An Approach to Multiple Attribute Decision Making with Intuitionistic Fuzzy Information and Its Application to Software Quality Evaluation

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Abstract. Quality evaluation is an important subject in quality management, and quality evaluation is the foundation of quality improvement. Software is a very complex system, so software quality evaluation becomes a very difficult work in many quality problems. In order to objectively reflect the fuzziness of component indexes and enhance the flexibility of decision-making, a component quality evaluation model based on intuitionistic fuzzy set is established. On the basis of ISO software quality measurement model, intuitionistic fuzzy information is introduced into software quality evaluation model and the specific steps of component quality evaluation are given, and the evaluation model based on intuitionistic fuzzy set is used to rank the software to be evaluated. The rationality and validity of the method are verified by an example, which provides a reference for component evaluation.

1. Introduction
Software quality evaluation refers to the reasonable evaluation and quantification of software according to software quality evaluation standards. It runs through the software life cycle and is implemented in parallel with the software development process. It measures the software quality in the whole process and continuously, reveals the current status of software quality, estimates the follow-up trend of software quality, and provides powerful means for the demander, developer and evaluator to accurately control the quality of software products. Software quality is a complex concept, different people will have different understanding from different perspectives\cite{1, 2}. In essence, software quality is the common concern of developers, users and evaluators, and is closely related to user needs, that is, without user needs, software development can not be started; what kind of user needs must have what kind of software quality. How to determine the quality of software requires a series of development standards and a set of feasible software quality evaluation standards to ensure the reasonable measurement of software quality. In different periods, even in the same industry, software quality evaluation standards are not necessarily the same.

Software quality evaluation is a typical multi-attribute decision-making problem\cite{3}, and the general quality evaluation model is shown in Figure 1. Multi-attribute decision-making can be described as the decision-making process of selecting good enough schemes from a limited set of schemes to obtain the optimal objective. However, it is noted that most decision-making problems are uncertain, and the traditional decision-making methods for different problems are usually expensive and rely on approximate mathematical methods such as linearization of nonlinear problems, which may lead to the lack of performance in decision-making problems. Therefore, the important aspect of practical decision-making is to provide the ability to deal with imprecise and fuzzy information. In this case, the fuzzy multi-attribute decision-making method is usually better than the traditional multi-attribute decision-making method. The fuzzy multi-attribute decision-making is regarded as the goal or
constraint condition, which is essentially a fuzzy decision-making process\(^4\). From the structure of fuzzy number, interval intuitionistic fuzzy set is a very useful way to describe decision information as an extension of fuzzy set, because the membership function and non-membership function of intuitionistic fuzzy set are of type, which can describe decision information in real society\(^5\), economy\(^6\) and management\(^7\) more reasonably.

![Figure 1. Product quality evaluation model](image)

2. Software quality and management system

Software is a logical result of human intellectual labor development, which has the properties of logicality, no material object, complexity and dependence. Software quality reflects product performance. Software quality inspection should run through product development, production, deployment, operation, modification and other aspects, so software quality evaluation is an abstract process\(^8\). There are many definitions of software quality. According to the quality attributes, the international standards define software quality as the sum of the elements that the product conforms to the actual requirements and the attached requirements. Fisher et al. think that software quality is the attribute set that describes the advantages and disadvantages of the machine and conforms to the standard requirements, that is, the most important function and performance must meet the product development criteria. There is a professional word standard work. The description of software quality includes four aspects, which are the set of characteristic attributes, the degree of combination of attributes, the degree of users’ evaluation of software and the degree of software usage. Therefore, software quality is an overall evaluation result composed of multiple attributes\(^9\).

