Methods for Identifying and Controlling Weak Links in the Supplier's Product Guarantee Capability

Tiefei Ma [a], Jie Dong [b], Han Jiang [c], Xiang Gao [d] *

[a] caltgcc@163.com, [b] Dongj@163.com, [c] JiangH@163.com, [d] gxiang199710@163.com

Systems Engineering Research Institute, Beijing, China

Abstract. Under the background of the transformation of quality management mode, in order to build a unified system framework of product assurance capability of suppliers at all levels, a method to identify the weak links of product assurance capability of suppliers is proposed. Firstly, the evaluation index system of product assurance capability is constructed from the perspective of the whole process and all elements, and the corresponding quantitative analysis method is given. In order to improve the scientificity of the analysis process, the characteristics of maturity level are refined, and the quantitative method of expert opinion weight coefficient based on compatibility analysis is proposed, which breaks through the limitation of traditional expert weight. Finally, aiming at defect recognition, a method of drawing risk radar map is proposed based on risk perspective. The example shows that the method proposed in this paper can effectively analyze the defects of supplier's engineering capability, and provide a strong basis for its continuous process improvement.

Keywords: engineering capability, risk radar chart, supplier, defect identification, maturity

1 Introduction

Product assurance is a refined quality management method. Through the application of system engineering method, we can grasp the key points and weak links in product development and production, implement the responsibilities of key positions, refine and decompose the quality management requirements, identify and control the risks in the whole process, and realize the whole process management and control of product quality [1].

With the accelerated pace of reform and the improvement of the overall level of national defense science and technology industry, the scale of aerospace equipment construction is becoming larger and larger, the system structure is becoming more and more complex, the requirement of equipment efficiency is getting higher and higher, and the difficulty of management is also increasing. In addition, military enterprises have gradually become the main body of market competition for independent operation, and some private enterprises and even joint ventures have become military enterprises. Fundamental changes have taken place in the internal and external environment of equipment procurement. Under the background of multi-resource integration of aerospace system engineering, how to comprehensively understand, evaluate, guide and improve the product assurance work of suppliers at all levels, and then reduce the risk of development process, has become the common concern of the

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military and the overall units.

Defect identification is the product of capability analysis, which originates from a subjective qualitative evaluation. With the introduction of "maturity", benchmarking has gradually become the mainstream of capability evaluation. At present, the maturity model has been widely used in various fields, and is based on the software capability maturity model[2]. It has developed a maturity model system suitable for different fields, including system engineering capability maturity model, personnel capability maturity model, integrated product and process development capability maturity model and project management capability maturity[3][4]. After recognizing the significance of the capability maturity model of systems engineering in the improvement of systems engineering capability, enterprises and institutions represented by Boeing and NASA have set up special departments to be responsible for the research of the capability maturity model of systems engineering, so as to evaluate and guide the process improvement of system engineering.

With the development of quality assurance engineering technology, the University of Maryland took the lead in applying maturity model in the field of reliability engineering and proposed a reliability capability assessment method[5]. Subsequently, Microsoft and the University of Maryland jointly carried out a reliability capability assessment study, and proposed a model[6]for evaluating the product quality assurance capability of electronic product manufacturers. The result is a list of critical tasks affecting product reliability, which can not cover the whole process and all elements. Wang Jing et al. [7] proposed the concept and evaluation framework of reliability system engineering capability, but did not form a systematic quantitative evaluation mechanism; on this basis, Pan et al. [8] proposed a reliability engineering capability maturity model (RE-CMM) for China's aviation industry, but it is difficult to effectively identify process defects, so as to achieve the effect of promoting improvement through evaluation.

Therefore, based on the system engineering maturity model and the operation mechanism of equipment product assurance engineering, this paper comprehensively combs the elements of engineering technology, methods, tools, standards, personnel and related supporting environment, establishes the evaluation index system of product assurance capability with engineering process as the core, and gives the quantitative evaluation method of product assurance capability. Based on the perspective of risk, a risk radar map method is proposed to effectively identify the risk of the whole factor process, so as to realize the effective implementation of evaluation to promote improvement in engineering applications.

