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Research on the Maturity Evaluation Model of Reliability Engineering Capability

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Reliability engineering capability mainly refers to a level of measurement in which product development enterprises integrate reliability engineering theory and technology into the entire life process of product development, production, and after-sales through a series of engineering practice activities, so as to form or achieve a certain level of reliability. It is closely related to the organizational structure, personnel literacy, management ability, and technical level of product development enterprises.
This study comprehensively evaluates the advantages and disadvantages of various aspects, and proposes an innovative Reliability Capability Maturity Model Integration (CMMI) maturity evaluation system for electronic product development enterprises, based on typical product development engineering practice experience. This system establishes a reliability engineering capability evaluation model based on the work required for the entire process of electronic product development. The evaluation is divided into four dimensions, namely organizational capability, management capability, technical capability, and support capability. Each dimension is divided into several sub dimensions, which subdivide the specific evaluation process, totaling 29 processes. Develop corresponding evaluation terms for each process to conduct evaluations. In this model, the maturity level of reliability engineering capability is divided into five levels, namely initial disorder level, basic execution level, comprehensive management level, quantitative management level, and excellence level. In the specific evaluation implementation, the corresponding process maturity level is first given based on the content of the evaluation terms, and then the domain level is calculated based on the weight coefficient of the process, finally obtaining the maturity level of each dimension and the overall reliability engineering capability of the enterprise.
On the basis of building an evaluation model, this study provides an application example of reliability engineering capability maturity evaluation. In engineering practice, self-evaluation can be carried out for evaluation items with low maturity, and targeted reliability improvement work can be carried out to achieve the overall improvement of enterprise reliability engineering capabilities.

Keywords: Reliability Engineering, Maturity , Evaluation Model.

1. Introduction

Reliability Engineering (RE) is an engineering technology that studies the struggle against faults throughout the entire life cycle of a product. It focuses on the functional performance of the product in the time dimension, and through methods such as design analysis, experimental research, on-site investigation, and fault maintenance, studies a series of technical and management activities to investigate the occurrence, development, prevention, and maintenance of faults until they are eliminated, in order to extend product life and improve usability. [1-3] Reliability engineering capability mainly refers to a level of measurement in which product development enterprises integrate reliability engineering theory and technology into the entire life process of product development, production, and after-sales through a series of engineering practice activities, so as to form or achieve a certain level of reliability. It is closely related to the organizational structure, personnel literacy, management capability, and technical level of product development enterprises.

There is currently a lack of mature evaluation models in the industry for the maturity of reliability engineering capabilities. This study analyzed the following models. 1) Crosby Quality Management Model. [4] This model was proposed by American quality management

master Philip B. Crosby in the 1970s, with "Zero Defects" as the core idea, emphasizing that quality is "conformance to requirements" rather than "perfection", quantifying quality loss with the "Price of Nonconformance" , and proposing a five stage maturity model, namely "Uncertainty", "Awakening", "Enlightenment", "Wisdom", and "Certainty". This model has a clear goal of "Zero Defects", emphasizes the prevention of quality, quantifies the economic losses caused by quality problems as costs, facilitates management decision-making, and emphasizes the driving force of quality concepts and culture in the enterprise. However, this model lacks specific implementation methods and tools for specific maturity evaluation, with overly single indicators and insufficient practicality. It is more suitable as an enlightenment framework for cultivating quality awareness. 2) Capability Maturity Model Integration (CMMI). CMMI is a process improvement framework developed by the Software Engineering Institute at Carnegie Mellon University, aimed at helping organizations enhance their capabilities in product development, service delivery, and project management. CMMI evaluates the standardization and efficiency of organizational processes by defining best practices and maturity levels, covering areas such as software development, hardware manufacturing, and service operations. The maturity levels of the model are defined as "Initial", "Managed", "Defined", "Quantitatively Managed" and "Optimizing." Organizations can gradually improve their process capabilities based on the target level. CMMI is a general process improvement framework that is currently widely used in the software industry. For the maturity evaluation of reliability engineering capabilities, an appropriate evaluation model can be developed based on its philosophy and framework. 3) IEEE Standard for Organizational Reliability Capability (IEEE Standard 1624-2008). [4] This standard is developed by the Institute of Electrical Electronics to provide a framework for organizations that design, manufacture, or procure electronic components or products to evaluate their organizational reliability capabilities. It defines organizational reliability capabilities and related concepts, provides a set of methods, tools, and guidelines for evaluating organizational reliability capabilities, and aims to help organizations evaluate and improve their procedures, practices, and activities to meet customer requirements for product reliability. But this standard mainly focuses on the factors that affect reliability at the organizational level, emphasizing the influence of "human", and is not comprehensive enough in the specific factors and practices that affect reliability.

