFR_{44}\}$ above which is described by the 7-level natural language variable (very strong, strong, a little strong, ordinary, a little weak, weak and very weak). The results constitute the FR-NFR correlation matrix, as shown in Table 1.

Table 1. The FR-NFR Correlation Matrix

	NFR_1	NFR_2	$\cdots$	NFR_{44}
FR_1	R_{11}	R_{12}	$\cdots$	R_{144}
FR_2	R_{21}	R_{22}	$\cdots$	R_{244}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
FR_n	R_{n1}	R_{n2}	$\cdots$	R_{n44}

Software FRs whose behaviors have been confirmed in the matrix are listed in 44 possible NFRs. R_{ij} in the matrix is the evaluator's natural language evaluation on the correlation between the *i*th FR and the *j*th NFR.

2.4 Calculation Process of the Fuzzy QFD

1. Expression of Natural Language Evaluation in Fuzzy Number

Due to the complexity and uncertainty of software system development and the fuzziness of human thinking, FR-NFRS correlation can only be described with the fuzzy number rather than the specified one. Triangular fuzzy number and trapezoidal fuzzy number are widely used at present [37]. However, the shape of the membership function of triangular fuzzy number is so simple that it cannot reflect the decision information of the decision-makers well in many cases. In particular, when the decision is made based on certain factors, the evaluation result is often greatly different from the actual situation. The shape of the membership function of trapezoidal fuzzy number is more complicated, so it's able to deal with the actual decision-making information and reflect the uncertainty of factors.

Definition 1 If the trapezoidal membership function $\mu_{\tilde{q}}(X): R \to [0,1]$ meets:

$$\mu_{\tilde{q}}(X)=\begin{cases} \dfrac{x-a}{b-a}, X \in [a,b); \\ 1 \quad , X \in [b,c); \\ \dfrac{d-X}{d-c}, X \in [c,d]; \\ 0 \quad , other \end{cases}$$

where $a, b, c, d \in R$, $a \le b \le c \le d$, and $\tilde{q} = (a, b, c, d)$ is the standard trapezoidal fuzzy number.

In this paper, the FR-NFRS correlation evaluation is made with the 7-level natural language {C1, C2, C3, C4, C5, C6, C7}, and fuzzily processed with the standard trapezoidal fuzzy number. The trapezoidal fuzzy membership function under 7-level language evaluation is shown in Figure 3. The interval [0, 1] is divided into 13 pieces, (0.077, 0.154, 0.231,...., 0.846, 0.923, 1).

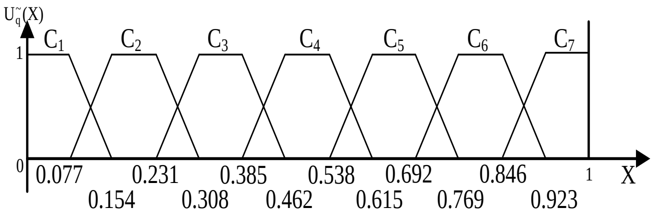

Figure 3. Trapezoidal Fuzzy Membership Function of Level 7 Language Variable Set

2. Defuzzification of the Trapezoidal Fuzzy Number

Since the direct calculation of the FR-NFR correlation matrix which is identified by the trapezoidal fuzzy number will cause the rapid expansion of the computing size and obstruct the practical application of this method (for example, for a 50 x 44 matrix, only three evaluators can produce 6600 evaluation data. If it's calculated with the trapezoidal fuzzy number directly, a most basic computation will have 26400 steps). Thus, the FR-NFR matrix expressed by the trapezoidal fuzzy number is deffuzzified in the paper.

In the defuzzifying method, the gravity of the trapezoid can mostly represent the essential characteristics of the trapezoidal fuzzy number. It expresses the concentration place of the membership degree of the fuzzy numbers in the field. Therefore, the gravity of the fuzzy set can be used to describe the distribution of the membership functions. In other words, the gravity of the fuzzy set can represent the evaluation of experts.

Definition 2 If universe σ is the bounded measurable value in the real number field, the gravity $G(A)$ of the trapezoidal fuzzy number A in σ is:

$$G(A) = \frac{\int_w \mu(x) \cdot xdx}{\int_w \mu(x)dx}$$

The gravity of a trapezoidal fuzzy number A(a, b, c, d) can be expressed as follows through the gravity calculation formula of trapezoid:

$$G(A) = \frac{(d^2 + cd + c^2) - (b^2 + ab + a^2)}{3(d + c - b - a)}$$

The defuzzified values of different levels of trapezoidal fuzzy numbers can be calculated by the above formula, as shown in Table 2.

