



Research on Software Quality Evaluation Model of Instrument and Control System in Nuclear Power Plant

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Abstract. As the nerve center of nuclear power plant, the quality of digital instrument and control system is directly related to the stable, safe and efficient operation of nuclear power plant. At the same time, with the advancement of the independent research and development process of instrument and control system, it puts forward higher requirements in terms of security and reliability. It is very important to evaluate the software quality of instrument and control system scientifically and reasonably. Therefore, a software quality evaluation model suitable for nuclear power instrument and control system is proposed in this paper. On the basis of three-tier architecture, by restricting the relative importance of the two major indicators of security and reliability, the weight vectors of the indicators of each tier are calculated through consistency test. Then the experts grade all the indicators of the lowest tier one by one. Finally weighted sum is made from bottom to top to calculate the software quality score of the instrument and control system. The method presented in this paper plays a guiding role in the software quality evaluation of instrumentation and control system in nuclear power plant.

Keywords: Instrument and control system · Evaluating indicator · Analytic hierarchy process

1 Introduction

With the rapid development of information technology, the use of various software products in the field of industrial control is becoming more and more popular, and their status is becoming more and more important. As the nerve center of nuclear power plant, the Digital Control System (DCS) plays an important role in ensuring the safe, reliable and stable operation of nuclear power plant [1]. Especially in the process of localization of DCS in nuclear power plants, the design and development of DCS software products are characterized by heavy tasks, high accuracy and reliability requirement. The quality of DCS software directly affects the stable, safe and efficient operation of nuclear power plant [2]. Quality control in the process of localization is the premise of ensuring the quality of nuclear software [3]. Therefore, it is urgent to evaluate the software quality of instrument and control system independently developed in nuclear power plant

objectively, scientifically and efficiently. According to ISO/IEC 25010 software quality evaluation standard, a new quantitative evaluation model based on analytic hierarchy process is proposed in this paper [4].

2 Software Quality Evaluation Index

Software quality evaluation, that is, the detection and measurement of software product quality characteristics, is based on the criteria of software quality evaluation, run through the software life cycle process, and implement in parallel with the software development process. It measures the software quality throughout and continuously in the software development process, and reveals the current state of software quality, and estimates the follow-up trend of software quality. It provides a powerful means of software quality quantitative management for the demander, developer and evaluator. Evaluators provide powerful means of quantitative software quality management to accurately control the quality of software products [5].

Software quality evaluation is a complex project. Because of the rapid development and updating of software technology, there is no unified evaluation standard at present. In recent years, McCall standard, Boehm standard, FURPS standard, Dromey standard, ISO 9126 standard and ISO/IEC 25010 standard are common software quality evaluation systems. Among them, the ISO/IEC 25010 standard is made progress from ISO 9126 standard. The quality attributes of software products are divided into eight characteristics, each of which is composed of a set of related sub-characteristics. The definition and division of these characteristics are detailed in Table 1.

Table 1. Software quality characteristics and sub-characteristics

Quality characteristics	Definition	Sub-characteristics
Functional applicability	It refers to the degree to which the software meets explicit and implicit requirements when the software is used under specified conditions	Functional correctness
		Functional integrity
		Functional fitness
Performance efficiency	It refers to the amount of resources used by software under specified conditions and the degree to which performance is provided	Time characteristic
		Resource utilization rate
		Capacity
Compatibility	It refers to the degree to which software can exchange information, systems or components with other software and perform the required functions while sharing the same hardware or software environment at the same time	Coexistence
		Interoperability

(continued)

Table 1. (continued)