This paper fully draws on the above model concepts and methods, focuses on the electronics industry, combines typical product development engineering practice experience, and conducts research on the Reliability Engineering Capability Maturity Model Integration (RE-CMMI) of electronic products based on the CMMI maturity evaluation framework.

2. Evaluation System

2.1. *Maturity level*

This paper refers to the CMMI maturity level classification and combines the characteristics of the electronics industry to describe the features of reliability engineering capabilities based on five levels, in order to better integrate each evaluation indicator for evaluation. The main features of each level are described as follows.

1) Level 1, initial disorder level

The characteristic of Level 1 is "one matter, one discussion". There is no formal organizational guarantee for product reliability in enterprises, only random activities are carried out, and there is no stable management mechanism. Enterprises lack reliable professionals and relevant plans, lack necessary resources, and always adopt a "fire extinguishing" approach to address problems, resulting in a lack of systematic growth for both the organization and individuals.

2) Level 2, Basic Execution Level

The characteristic of Level 2 is ″copying blindly″. The enterprise has established a basic management system to meet the explicit requirements of the industry, standards, and customers, and only engages in simple reliability related activities. Reliability has not been identified as a strategic priority, and passive improvements have been carried out for major issues. The enterprise has the ability to solve basic problems and follows industry conventions in the process, but lacks effective collaboration.

Enterprises may have a small number of reliability professionals, but the overall personnel lack comprehensive and in-depth understanding of reliability knowledge and skills, and lack awareness and atmosphere for proactive improvement. Enterprises have basic and necessary related resources.

3) Level 3, Comprehensive Management Level

The characteristic of Level 3 is "overall planning and consideration". Reliability has been identified as a strategic priority for enterprises, and a systematic reliability management mechanism has been actively established to systematically control risks. The relevant technical and management personnel have mastered the reliability knowledge and skills required for their work, and have a professional reliability technology team. Reliability work is effectively integrated into design, manufacturing, after-sales and other activities, with a relatively complete technical guidance document system, proactive awareness and planned continuous improvement, effective problem closure and formation of knowledge and ability. Enterprises proactively plan and allocate resources related to reliability, possessing internal and external resources for conducting reliability activities.

4) Level 4, Quantitative Management Level

The characteristic of level 4 is "refinement and quantification". The enterprise has established a management mechanism that adapts to quantitative requirements. The personnel system comprehensively masters reliability knowledge and skills, possesses quantitative reliability design, analysis, and evaluation capabilities, forms an innovative mechanism and atmosphere for sustainable improvement, forms a relatively excellent team of reliability talents, optimizes resource allocation, and is fully utilized.

5) Level 5, Excellent Level

The characteristic of Level 5 is "forward-looking and leading". Enterprises can quickly predict and adapt to changes in the environment, proactively self optimize, lead industry development with reliability strategies and technological levels, continuously apply new technologies and develop new methods, and have forward-looking resource allocation and application.

2.2. *Indicator Architecture*

Reliability Engineering is an engineering technology that studies the struggle against failures throughout the entire life cycle of a product. [6-7] The reliability engineering capability of an enterprise refers to its ability to timely solve and prevent faults. The ability to fight against faults can be evaluated from four dimensions: organization, management, technology, and support.

2.2.1. *Organizational capability*

Organizational capability is mainly reflected in the enterprise's understanding of reliability work, and the evaluation of organizational behavior for fault resolution and prevention. Firstly, enterprises should carry out reliability related work planning, formulate strategic goals, and implement them. Secondly, enterprises should establish reliability related institutions, set up corresponding positions, have professional personnel to carry out reliability work, and develop corresponding systems to ensure the normalization of work. Therefore, in the dimension of organizational capability, four evaluation domains can be established, namely ① Strategic objectives, ② Organizational personnel, ③Standardization, system and process setting, ④ Training and assessment, to evaluate the organizational capability to respond to failures.