Table 2 The Defuzzified Values of Different Levels of Trapezoidal Fuzzy Numbers

Level	Trapezoidal Fuzzy Numbers	Defuzzified Values
C1	（0，0，0.077，0.154）	0.060
C2	（0.077，0.154，0.231，0.308）	0.193
C3	（0.231，0.308，0.385，0.462）	0.347
C4	（0.385，0.462，0.538，0.615）	0.500
C5	（0.538，0.615，0.692，0.769）	0.654
C6	（0.692，0.769，0.846，0.923）	0.808
C7	（0.846，0.923，1，1）	0.940

3. Calculation of Relative Importance and Absolute Importance

Assuming there are m relevant personnel evaluating the FRs of n systems, the importance evaluation given by the *k*th evaluator is W_1^k, W_2^k … W_n^k and the FR-NFR correlation matrix is $D^k = \left(R_{ij}^k\right)_{n\times 44}$, Then, the following can be obtained:

$$(D^k, W) = \begin{vmatrix} R_{11}^k & \cdots & R_{1j}^k & \cdots & R_{144}^k & w_1^k \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{i1}^k & \cdots & R_{ij}^k & \cdots & R_{i44}^k & w_i^k \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{n1}^k & \cdots & R_{nj}^k & \cdots & R_{n44}^k & w_n^k \end{vmatrix}$$

where R_{ij}^k is the FR_i - NFR_j correlation evaluation given by the *k*th evaluator by the natural language; w_i is the importance of FR1, FR2, … , FRn, expressed by the natural language. If $\overline{w}_i$ is set to be the average importance of FR_i and $\overline{R}_{ij}$ is the average correlation between FR_i and NFR_j, the following can be obtained:

$$\overline{w}_i = \frac{1}{m}\sum_{k=1}^{m} G\left(fuzz\left(w_i^k\right)\right), \quad \overline{R}_{ij} = \frac{1}{m}\sum_{k=1}^{m} G\left(fuzz\left(R_{ij}^k\right)\right)$$

Note: *fuzzy* in the formula is the trapezoidal fuzzy function of the natural language variable and *G* is the gravity defuzzifying function.

Relative importance AR_j and average relative importance *AAR* of NFRs can be calculated through $\overline{w}_i$ and $\overline{R}_{ij}$.

$$AR_j = \sum_{i=1}^{n} \overline{w}_i \cdot \overline{R}_{ij} \qquad (1)$$

$$AAR = \frac{1}{n}\sum_{j=1}^{n} AR_j \qquad (2)$$

Absolute importance *RR* of NFR can be got through the standardized treatment of *AR*. For example, the absolute importance RR_j of the *j*th NFRj is

$$RR_j = \frac{AR_j}{\sum_{j=1}^{n} AR_j} \qquad (3)$$

4. NFR Screening Algorithm

If RR_j of NFR_j is equal to or greater than *AAR*, it means NFR_j is necessary; in contrary, if RR_j of NFR_j is less than *AAR*, it means that the software system does not need this NFR. The screening algorithm is shown in Figure .4.

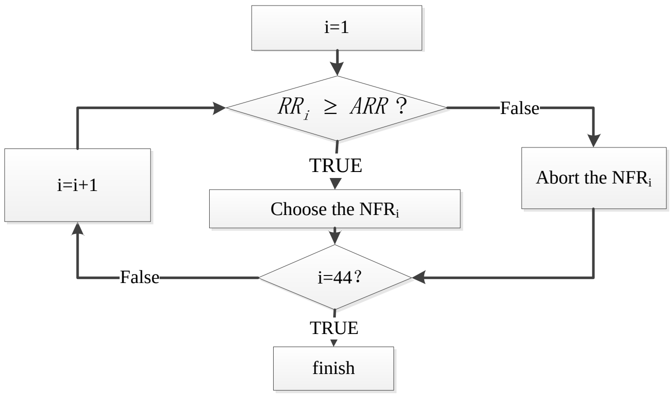

Figure 4. The Screening Algorithm

2.5 Example Calculation

Due to the limitation of space, this paper makes calculation with the correlation evaluation matrix which is composed of 20 NFRs in quality property and 10 FRs as examples, as shown in Table 3. *AR*s, *RR*s and *ARR*s of NFRs and the final screening results are shown in Table 4.

Due to the limitation of space, this paper makes calculation with the defuzzified correlation evaluation matrix which is composed of 20 NFRs in quality property and 10 FRs, as examples as shown in Table 3.