Software quality measurement is a component of product measurement and a key step in the process of product project comprehensive control\(^10\). The main measurement object is software product itself, product process and quality performance in project control. The purpose is to evaluate product quality, promote product design and product service optimization, reduce product development and after-sales service costs, and control development by using software quality measurement closely related to the quality cycle. It is applied in every stage of the software development process and after the software transaction stage. The purpose of the software measurement for the traded software is to improve some defects and the maintenance of the software itself In other words, the practical significance of software quality measurement lies in the selection, judgment and use of products. Software quality measurement model, also known as evaluation criteria model, identifies, manages and evaluates product quality characteristics as a whole, which is the framework foundation of product quality evaluation. It shows researchers’ recognition and attention to product quality. By controlling the quality in the process of software development, high-quality products that meet the requirements and are satisfactory to users are developed. The four common
software quality evaluation standards are Boehm model (1978), McCall (1978), ISO (1985), ISO (1993)\cite{11}. Table 1 lists the standards and objectives of these models respectively.

Table 1. Software quality measurement models and objectives

| Target         | Boehm | McCall | ISO(85) | ISO(93) |
|----------------|-------|--------|---------|---------|
| Correctness C1 | ✓     | ✓      | ✓       | --      |
| Reliability C2 | ✓     | ✓      | --      | --      |
| Availability C3| ✓     | ✓      | --      | --      |
| Efficiency C4  | ✓     | ✓      | ✓       | ✓       |
| Maintainability C5 | ✓ | ✓ | ✓ | ✓ |
| Testability C6 | ✓     | ✓      | ✓       | ✓       |
| Operability C7 | --    | ✓      | --      | --      |
| Flexibility C8 | --    | ✓      | --      | --      |
| Flexibility C9 | ✓     | ✓      | --      | --      |
| Reusability C10| ✓     | ✓      | --      | --      |
| Portability C11| ✓     | ✓      | --      | ✓       |
| Clarity C12    | ✓     | --     | --      | --      |
| Modifiability C13| ✓ | -- | -- | -- |
| Document C14   | ✓     | --     | --      | --      |
| Understandability C15| ✓ | -- | -- | -- |
| Effectiveness C16| ✓ | -- | -- | -- |
| Functional C17 | --    | --     | --      | ✓       |
| Universal C18  | ✓     | --     | --      | --      |
| Economy C19    | ✓     | --     | ✓       | --      |
| Security C20   | ✓     | --     | ✓       | --      |
| Applicability C21| ✓ | -- | ✓ | -- |

Boehm quality model researches from three aspects: product usability (reliability, efficiency, artificial engineering), easy maintenance (testability, comprehensibility, modifiability) and easy transplantation\cite{12}. The middle layer provides equipment independence, self-contained, accuracy, readiness, self description, easy explanation, equipment efficiency, easy storage and access, communication, and easy addition 15 quantifiable software quality attributes such as additive The model is characterized by describing the concept of quantitative evaluation of product quality and measurement formula, which is the first widely recognized attribute model. The model contains the hardware attributes that MC call model does not have. The shortcomings of the model are that the judgment of measurement items is too subjective, which is not conducive to finding the early deficiencies of software products and can not effectively reduce product maintenance costs in a timely manner (2) McCall quality model in the 1970s, through in-depth discussion of product quality characteristics, McCall researchers developed three-level models of software quality characteristics, standards and measurement, namely McCall quality model, also known as GE model [32]. The model defines and identifies software quality from the perspectives of product modification, operation and adaptation, and sets up 11 quality characteristics, 23 quality attributes and the description of the relationship among them. The characteristics of the model represent the objective performance of software quality, and the attributes can be used as evaluation criteria to describe the quality of products. ISO attribute model holds that the quality element is the description of the external characteristics of software quality, and the quality attribute is the description of the internal attributes.
of products, which are collectively referred to as the product quality element and sub elements. ISO model defines six external characteristics of product quality and 21 internal attributes of product quality, among which attribute is an independent factor in the process of software product.

3. The method of intuitionistic fuzzy information

Since professor Zadeh established the theory of fuzzy sets in 1965, the research scope of mathematics theory and application has expanded from the precise problem to the field of fuzzy phenomenon. In 1986, Bulgarian scholar Atanassov proposed the concept of intuitionistic fuzzy sets\(^\text{[13]}\). Because the characteristics of intuitionistic fuzzy sets are to consider both subordinate and non subordinate information at the same time, it provides more information in describing the attributes of things How to choose. Intuitionistic fuzzy sets have been widely used in medical diagnosis, decision-making, machine learning, logical planning, pattern recognition, market forecasting and many other fields. The framework of the proposed method is shown in Figure 2.