2.2.2. *Management capability*

The ability to solve faults, with organizational support, needs to be achieved through management. Management mainly includes the work plan arrangement and control of faults throughout the entire process of product audit, production, and after-sales in order to reduce the probability of faults. Therefore, in the dimension of management capability, four evaluation domains are established, namely ⑤ Planning management, ⑥Design process management and control, ⑦ Production process management and control, ⑧After-sales and problem handling.

2.2.3. *Technical capability*

Fighting against faults requires technical means and abilities to identify and solve them. Firstly, enterprises should have a clear understanding of

product positioning, application scenarios, and functional performance requirements, and be able to effectively translate them into product reliability requirements. In the design work carried out in response to requirements, it is necessary to be able to translate requirements into design in a reasonable manner, and timely identify and prevent the occurrence of faults in the design. In the trial production and evaluation of experiments, there should also be the ability to detect, analyze, and solve faults, and timely feedback to the design end for improvement, in order to avoid the continuous occurrence of faults. Based on the above analysis, three evaluation domains can be established in the dimension of technical capability, namely ⑨ requirement identification, ⑩design analysis, and ⑪Test and evaluation.

2.2.4. *Support capability*

To reduce the probability of failure and improve product reliability, enterprises need to have corresponding software and hardware capabilities to provide support. Equipment and tools are necessary conditions for carrying out reliability activities, and the construction and use of corresponding databases (including historical fault libraries, reliability design criteria libraries, related models and case libraries, etc.) are the guarantee for efficient and high-quality reliability work. The richness and high application value of data in the database also reflect the level of reliability engineering capability of the enterprise to a certain extent. Therefore, in the dimension of supporting capabilities, two evaluation domains are established, namely ⑫ Equipment and tool support, ⑬Database construction and use.

In summary, the maturity evaluation of enterprise reliability engineering capability can be divided into 4 dimensions and 13 domains based on the work required for the entire process of electronic product development, focusing on the engineering capability to fight against faults. For the implementation of reliability work, each domain can be divided into several processes, totaling 29 evaluation processes. Thus, a reliability engineering capability maturity evaluation index framework is formed. All the dimensions, domains, and processes, are shown in Table 3.

2.3. *Evaluation Clause Setting*

In each evaluation process, several evaluation clauses can be set to facilitate specific evaluations. Taking the reliability strategy objectives and planning items as an example, it includes three evaluation clauses. 1) Establish an indicator system based on reliability strategic objectives. 2) Determine the reliability objectives related to the product and conduct monitoring and management. 3) Management and improvement of reliability system indicators. Due to the length limitation of the paper, the evaluation clauses for each process will not be further described.

3. Maturity Level Assessment

The key to using this model for evaluation is to provide a level for each process, in order to obtain each domain, each dimension, and ultimately the overall maturity level. This study proposes the following implementation strategies for level assessment.

3.1. *Fuzzy judgment of process level*

In the evaluation, evaluators evaluate the process capability level of the enterprise based on the evaluation clauses of each process, referring to the maturity level characteristics. A 5-point scale (integer) is used to score each process, and the score corresponds to its level.

Taking the evaluation domain "Organizational Personnel" as an example, there are three evaluation processes under it, namely "organization setting", "position setting", and "staffing", and their fuzzy judgment vectors are X, Y, and Z, respectively. According to the scores given by the evaluators, the fuzzy judgment matrix for this domain can be expressed as:

$$R=\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}=\begin{bmatrix} x_1 & x_2 & x_3 & \dots \\ y_1 & y_2 & y_3 & \dots \\ z_1 & z_2 & z_3 & \dots \end{bmatrix} \quad (1)$$

3.2. *Fuzzy Judgment of Evaluation Domain Level*

When determining the capability level of the evaluation domain, it is first necessary to determine the weight values of each process. For the convenience of evaluation, a weight priority relationship is used to determine the importance of variable i compared to variable j. The value of

aij is an integer from 1 to 5, where 1 represents equal importance of two indicators and 5 represents particularly important i compared to j. This forms a priority relationship judgment matrix. Taking the "Organizational Personnel" domain as an example, form the importance priority relationship matrix table shown in Table 1.