Table 3. Correlation Evaluation Matrix

	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR10
Replaceability	0.295	0.749	0.398	0.251	0.449	0.354	0.354	0.398	0.501	0.603
Installability	0.896	0.647	0.302	0.749	0.295	0.347	0.456	0.456	0.200	0.544
Consistency	0.500	0.705	0.896	0.551	0.596	0.647	0.398	0.845	0.500	0.705
Adaptability	0.449	0.603	0.845	0.647	0.456	0.156	0.405	0.501	0.456	0.698
Testability	0.251	0.302	0.244	0.398	0.500	0.500	0.302	0.507	0.603	0.347
Stability	0.456	0.354	0.405	0.500	0.552	0.647	0.456	0.705	0.347	0.596

Changeability	0.302	0.742	0.353	0.603	0.705	0.302	0.200	0.449	0.654	0.347
Analyzability	0.200	0.200	0.302	0.603	0.654	0.398	0.354	0.405	0.251	0.793
Time Behaviour	0.500	0.552	0.493	0.200	0.507	0.347	0.647	0.647	0.705	0.500
Resource Utilization	0.698	0.501	0.200	0.500	0.552	0.501	0.603	0.156	0.354	0.295
Understandability	0.449	0.757	0.845	0.456	0.295	0.398	0.603	0.654	0.104	0.507
Operability	0.507	0.353	0.449	0.347	0.405	0.501	0.742	0.544	0.749	0.647
Recoverability	0.449	0.603	0.251	0.647	0.647	0.808	0.500	0.296	0.552	0.398
Maturity	0.698	0.354	0.647	0.852	0.347	0.302	0.493	0.500	0.309	0.449
Fault Tolerance	0.258	0.500	0.449	0.449	0.296	0.698	0.251	0.654	0.551	0.354
Suitability	0.442	0.552	0.603	0.302	0.500	0.501	0.654	0.603	0.302	0.545
Security	0.200	0.302	0.596	0.449	0.193	0.405	0.501	0.354	0.493	0.801
interactivity	0.354	0.691	0.852	0.551	0.449	0.449	0.347	0.251	0.500	0.940
Interoperability	0.405	0.501	0.603	0.500	0.449	0.200	0.493	0.493	0.552	0.559
Accuracy	0.603	0.742	0.353	0.200	0.442	0.251	0.493	0.405	0.696	0.493

In addition , there are three part experts evaluating 10 FRs , the importance evaluation given by the *k*th evaluator is W_1^k, W_2^k W_3^k , which is expressed by 7-level natural language,as examples as shown in Table 4. Then the importance evaluation of the 10FRs, it is weight, get the new vector by fuzzying and defuzzified number. After average three part experts, the weight of every FR become a set of vectors, as examples as shown in Table 5.

Table 4. The mportance Evaluation of the 10FRs

	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR10
experts A	C_4	C_6	C_6	C_5	C_6	C_6	C_5	C_6	C_5	C_5
experts B	C_5	C_6	C_6	C_5	C_6	C_6	C_5	C_4	C_4	C_4
experts C	C_5	C_6	C_6	C_5	C_6	C_6	C_6	C_5	C_5	C_4

Table 5 The Weight of the 10FRs

	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR10
weight	0.603	0.808	0.808	0.654	0.808	0.808	0.705	0.654	0.603	0.551

Calculate the vector of table 3 and table 5 by formula1-3, then ARs, RRs and ARRs of NFRs and the final screening results are shown in Table 6.

Table 6 AR and RR values of different NFRs

NFR		*AR*	*RR*100*	result
Portability	Replaceability	3.06	4.51	
	Installability	3.36	4.94	
	Consistency	4.48	6.60	√
	Adaptability	3.63	5.34	√

Maintainability	Testability	2.76	4.06	
	Stability	3.50	5.16	√
	Changeability	3.30	4.85	
	Analyzability	2.87	4.23	
Performance Efficiency	Time Behaviour	3.55	5.22	√
	Resource Utilization	3.07	4.51	
Usability	Understandability	3.62	5.32	√
	Operability	3.60	5.30	√
Reliability	Recoverability	3.66	5.38	√
	Maturity	3.42	5.03	√
	Fault Tolerance	3.15	4.64	
Functionality	Suitability	3.54	5.21	√
	Security	2.95	4.34	
	interactivity	3.77	5.55	√
	Interoperability	3.30	4.85	
	Accuracy	3.36	4.95	
ARR			5.00	

3. Conclusion

This paper set up the model which express correlation evaluation with the 7-level natural language, build software FR-NFR correlation matrix, fuzzy the matrix vector by the trapezoidal fuzzy number, then calculate the relative importance and absolute importance of NFR, at last get the importance NFR by the NFR screening algorithm.In addition,this paper generalizes 44 NFRs based on the literature research and puts forward a systemized software NFR determination based on the fuzzy-QFD process according to the correlation and interdependence between FR and NFR of software, which provides a new solution for the identification of NFR in the real software program.

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