![Figure 2](image.png)

Figure 2. The framework of the proposed method.

According to the above four common software quality evaluation standards, it may be assumed that the expert group establishes the following fuzzy rules according to the software quality evaluation standards, as shown in Table 2:
Table 2. The intuitionistic fuzzy numbers corresponding to the language information.

| Language information         | Intuitionistic fuzzy numbers                      | $\alpha$, $\beta$ value |
|-----------------------------|--------------------------------------------------|--------------------------|
| Extremely poor (EP)         | $0.1 - \alpha \times \pi, 0.1 + \beta \times \pi$| $\alpha = 0, \beta = 1$ |
| Very poor (VP)              | $0.2 - \alpha \times \pi, 0.2 + \beta \times \pi$| $\alpha = 0.5, \beta = 0.5$ |
| Poor (P)                    | $0.3 - \alpha \times \pi, 0.3 + \beta \times \pi$| $\alpha = 0.5, \beta = 0.5$ |
| Slightly poor (SP)          | $0.4 - \alpha \times \pi, 0.4 + \beta \times \pi$| $\alpha = 0.5, \beta = 0.5$ |
| Middle (M)                  | $0.5 - \alpha \times \pi, 0.5 + \beta \times \pi$| $\alpha = 0.5, \beta = 0.5$ |
| Slightly good (SG)          | $0.6 - \alpha \times \pi, 0.6 + \beta \times \pi$| $\alpha = 0.5, \beta = 0.5$ |
| Good (G)                    | $0.7 - \alpha \times \pi, 0.7 + \beta \times \pi$| $\alpha = 0.5, \beta = 0.5$ |
| Very good (VG)              | $0.8 - \alpha \times \pi, 0.8 + \beta \times \pi$| $\alpha = 0.5, \beta = 0.5$ |
| Extremely good (EG)         | $0.9 - \alpha \times \pi, 0.9 + \beta \times \pi$| $\alpha = 1, \beta = 0$ |

We use the intuitionistic fuzzy information method mentioned in [14] to evaluate software quality.

4. Example
Assuming that an enterprise pre purchases a certain type of software products, there are five similar software (software A1, software A2, software A3, software A4 and software A5) for selection, the ranking results are given by using the intuitionistic fuzzy information evaluation method, and the software quality of these five possible software systems is evaluated. After the preliminary screening, a committee composed of three experts as decision makers decided to evaluate according to the four attributes of hardware / software cost investment, contribution to organizational performance, portability and reliability, as shown in Figure 3, the evaluation results were listed in the following matrix.

![Figure 3. Evaluation index system of software quality](image)

Next, we apply the operator to the multi-attribute decision making of software quality evaluation with intuitionistic fuzzy information. The method includes the following steps:

**Step 1.** Use the decision information given in the matrix $\tilde{R}$, and $\tilde{a}_{ij} = (\tilde{a}_{ij})^{\omega_{ij}}$, we get:
Then by score functions, we can get:

Step 2. Use matrix including the decision information, and the operator associated weighting vector, so that obtain the overall preference values of the software systems.

\[ \hat{a}_{1} = (0.22, 0.45), \hat{a}_{2} = (0.64, 0.05), \hat{a}_{3} = (0.71, 0.02), \hat{a}_{4} = (0.02, 0.81) \]
\[ \hat{a}_{5} = (0.43, 0.35), \hat{a}_{6} = (0.46, 0.11), \hat{a}_{7} = (0.76, 0.22), \hat{a}_{8} = (0.12, 0.66) \]
\[ \hat{a}_{9} = (0.33, 0.45), \hat{a}_{10} = (0.64, 0.14), \hat{a}_{11} = (0.65, 0.19), \hat{a}_{12} = (0.33, 0.05) \]
\[ \hat{a}_{13} = (0.54, 0.12), \hat{a}_{14} = (0.55, 0.05), \hat{a}_{15} = (0.71, 0.15), \hat{a}_{16} = (0.13, 0.74) \]
\[ \hat{a}_{17} = (0.54, 0.24), \hat{a}_{18} = (0.27, 0.17), \hat{a}_{19} = (0.58, 0.24), \hat{a}_{20} = (0.35, 0.45) \]