2 Construction of evaluation index system of product assurance capability and extraction of grade characteristics

2.1 Evaluation index system of product assurance capability

Product assurance is a systematic project, which needs to achieve the established goals and meet the needs of users from the perspective of management and technology. Product assurance management capability provides strong organizational guarantee for all product assurance engineering activities, and provides scientific and effective management for the development of activities, so as to ensure that the predetermined product assurance objectives are achieved with the least resources; Product assurance technology capability provides strong support for all product assurance management activities in terms of software and hardware, and provides advanced technical support for product development process to meet product assurance requirements. Through standard retrieval, literature review and engineering practice, the engineering practice experience and academic research achievements related to equipment product assurance work are solidified into the evaluation process, and the evaluation index system of product assurance engineering capability is constructed based on the maturity model from the perspective of management and technology, as shown in figure 1.

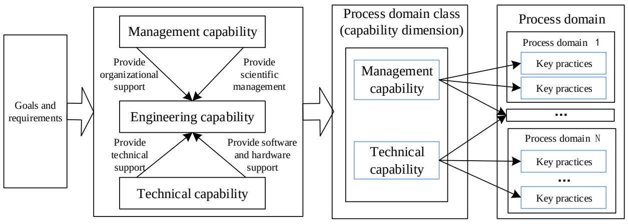

Figure 1. Product Assurance Capability Classification.

Based on the maturity model, the above two capabilities are systematically analyzed: each process domain class contains several process domains (i.e., assessment items), and each process domain contains several key practices (i.e., assessment elements) to achieve its own objectives, as shown in figure 2.

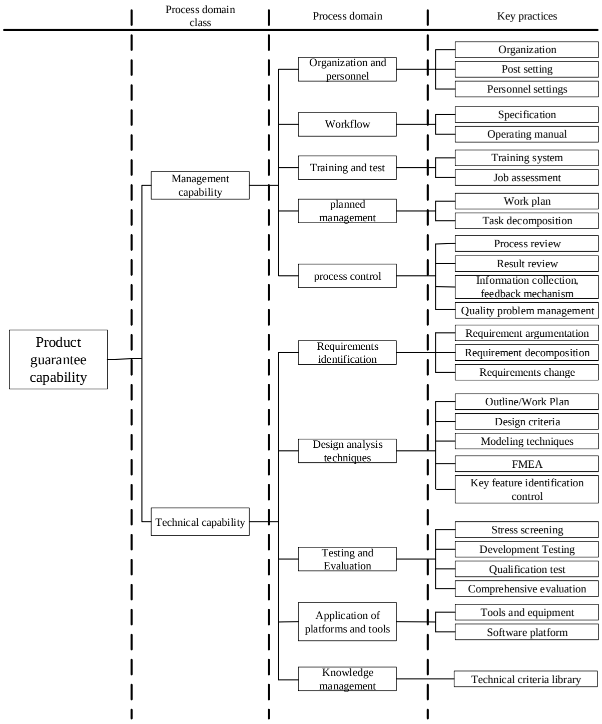

Figure 2. Evaluation index system of product assurance capability of supplier

Considering the differences in the characteristics of the supplier units, the evaluation expert group shall tailor the evaluation elements according to the characteristics of the products developed by the evaluated units, and assign weights to each evaluation element. In view of the systematic, flexible and practical characteristics of the analytic hierarchy process, the analytic hierarchy process[9]can be used to assign the index weight on the basis of the established hierarchical index system.

2.2 Characteristics of product assurance capability maturity level

The product assurance capability level of supplier is expressed by maturity classification. In order to avoid excessive loss of information in the evaluation process caused by Boolean evaluation method, the capability is divided into five levels. Table 1 presents six engineering capability levels and the corresponding typical characteristics (that is, evaluation basis) are given. Level 1 is the lowest level, and level 5 is the highest level. Capability assessment based on the typical characteristics of each level can effectively reduce the impact of individual subjectivity on the evaluation results. In addition, the change from a lower capability level to a higher capability level can provide a ladder goal and evolution path for continuous process improvement. The improvement of maturity level is gradual, and the typical characteristics describe the six engineering capabilities of a specific level of maturity.