Quality characteristics	Definition	Sub-characteristics
Easy to use	It refers to the degree to which software can achieve specific goals effectively, efficiently and satisfactorily when it is used by specific users in a specific environment	Identifiability
		Easy to learn
		Maneuverability
		User error protection
		Beautiful user interface
Reliability	It refers to the degree to which software performs specified functions over a specified period of time and under specified conditions	Accessibility
		Maturity
		Effectiveness
		Fault tolerance
		Easy to recovery
Security	It refers to the extent to which software can effectively prevent unauthorized access to source, target, or related data by others	Confidentiality
		Completeness
		Anti repudiation
		Accountability
		Authenticity
Maintainability	It refers to the degree to which maintainers can modify the effectiveness and efficiency of software	Modularization
		Reusability
		Easy to analysis
		Easy to modified
		Easy to test
Portability	It refers to the degree of effectiveness and efficiency of software transferring from one hardware, software, or other operating or usage environment to another	Adaptability
		Easy to install
		Substitutability

Because of the particularity of the instrumentation and control system software in nuclear power plants, the software of different security levels must conform to the national and international standards. Especially its security and reliability must strictly comply with the requirements for IEC 60880-2006, IEC 62138-2004, IEC 61513-2011 and NUREG/CR 6101-1993 [6]. So in the process of studying DCS software quality evaluation model, security and reliability must be considered as key factors. In order to explain the process of quality assessment, this paper only establishes the software quality evaluation model of Instrument and Control System according to commercial software.

3 Software Quality Evaluation Model Based on Analytic Hierarchy Process

When the software quality evaluation system is established, the qualitative indicators are basically established. The establishment of quantitative indicators requires a scientific and rational distribution of the weight of each evaluation index. Common weight allocation methods include expert estimation method, analytic hierarchy process, fuzzy inverse equation method, ring ratio method, entropy method, etc. This paper uses analytic hierarchy process to determine the weight of evaluation index.

3.1 Establishing Hierarchical Model

According to the analytic hierarchy process, the ISO/IEC 25010 quality evaluation system standard is divided into three levels: total quality layer A, quality characteristic layer B and sub-feature layer C. Among them, the total quality layer is the final evaluation result; the quality characteristic layer is divided into eight characteristics: functional applicability, performance efficiency, compatibility, easy to use, reliability, security, maintainability and portability; the sub-feature layer includes 31 sub-features in Table 1. The hierarchical model is shown in Fig. 1.

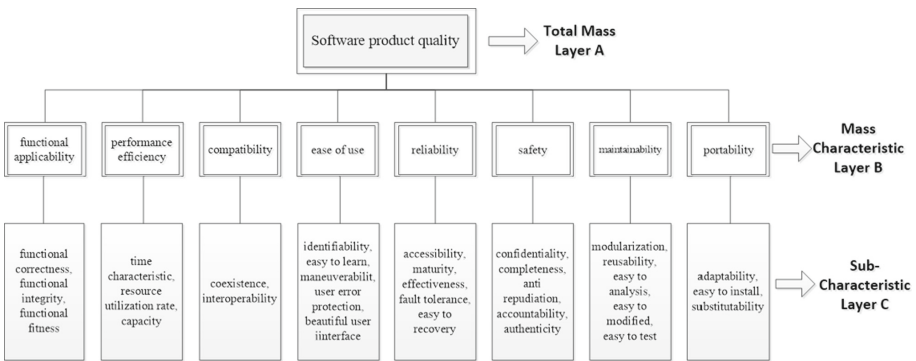


Fig. 1. Hierarchical Structure Model of Software Quality Evaluation

3.2 Constructing Judgment Matrix

In determining the weights of factors at different levels, if only the qualitative results, it is often not easy to be accepted by others, so Saaty et al. put forward the consistent matrix method, that is, not to put all factors together, but to compare two factors [7]. At this time, the relative scale is used to reduce the difficulties of comparing many factors of different nature, so as to improve the accuracy. For example, each element of the quality characteristic layer is compared in two ways and graded according to its relative importance. To quantify the results of the importance comparison among the elements, Table 2 lists nine importance levels given by Saaty and their assignments.

