Research and Analysis of Software Defect Measurement Elements Based on Analytic Hierarchy Process

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Abstract. It is not convenient for the general software quality evaluation system to be directly and quickly applied to the software quality evaluation to be tested. Therefore, this paper proposes a method suitable for the analysis of factors affecting software quality based on analytic hierarchy process. The analytic hierarchy process is used as the main framework, the distribution of the software's own properties and accumulated test findings as input, the constructed defect weight ratio is used as the judgment matrix, then do the hierarchical analysis. Through the analytic hierarchy process to analyse the weight of the factors of the software itself, test organizations can quickly make a fuzzy assessment of software quality, and provides the reference basis for the reasonable allocation of test resources.

1. Introduction

1.1 Software Defects
A software defect is a problem, error, or hidden defect in a computer or program that undermines its ability to function properly. Software defects can cause the software to fail to meet certain requirements in operation because of exceptions [1]. There is no software without defects, and the defects in the software will flow throughout the software development life cycle.

1.2 Software Defect Measurement
Software defect measurement is an important part of software measurement. Software defect measurement is to collect and quantify the defect data in the project process, unified management of scattered defect data [2], to make it orderly and clear. Then, by using a series of mathematical functions to process the data and analyze information such as defect density and trend, to improve product quality. However, software defect measurement enables project managers and decision makers to understand various indicators in software product development and testing, quantitative analysis of software defects, according to the empirical value of the various indicators obtained by the study and analysis, so as to make adjustments and decisions.

1.3 Analytic Hierarchy Process
Analytic Hierarchy Process (AHP) is an auxiliary decision-making method that simulates the process of human thinking [3], analyzing and judging complex problems. The elements related to decision are
decomposed into target layer, criterion layer, and scheme layer. It should be a combination of qualitative and quantitative method rather than systematic, hierarchical analysis method.

2. Analytic hierarchy process implementation process

2.1 The Application Model of Analytic Hierarchy Process in Software Testing

Software testing is an effective technical means to ensure the quality of software products for the purpose of finding defects. It is very important to evaluate software quality effectively and allocate test resources reasonably. This paper proposes a process of analytic hierarchy process (AHP) based on historical test data and test experience.

As shown in Figure 1, test experience and historical test data are taken as prior knowledge. Then, hierarchical analysis is conducted to analyze the possible influence degree of software attributes on software defects. Construct the weight matrix, and then a series of analysis processes such as consistency verification are conducted. If the analytic hierarchy process results are reasonable, software quality can be pre-evaluated according to the results, and provides the reference basis for the reasonable allocation of test resources.

![Analytic hierarchy process diagram](image)

**Figure 1.** The application model of analytic hierarchy process in software testing

The specific implementation steps of AHP algorithm are as follows.

1) Build a hierarchical model

Determine the weight of each attribute affecting the analysis object to the analysis object. For example, if a certain software is the analysis object[4], the key level, software scale, whether it is new research, whether it is reused, software complexity and other attributes will be taken as the criterion layer, respectively C1, C2... Cn, with the analysis object as the target layer O.

2) Construct judgment matrix
The comparison matrix \( A \) is constructed. According to the comparison scale, each attribute of the analysis object is compared in pairs to represent the importance of each criterion \( C_1, C_2 \ldots C_n \) to target \( O \).

\( a_{ij} \) is the comparison result of the importance of factor \( C_i \) and factor \( C_j \), and the 9 importance levels and their values given by Saaty are listed in table 1. A matrix formed by pairwise comparisons is called a judgment matrix. The judgment matrix has the following properties:

\[
a_{ij} = \frac{1}{a_{ji}}
\]

The scaling method of judgment matrix element \( a_{ij} \) is shown in table 1.

**Table 1. Comparative scale**

| Factor i is more important than factor j | values |
|----------------------------------------|--------|
| The same                               | 1      |
| Between same and A bit better           | 2      |
| A bit better                           | 3      |
| Between A bit better and better         | 4      |
| better                                 | 5      |
| Between better and obviously better     | 6      |
| Obviously better                       | 7      |
| Between obviously better and absolute   | 8      |
| Absolute better                        | 9      |

3) Calculate weights and phase quantities

The weight arithmetic average method is used to determine the weight of each influencing factor, and the steps are as follows.