Considering that it is very difficult to determine the precise value of the evaluation elements, but it is easy to make a fuzzy evaluation with natural language, and the ability evaluation itself is a kind of psychological feeling, even through the division of five grades and the construction of typical characteristics, it is difficult to form an absolutely definite boundary between grades, so as to realize the quantitative evaluation of ability grades more scientifically. Establish the correspondence between the ability level described in natural language and the triangular fuzzy number, as shown in **Table 1**.

Table 1. Characteristics of product assurance capability level

Competency level			**Typical characteristics**
Natural language variables	Triangular Fuzzy Number		
Level 1	Initial stage	(0,0,0.25)	Various works are carried out one after another, but they are in a state of chaos, without good planning and follow-up monitoring, and are not linked to the design, test and production processes; the support capacity of the organization is very poor.
Level 2	Repeatabl e level	(0,0.25,0.5)	A strategy and implementation outline for product assurance work have been established. A dedicated person is responsible for the work, and a project product ensures the successful completion of the work, which can be replicated in other projects within the organization.
Level 3	Defined level	(0.25,0.5,0.75)	There is a verified and fully revised standard system, and product assurance work has established norms and basis. Strictly define

			the implementation process of product assurance work, including standards and procedures for implementation, verification mechanisms, and completion criteria.
Level 4	Managed level	(0.5,0.75,1)	The progress of product assurance work can be measured using quantitative standards, which can establish a foundation for evaluating the effectiveness of product assurance work. When the unacceptable range is reached, corresponding measures can be taken to correct it, achieving control and management of product assurance.
Level 5	Optimized level	(0.75,1,1)	The supplier integrates and optimizes the product assurance work carried out, emphasizing gradual process improvement. They are able to spontaneously organize and have the ability to identify potential defects and carry out targeted process improvement.

3 Quantitative analysis of product assurance capability and defect identification

3.1 Weighted quantification of evaluation values considering consistency of results

In order to reduce the influence of expert subjectivity on the evaluation results, this paper adopts the form of expert group scoring, which can reduce the influence of individual on the results to a certain extent. Due to the difference of expert experience and emphasis, in order to further reduce the individual subjective influence, the expert weight system quantification method is improved, and an expert opinion weight coefficient quantification method based on the compatibility analysis of evaluation results and taking the evaluation points as the unit is proposed to realize the weighted comprehensive analysis of evaluation results. The specific process is shown in figure 3.

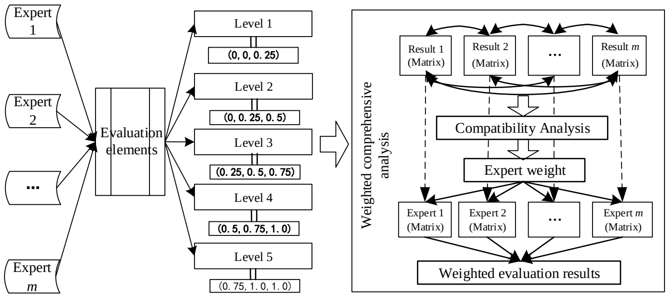

Figure 3. Quantitative evaluation process

- Quantitative processing of evaluation result

Letting *m* experts to form an expert group to evaluate the *h* evaluation points to form a natural language evaluation matrix $\tilde{D}_e = [\tilde{u}_i] = [\tilde{u}_1, \tilde{u}_2, \tilde{u}_3, \cdots, \tilde{u}_h]$, where $e = 1, 2, 3, \cdots, m$ represents the number of the experts; $\tilde{u}_i$ Indicates the natural language evaluation value of the evaluation point *i* by the expert *e*. If the evaluation result is "Repeatable level", $\tilde{u}_i$ can be expressed as $\tilde{u}_i =$ "Level 2" or "Repeatable level". The natural language evaluation matrix is transformed into a fuzzy evaluation matrix $\tilde{A}_e = [\tilde{a}_i] = \left[\tilde{a}_1, \tilde{a}_2, \tilde{a}_3, \cdots, \tilde{a}_h\right]$, where $\tilde{a}_i$ is a triangular fuzzy number $\tilde{a}_i = \left(a_{iL}, a_{iM}, a_{iH}\right)$. Corresponding $\tilde{a}_i = (0.25, 0.5, 0.75)$ if $\tilde{u}_i =$ "Level 2" or "Repeatable Level".