Table 1. RAMS Styles in Microsoft Word RAMS Template

Organization Personnel	Organization Setting (W_1)	Position Setting (W_2)
Organization Setting (W_1)	a_{11}	a_{12}
Position Setting (W_2)	a_{21}	a_{22}
Staffing (W_3)	a_{31}	a_{32}

Calculate the product of the values in each row of Table 2, expressed as:

$$M_i = \prod_{j=1}^{3} a_{ij}, i = 1,2,3 \quad (2)$$

Calculate the 3rd root of Mi and normalize it,

$$W_i = \frac{\sqrt[3]{M_i}}{\sum_{j=1}^{3} \sqrt[3]{M_j}}, i = 1,2,3 \quad (3)$$

The calculated W1, W2, and W3 correspond to the weight values of "Organization Setting", "Position Settings", and "Staffing" under the "Organizational Personnel" domain, respectively.

After determining the weight values of each evaluation process, combined with the fuzzy judgment matrix of the domain, the fuzzy judgment vector of the domain can be obtained:

$$U = W \bullet R = [W_1, W_2, W_3] \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [m_1, m_2, m_3, m_4, m_5] \quad (4)$$

The fuzzy judgment vector obtained by calculation is rounded up to obtain the level, and using the maximum membership criterion, the reliability capability maturity level of the "organizational personnel" domain can be obtained.

Similarly, the maturity level of capabilities in other domains can be obtained.

3.3. *Dimension Level Assessment*

When rating a dimension, the "weakness principle" is adopted, where all domains are considered equally important and no longer distinguished by weight. The lowest level among all domains in that dimension determines its maturity level. When organizing improvement activities based on the evaluation results, priority can be given to improving weak areas in order to enhance reliability engineering capabilities.

3.4. *Enterprise Level Assessment*

When evaluating the overall level of an enterprise, the "weakness principle" is also adopted, and the dimension of the lowest level determines the overall level of the enterprise.

4. Application Examples

This study evaluates an electronic enterprise using the reliability engineering capability maturity model as an application example. Similar to other evaluation and certification activities, reliability engineering capability maturity assessment also includes stages such as evaluation preparation, on-site audit, result evaluation, result analysis, and improvement.

4.1 *Evaluation Preparation*

The evaluation team should send the evaluation related procedures, models, and survey questionnaires based on evaluation criteria to relevant personnel in advance, and fully publicize the purpose, procedures, methods, etc. of the evaluation activity, in order to prepare for the subsequent evaluation to fully and objectively understand the situation.

4.2 *On-site Audit*

On-site audit includes personnel interviews and document review. The personnel interview mainly aims to understand the institutional requirements, organizational methods, and implementation processes of relevant activities of the enterprise.

Document review is mainly aimed at reviewing the relevant documents, records, reports, and other witness materials involved in conducting reliability activities.

4.3 *Result evaluation*

4.3.1 *Determine weight values*

Taking the "Organizational Personnel" domain as an example, the process priority relationship matrix obtained from the evaluation team's investigation is shown in Table 2.

Table 2. Example Table of Process Priority Relationship Matrix

Organization Personnel	Organization Setting (W_1)	Position Setting (W_2)
Organization Setting (W_1)	*1*	*2*
Position Setting (W_2)	*1/2*	*1*
Staffing (W_3)	*1/4*	*2/3*

By calculating and normalizing using equation (3), the weight values for the processes of "Organization Setting", "Position Setting", and "Staffing" are 0.54, 0.31, and 0.15, respectively. Similarly, the weight values of processes contained in other domains can be calculated. The weight values of each process are shown in Table 3.