First calculate the weight of each effective judgment matrix and use the square root method to calculate the product \( M_i \) of each row of elements in the judgment matrix. The calculation formula is as follows:

\[
M_i = \prod_{j=1}^{n} C_{ij} \quad (i = 1, 2, \ldots, n)
\]

Then calculate:

\[
\overline{W}_i = \sqrt[\nu]{M_i}
\]

next calculate:

\[
W_i = \frac{\overline{W}_i}{\sum_{j=1}^{n} \overline{W}_j}
\]

\( W_i \) is the eigenvector, that is, the corresponding weight coefficient.

4) Consistency test

Lambda Max is the largest eigenvalue of matrix \( A \). The consistency index is defined as CI. CI=0. CI is close to 0, with satisfactory consistency; The larger the CI, the greater the inconsistency.
\[ \text{CI} = \frac{\lambda_{\text{max}} - n}{n-1} \]  

(5)

To measure the size of CI, random consistency index RI was introduced:

\[ \text{RI} = \frac{\text{CI}_1 + \text{CI}_2 + \ldots + \text{CI}_n}{n} \]  

(6)

The random consistency index RI is related to the order of the judgment matrix. Generally, the greater the order of the matrix, the greater the possibility of consistent random deviation[5]. The corresponding relation is shown in Table 2. RI values vary slightly depending on the criteria.

| Matrix order | Mean random consistency index RI standard value |
|--------------|-----------------------------------------------|
| 1            | 0                                             |
| 2            | 0                                             |
| 3            | 0.58                                          |
| 4            | 0.90                                          |
| 5            | 1.12                                          |
| 6            | 1.24                                          |
| 7            | 1.32                                          |
| 8            | 1.41                                          |
| 9            | 1.45                                          |
| 10           | 1.49                                          |

Table 2. Mean random consistency index RI standard value

Considering that the deviation of consistency may be caused by random reasons, when testing whether the judgment matrix has satisfactory consistency, we also need to compare CI with random consistency index RI, the test coefficient CR is obtained.

\[ \text{CR} = \frac{\text{CI}}{\text{RI}} \]  

(7)

Generally, if CR<0.1, the judgment matrix is considered to have passed the consistency test; otherwise, it will not have satisfactory consistency.

2.2 Advantages and Disadvantages of AHP

1) Advantages of AHP
   - Systematic analysis method
     AHP takes the research object as a system and makes decisions according to the thinking mode of decomposition, comparative judgment and synthesis. It has become an important tool for systematic analysis developed after mechanism analysis and statistical analysis. In particular, this method can be applied to the system evaluation of unstructured characteristics and multi-objective, multi-criterion, multi-period[6], etc.
   - Concise and practical decision-making method
     Combine qualitative method with quantitative method organically, make the complicated system decomposition, to people of mathematical thinking process, systematic, convenient for people to accept, and to all the objectives, principles and difficult to quantify process of decision-making problem into a single objective problem, multi-level determined by comparing the two elements of the same level relative to a level elements on the number of relations, finally carries on the simple mathematical operations. The calculation is simple, and the result is simple and clear, which is easy for decision-makers to understand and grasp.
   - Less quantitative data information is needed
     AHP mainly starts from the evaluator's understanding of the essence and elements of the evaluation problem[7, 8], which is more qualitative than the general quantitative method. This kind of thinking can deal with many practical problems that cannot be tackled with traditional optimization techniques.

2) Disadvantages of AHP
   - Less quantitative data, more qualitative components, and less convincing


Nowadays, in the evaluation of scientific methods, it generally requires more rigorous mathematical argumentation and perfect quantitative methods. Analytic hierarchy process (AHP) is a method with the decision-making mode of simulating human brain, so it must have more qualitative color and can be used as a reference for decision-making.

- When there are too many indicators, the data statistics are large and the weight is difficult to determine.
- If there are more and more indicators, it may be difficult for us to judge the importance between every two indicators, and it may even affect the consistency of hierarchical single sort and total sort, so that the consistency test cannot be passed.

3 Matters needing attention

In the application of AHP, if the selected elements are not reasonable, their meaning is not clear, or the relationship between elements is not correct, will reduce the quality of AHP results, and even lead to AHP decision failure. In order to ensure the rationality of hierarchical substructure, the following principles should be grasped:

- Grasp the main factors in the decomposition and simplification of the problem, without missing much;
- Pay attention to the intensity relationship between the comparison elements. Elements that are too different cannot be compared at the same level.