- Determination of expert opinion weight

The initial weight is set for the experts in the form of equal division, and the prior weight of each expert is $\omega_{sc} = 1/m$. The evaluation results of each expert are analyzed by using the compatibility test method[10], that is, the compatibility between fuzzy evaluation matrices is analyzed to obtain the opinion weight of each expert for each evaluation point, that is, the posterior weight, which can be expressed as:

$$\omega_{dc}^{e} = \frac{\sum_{h=1,h\neq e}^{m} S(\tilde{A}_e, \tilde{A}_h)}{\sum_{e=1}^{m} \sum_{h=1,h\neq e}^{m} S(\tilde{A}_e, \tilde{A}_h)}, \tag{1}$$

where $S(\tilde{A}_e, \tilde{A}_h) = \left[V(\tilde{a}_i^e, \tilde{a}_i^h)\right]$, $V(\tilde{a}_i^e, \tilde{a}_i^h) = \frac{1}{3} \otimes \left(1 - \left|\tilde{a}_{iL}^e - \tilde{a}_{iL}^h\right|, 1 - \left|\tilde{a}_{iM}^e - \tilde{a}_{iM}^h\right|, 1 - \left|\tilde{a}_{iH}^e - \tilde{a}_{iH}^h\right|\right)$

The prior weight and the posterior weight of each expert opinion are integrated, and the comprehensive weight matrix of the opinion weight of each expert for each evaluation key point is obtained.

$$\omega_c^e = \gamma \omega_{sc}^e \oplus (1-\gamma) \omega_{dc}^e, \tag{2}$$

where γ represents the prior weight coefficient, $0 \le \gamma \le 1$, $\oplus$ represents the addition of fuzzy operation.

- Weighted quantification of evaluation results

A fuzzy comprehensive evaluation matrix of that evaluation element is established by integrate the weight of each expert opinion and the evaluation result:

$$\tilde{A} = \omega_c^1 \otimes \tilde{A}_1 \oplus \omega_c^2 \otimes \tilde{A}_2 \oplus \cdots \oplus \omega_c^m \otimes \tilde{A}_m, \tag{3}$$

The fuzzy comprehensive evaluation matrix is defuzzified by calculating the expected value of the triangular fuzzy a_i number.

$$E(a_i) = \frac{((1-\lambda)a_{iL} + a_{iM} + \lambda a_{iH})}{2}, \tag{4}$$

where λ depends on the risk attitude of the decision maker, $0 \le \lambda \le 1$. $\lambda > 0.5$ represents risk-seeking, $\lambda = 0.5$ represents risk-neutral, and $\lambda < 0.5$ represents risk-averse. In group decision-making, the risk attitude of each decision-maker is usually difficult to unify, and the compromise principle is usually selected, that is, $\lambda = 0.5$.

$$E(a_i) = \frac{(a_{iL} + 2a_{iM} + a_{iH})}{4}, \tag{5}$$

The above equation can also be obtained according to Yager's third fuzzy utility function[11].

3.2 Risk radar chart method for defect identification

In order to intuitively find out the weak links of the product assurance capability, give the improvement items and priorities, and then efficiently carry out process improvement according to the level characteristics given in Table 1, this paper uses a visual "radar chart" prediction method, which can analyze the evaluation points from the perspective of short board. It is helpful to expose the existing problems as early as possible in the process of project implementation, improve the credibility of the evaluation and help the organization to take timely improvement measures.

The importance and the evaluation value of each evaluation key point are synthesized to draw a "radar chart". The detailed steps are as follows: marking the importance and the evaluation value of each evaluation key point on a diagonal line corresponding to a regular polygon, wherein a dotted line represents the importance, and a solid line represents the evaluation value. For example, 5 evaluation elements are evaluated, and according to the evaluation results, the radar chart is shown in figure 4.