Table 2. Scaling and meaning of judgment matrix

Scaling	Meaning
$a_{ij} = 1$	i index is as important as j index
$a_{ij} = 3$	i index is slightly more important than j index
$a_{ij} = 5$	i index is more important than j index
$a_{ij} = 7$	i index is obviously more important than j index
$a_{ij} = 9$	i index is absolutely more important than j index
$a_{ij} = 2n, n = 1, 2, 3, 4$	the importance of i index is between $a_{ij} = 2n - 1$ and $a_{ij} = 2n + 1$ in comparison with j index

A matrix consisting of two or two comparisons is called a judgment matrix $A = (a_{ij})_{k \times k}$, k is the number of indicators, as Formula 1. The matrix has the following characteristics:

- I) $a_{ij} > 0$, specifically, if index i is more important than index j , then $a_{ij} > 1$, whereas $0 < a_{ij} < 1$;
- II) $a_{ij} = 1/a_{ji}$, if the relative importance of index i and index j is a_{ij} , then the relative importance of index i and index j is $1/a_{ij}$;
- III) $a_{ii} = 1$, the diagonal line of the matrix is 1.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1k} \\ a_{21} & a_{22} & \cdots & a_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ a_{k1} & a_{k2} & \cdots & a_{kk} \end{bmatrix} \tag{1}$$

Considering the importance of security and reliability in the operation and maintenance of DCS software, it is necessary to add a restriction condition to construct the judgment matrix: $a_{pq} > 5$, index $p \in [\text{Security, Reliability}]$, index $q \in [\text{Functional applicability, Performance efficiency, Compatibility, Easy to use, Maintainability, Portability}]$.

3.3 Computing Weight Vector

The judgment matrix is obtained through comprehensive evaluation and decision-making by professionals and relevant experts according to the set principles. After the judgment matrix is established, the weight vector is calculated. Firstly, the P_i that means the element product of each line in matrix A is calculated:

$$P_i = \prod_{j=1}^k a_{ij} \tag{2}$$

$i = 1, 2, \dots, k$;

Calculate the extraction of a root, v_i is obtained:

$$v_i = \sqrt[k]{P_i} \quad (3)$$

$i = 1, 2, \dots, k$;

By normalizing v_i , w_i is obtained:

$$w_i = v_i / \sum_{i=1}^k v_i \quad (4)$$

$i = 1, 2, \dots, k$;

$W = [w_1, w_2, \dots, w_k]^T$ Vector is the matrix weight vector required.

3.4 Checking consistency

Since the judgment matrix is based on the expert's independent judgment and is obtained by comparing the two indexes in the hierarchy, it is necessary to check the consistency of the judgment matrix. If the consistency requirement is not satisfied, the judgment matrix needs to be regenerated. The inspection steps are as follows:

(1) Calculate the S_j that means the sum of each column of elements in matrix A:

$$S_j = \sum_{i=1}^k a_{ij} \quad (5)$$

$j = 1, 2, \dots, k$;

(2) Calculate the λ_{max} that means the maximum eigenvalue of matrix A:

$$\lambda_{max} = \sum_{i=j=1}^k w_i S_j \quad (6)$$

(3) Calculate the Computational consistency test index CI:

$$CI = (\lambda_{max} - k) / (k - 1) \quad (7)$$

(4) Calculate the Computing Random Consistency Ratio CR:

$$CR = CI/RI \quad (8)$$

RI is called the mean random consistency index. The specific values are shown in Table 3 [8]. When $CR < 0.1$, then the judgment matrix A has satisfactory consistency; otherwise, the judgment matrix needs to be modified until it has satisfactory consistency.