Then by score functions, we can get:

\[ \hat{a}_{(1)} = (0.71, 0.02), \hat{a}_{(2)} = (0.64, 0.05), \hat{a}_{(3)} = (0.22, 0.56) \]
\[ \hat{a}_{(4)} = (0.76, 0.22), \hat{a}_{(5)} = (0.46, 0.11), \hat{a}_{(6)} = (0.43, 0.35) \]
\[ \hat{a}_{(7)} = (0.65, 0.19), \hat{a}_{(8)} = (0.64, 0.14), \hat{a}_{(9)} = (0.33, 0.45) \]
\[ \hat{a}_{(10)} = (0.71, 0.15), \hat{a}_{(11)} = (0.55, 0.05), \hat{a}_{(12)} = (0.54, 0.12) \]
\[ \hat{a}_{(13)} = (0.58, 0.24), \hat{a}_{(14)} = (0.54, 0.24), \hat{a}_{(15)} = (0.27, 0.17), \hat{a}_{(16)} = (0.35, 0.45) \]

Step 2. Use matrix \( \tilde{R} \) including the decision information, and the operator associated weighting vector \( w = (0.20, 0.30, 0.30, 0.2) \), so that obtain the overall preference values \( \tilde{r}_{i} \) of the software systems \( A_{i} (i = 1, 2, \ldots, 5) \).

\[ \tilde{r}_{1} = (0.28, 0.59), \tilde{r}_{2} = (0.58, 0.36), \tilde{r}_{3} = (0.65, 0.32) \]
\[ \tilde{r}_{4} = (0.34, 0.48), \tilde{r}_{5} = (0.53, 0.26) \]

Step 3. Calculate the values \( S(\tilde{r}_{i}) (i = 1, 2, \ldots, 5) \) of the overall intuitionistic fuzzy preference values \( \tilde{r}_{i} (i = 1, 2, \ldots, 5) \).

\[ S(\tilde{r}_{1}) = -0.31, S(\tilde{r}_{2}) = 0.22, S(\tilde{r}_{3}) = 0.33 \]
\[ S(\tilde{r}_{4}) = -0.14, S(\tilde{r}_{5}) = 0.27 \]

Step 4. Rank all the software systems \( A_{i} (i = 1, 2, 3, 4, 5) \) in accordance with the scores \( S(\tilde{r}_{i}) \) \( (i = 1, 2, \ldots, 5) \) of the overall preference values \( \tilde{r}_{i} (i = 1, 2, \ldots, 5) \); \( A_{1} > A_{3} > A_{4} > A_{2} > A_{5} \), and thus the most desirable software system is \( A_{1} \).

5. Conclusion

With the development of software technology, software has become an important part of people's life and work. Quality as the core vitality of software products, people's requirements for software quality are gradually improving. Software product quality is a complex combination of quality factors. Quality evaluation is an objective judgment of the quality status of software. In the evaluation process, it has high complexity, uncertainty and invisibility, which provides a reliable basis for the implementation of quality control. Therefore, a reasonable evaluation method is not only the needs of software quality developers, but also the research objectives of software quality researchers. On the basis of previous research, this paper puts forward a method of software quality evaluation based on intuitionistic fuzzy information. The evaluation method based on intuitionistic fuzzy set can solve the problem of objecting and uncertain information in the evaluation process. Compared with the fuzzy evaluation, the intuitionistic fuzzy set makes the most of the evaluation information, which makes the evaluation result more comprehensive, scientific and reasonable. The evaluation method on the basis of ISO software quality measurement model, intuitionistic fuzzy information is introduced into software quality evaluation model is an effective evaluation method, which has certain promotion value.
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