4.3.2 *Determine process level*

According to the evaluation criteria of the "Organizational Personnel" domain, the fuzzy judgment matrix obtained from on-site evaluation is as follows.

$$R=\begin{bmatrix}2 & 1 & 2 & 2 & 2\\ 1 & 2 & 1 & 2 & 1\\ 2 & 3 & 3 & 3 & 3\end{bmatrix} \quad (5)$$

The fuzzy judgment vector for the "organizational personnel" domain is calculated as follows:

$$U=\begin{bmatrix}1.69 & 1.61 & 1.84 & 2.15 & 1.84\end{bmatrix} \quad (6)$$

Round up:

$$\lceil U \rceil=\begin{bmatrix}2 & 2 & 2 & 3 & 2\end{bmatrix} \quad (7)$$

According to the maximum membership criterion, the reliability engineering capability maturity level of the "Organizational personnel" domain is level 2.

By following the above process, the level of other domains can be calculated.

4.3.3 *Determine dimensions and enterprise level*

According to the "short board principle", determine the levels of each dimension in sequence and ultimately determine the maturity level of the enterprise.

According to the above process, the enterprise's evaluation results based on the model are detailed in Table 3.

4.4 *Result Analysis and Improvement*

According to the results in Table 4, the maturity level of the reliability engineering capability of the enterprise is level 2. The levels of "technical capability" and "support capability" are 3, but the organizational and management capabilities are relatively weak, indicating that the enterprise has strong capabilities in reliability engineering technology. However, the management is still weak in reliability awareness and related actions. If the enterprise needs to improve its reliability engineering capabilities, it should mainly focus on organizational and management aspects. Specific improvement directions can be analyzed in depth for lower level domains, and improvement measures can be formulated to enhance the overall reliability engineering capability of the enterprise.

Table 3. Evaluation Example of Enterprise Reliability Engineering Capability Maturity

Dimension	Capability level	Domain	Capability level	Process	Weight value	Evaluate Results
Organizational Capability	2	Strategic objectives	2	Formulation and implementation of strategic objectives	1	Record the evaluation results of each evaluator.
		Organization personnel	2	Organization setting	0.54	
				Position setting	0.31	
				Staffing	0.15	
		Specification, system and process setting	3	System and process settings	0.67	
				Operation specification	0.33	
		Training and assessment	2	personnel training	0.5	
				Department and personnel assessment	0.5	
Management Capability	2	Plan management	2	Work planning	0.56	
				Work breakdown structure	0.22	
				Task plan	0.22	
		Design process management and control	2	Work inspection	0.41	
				Milestone review	0.32	
				Supplier management	0.27	
		Production process management and control	2	Key process control	0.62	
				Nonconforming products control	0.38	
		After sales and problem handling	2	Information collection and management	0.5	
				Problem closed loop control	0.5	
Technical Capability	3	Requirements Identification	3	Requirement analysis	0.65	
				Requirement decomposition	0.23	
				Requirement change and control	0.12	
		Design analysis	3	Design analysis activities	1	
		Test and evaluation	3	Test and verification plan	0.25	
				Test and verification activities	0.25	
				Result evaluation	0.25	
				Fault analysis and improvement	0.25	
Support Capability	3	Equipment and tool support	3	Equipment capacity and status	0.75	
				Use of auxiliary tools	0.25	
		Database construction and use	3	Database construction and use capacity	1	

5. Conclusion

This study refers to the CMMI model and establishes a reliability engineering capability maturity evaluation model system. The evaluation is conducted from four dimensions: organizational capability, management capability, technical capability, and support capability, covering all elements of reliability organizational management and the entire product development process. In terms of grading, based on the characteristics of the electronics industry, typical feature descriptions for each grade are provided, which facilitates evaluators to provide more objective and accurate grading for each evaluation item. Regarding the use of the model, the study also provided grading methods at different levels. Finally, based on a case study of an electronic enterprise evaluation, the evaluation process, evaluation results, and their application were demonstrated. In engineering practice, enterprises can apply this model to conduct self-evaluation or third-party evaluation. For projects with lower maturity levels, targeted reliability improvement work can be carried out to achieve the overall improvement of the enterprise's reliability engineering capabilities. Enterprises can also apply this model to conduct supplier selection and management, ensuring that the supplier's capability level meets the requirements of the enterprise, and growing together with the supplier in reliability engineering capabilities, thereby achieving the improvement of reliability engineering capabilities in the electronics industry chain.

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