3.5 Computing Comprehensive Score

According to the above steps, the weight vectors W' are calculated for eight indicators, such as functional applicability and compatibility, in the quality characteristic layer B.

$$W' = [w_1, w_2, \dots, w_8]^T \quad (9)$$

Table 3. Average random consistency index number table

Matrix order	RI
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41

Then, in the sub-feature layer C, the weight vector W_m is calculated for each sub-feature index subordinate to eight indexes, and each sub-feature is scored one by one, and the scoring vector is obtained, as shown in Table 4.

$$W_m = [w_{m1}, w_{m2}, \dots, w_{mq}]^T \tag{10}$$

$$G_m = [g_{m1}, g_{m2}, \dots, g_{mq}] \tag{11}$$

$\sum_{i=1}^q g_{mi} = 100, m = 1, 2, \dots, 8, q$ is the number of sub-properties under a certain mass characteristic.

Table 4. Weights and scores of indicators in layer B and C

Quality characteristics	Weighted score	Sub-characteristics	Weight	Score
Functional applicability w_1	$t_1 = G_1 \cdot W_1$	Functional correctness	w_{11}	g_{11}
		Functional integrity	w_{12}	g_{12}
		Functional fitness	w_{13}	g_{13}
Performance efficiency w_2	$t_2 = G_2 \cdot W_2$	Time characteristic	w_{21}	g_{21}
		Resource utilization rate	w_{22}	g_{22}
		Capacity	w_{23}	g_{23}
Compatibility w_3	$t_3 = G_3 \cdot W_3$	Coexistence	w_{31}	g_{31}
		Interoperability	w_{32}	g_{32}
Easy to use w_4	$t_4 = G_4 \cdot W_4$	Identifiability	w_{41}	g_{41}
		Easytolearn	w_{42}	g_{42}
		Maneuverability	w_{43}	g_{43}
		User error protection	w_{44}	g_{44}
		Beautiful user interface	w_{45}	g_{45}

(continued)

Table 4. (continued)

Quality characteristics	Weighted score	Sub-characteristics	Weight	Score
Reliability w_5	$t_5 = G_5 \cdot W_5$	Accessibility	w_{51}	g_{51}
		Maturity	w_{52}	g_{52}
		Effectiveness	w_{53}	g_{53}
		Fault tolerance	w_{54}	g_{54}
		Easy to recovery	w_{55}	g_{55}
Security w_6	$t_6 = G_6 \cdot W_6$	Confidentiality	w_{61}	g_{61}
		Completeness	w_{62}	g_{62}
		Anti repudiation	w_{63}	g_{63}
		Accountability	w_{64}	g_{64}
		Authenticity	w_{65}	g_{65}
Maintainability w_7	$t_7 = G_7 \cdot W_7$	Modularization	w_{71}	g_{71}
		Reusability	w_{72}	g_{72}
		Easy toanalysis	w_{73}	g_{73}
		Easy tomodified	w_{74}	g_{74}
		Easy totest	w_{75}	g_{75}
Portability w_8	$t_8 = G_8 \cdot W_8$	Adaptability	w_{81}	g_{81}
		Easy to install	w_{82}	g_{82}
		Substitutability	w_{83}	g_{83}

So far, we can construct the scoring vector T of eight indicators in layer B , and calculate the final comprehensive score F of quality evaluation.

$$T = [t_1, t_2, \dots, t_8] \quad (12)$$

$$F = T \cdot W' \quad (13)$$

4 Concluding remarks

In order to evaluate the software quality of DCS system in nuclear power plant scientifically and effectively, a new quantitative evaluation method and model based on analytic hierarchy process (AHP) is proposed according to ISO/IEC 25010 standard. The model constructs a judgment matrix of relative importance for each evaluation index, and assigns two high important values of security and reliability. Through consistency test, the weight vectors of each index are obtained. The lowest indexes are scored by experts one by one, and the weighted sum is made from bottom to top. Finally, the software quality score of DCS system is calculated. The quality evaluation model proposed

in this paper draws lessons from the traditional analytic hierarchy process and restricts the relative important value of some evaluation indexes. It conforms to the two high performance standards of DCS system for security and reliability, and plays a guiding role in the software quality evaluation activities of instrument and control system in nuclear power plants.

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