3 Application of AHP in software defect distribution measurement

3.1 Construct Judgment Matrix

By analyzing the empirical data of previous tests, the following testing rules are obtained:

1) Critical level, the higher the software security software, the more will cause attaches great importance to the research and development personnel, in the later code defects exist in the process of software testing is less, on the contrary, the software security level is low, can't has drawn great attention of developers, in the process of software testing will be exposed to more problems, so that software security key level is one of the factors affecting the quality of software.

2) For software with large code scale, the general function interface is more complex, and the complexity of the software is gradually increasing. There are more software defects than those with small code scale.

3) Software defect is not only related to the scale of software, and software complexity, code, a lot of factors, such as historical information, so consider new developed software and reuse software attribute, newly developed software, due to lack of historical reference information, there are unknown defects, and on the existing software, reuse changes to development again, because may refer to history information of software, draw lessons from the mature code function module, relatively few software defects found in the late.

Table 3. Input file (Judgment matrix)

| Factors | A1   | A2   | A3   | A4   | A5   |
|---------|------|------|------|------|------|
| A1      | 1    | 1/4  | 1/4  | 1/2  | 1/5  |
| A2      | 4    | 1    | 2    | 3    | 1    |
| A3      | 4    | 1/2  | 1    | 5    | 1/3  |
| A4      | 2    | 1/3  | 1/5  | 1    | 1/2  |
| A5      | 5    | 1    | 3    | 2    | 1    |
Therefore, this paper studies the proportion of software defects affected by attributes such as software key level, software scale, new research software, reused software and software complexity. Through analytic hierarchy process, we can further understand the weight of software key level, software scale, new research software, reused software and software complexity attributes that affect software quality. The weight judgment matrix is shown in Table 3. A1, A2, A3, A4, A5 represent Key levels, Software size, new software, Reuse modules, Software complexity.

3.2 AHP Implementation
Through MATLAB to calculate the weight and consistency test rate, the weight judgment matrix as the input file, named as data.xls, the output file as result.xls, MATLAB program to achieve the hierarchical analysis process of the code as follows:

```matlab
clear;
inputfile='C:\Users\xzw\Desktop\data.xls'; RI=[0 0 0.58 0.90 1.12 1.24 1.32 1.41 1.45 1.49 1.51];
outputfile = 'C:\Users\xzw\Desktop\result.xls';
[num,txt]=xlsread(inputfile,1);
[rows,cols]=size(num);
prodvalue=prod(num,2);
rootvalue=power(prodvalue,1/rows);
sumrootvalue=sum(rootvalue);
wi =rootvalue/sumrootvalue;
awi=num*wi;
awi_wi=awi./wi;
Ci=(mean(awi_wi)-rows)/(rows-1);
consistencyrate=Ci/RI(rows);
txt(2:end,2:end) = num2cell(num);
txt(1,cols+2:cols+3)= {'weight','CR'}; txt(2:end,cols+2) = num2cell(wi);
txt{2,cols+3}= consistencyrate;
xlswrite(outputfile,txt);
disp('complete');
```

4. Results
The output result file of MATLAB is shown as follows. According to Table 4, the weight vector is Wi. Wi= (0.059614, 0.310607, 0.209288, 0.095709, 0.324783)\T.

| factors | A1   | A2   | A3   | A4   | A5   | Weight  | CR       |
|---------|------|------|------|------|------|---------|----------|
| A1      | 1    | 1/4  | 1/4  | 1/2  | 1/5  | 0.059614| 0.075958 |
| A2      | 4    | 1/4  | 1/2  | 3    | 1    | 0.310607|          |
| A3      | 4    | 1/2  | 1    | 5    | 1/3  | 0.209288|          |
| A4      | 2    | 1/3  | 1/5  | 1    | 1/2  | 0.095709|          |
| A5      | 5    | 1    | 3    | 2    | 1    | 0.324783|          |

The consistency ratio is 0.075958<0.1, which is verified by consistency. The weight vector Wi represents the weight of the critical level, software scale, new research software, reused software, complexity and other attributes of the analysis software to the defects in the software.
5. Conclusion
Based on the research and analysis of software defect measurement method, this paper studies the
evaluation of analytic hierarchy process (AHP) in software defect measurement and describes the
measurement element selection. This paper is realized in the experimental software MATLAB, in the
process of software testing, the software with high safety level, large code size, high complexity can be
focused on the software test, and reasonable allocation of test resources, so as to improve the efficiency
of software testing, to ensure the quality of the software.

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