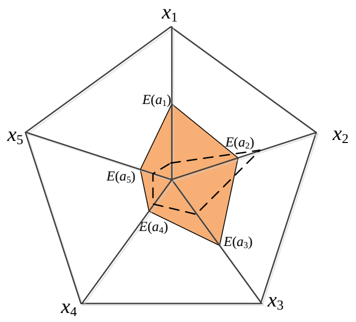

Figure 4. Example of a radar chart

Obviously, the evaluation elements with high importance and low evaluation value are weak links. In order to identify these weak links more intuitively, this paper proposes the drawing method of risk radar chart based on the risk perspective. The technical risk of the *i*th evaluation key point can be calculated by the following formula:

$$p_i = w_i \left(1 - E(a_i)\right), \tag{6}$$

The radar chart shown in Figure 4 is converted into a risk radar chart, and the result is shown in Figure 5. By comparison, it can be seen that the risk value of x_2 is the highest, and although the evaluation values of x_4 and x_5 are smaller, due to their low importance, the technical risk is not high, and their improvement priority should be after x_3.

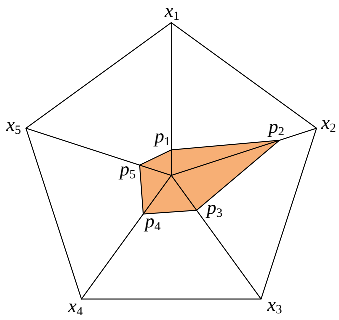

Figure 5. Risk radar chart

4 Case Study

Three experts were organized to identify the weak environment of product assurance engineering capability by taking a supplier of equipment basic parts as the application object. With four evaluation points as an example, based on the analytic hierarchy process, the importance of each evaluation point is [0.5, 0.2, 0, 0.3]. Since the importance of K_3 is zero, its evaluation value can be ignored. According to the evaluation results, the fuzzy evaluation matrix [a_1, a_2, a_4] is obtained as follows.

$$\tilde{A}_1 = \left[(0.5, 0.75, 1)\ (0.5, 0.75, 1)\ (0.75, 1, 1)\right]$$

$$\tilde{A}_2 = \left[(0.25, 0.5, 0.75)\ (0.5, 0.75, 1)\ (0.25, 0.5, 0.75)\right]$$

$$\tilde{A}_4 = \left[(0.5, 0.75, 1)\ (0.75, 1, 1)\ (0.25, 0.5, 0.75)\right]$$

Taking the expert prior weight $\omega_{sc} = 1/3$, based on formula 1, the expert posterior weight can be expressed as:

$$\omega_{dc}^1 = (0.5, 0.25, 0.333);$$

$$\omega_{dc}^2 = (0.375, 0.25, 0.333);$$

$$\omega_{dc}^3 = (0.125, 0.5, 0.333);$$

Let $\gamma = 0.33$, based on formula 2, the final expert weight is:

$$\omega^1 = (0.444, 0.278, 0.333);$$

$$\omega^2 = (0.361, 0.278, 0.333);$$

$$\omega^3 = (0.194, 0.444, 0.333);$$

Based on formula 3, the fuzzy comprehensive evaluation matrix is obtained as:

$$\tilde{A} = \left[(0.41, 0.66, 0.91)\ (0.61, 0.86, 1)\ (0.42, 0.66, 0.83)\right]$$

Select the risk-neutral type. Based on formula 5, the obtained comprehensive evaluation matrix is as follows:

$$E(\tilde{A}) = \left[0.66\ 0.83\ 0.65\right]$$

Draw a risk radar chart to identify weak links, as shown in Figure 6.

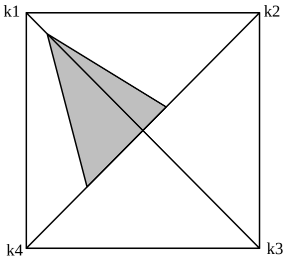

Figure 6. Risk radar chart analysis results

Therefore, the improved priority order is: K_1, K_4, K_2, K_3.

5 Conclusions

The supplier's product assurance capability reflects a company's capability to meet product assurance requirements. In this paper, the defect identification of product assurance capability of supplier is taken as the goal, and the evaluation index system of product assurance capability is established with the process as the core. In order to improve the scientificity of the evaluation results, the characteristics based on maturity level are refined. The quantitative method of expert weight coefficient based on compatibility analysis is put forward, and the drawing method of risk radar chart based on risk perspective is put forward, which lays a foundation for accurately identifying identifying product assurance capability defects and achieving continuous process improvement with goals and paths.

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