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The Reliability Evaluation Method of Software and Hardware Integrated Systems Based on Belief Reliability

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Abstract. Existing software and hardware integrated systems reliability evaluation methods ignore the problem of different failure mechanisms of hardware and software; thus, there are some limitations. In view of the above problems, this paper firstly studies time/state-based failure. Moreover, for the problem of reliability measurement in the presence of epistemic uncertainty, a calculation method of epistemic uncertainty factor of software and hardware integrated systems based on failure mode and effect analysis application effect and software and hardware comprehensive reliability test application effect is proposed. Furthermore, a belief reliability evaluation method with comprehensive consideration of design margin, aleatory uncertainty and epistemic uncertainty is presented. Finally, the proposed method is demonstrated and verified through application case. The results show that the existence of epistemic uncertainty will reduce people's trust in "system reliability".

Keywords: software and hardware integrated systems, belief reliability, failure mode and effect analysis, epistemic uncertainty

1. Introduction

A system based on microelectronics technology and embedded software that implements information sharing, system integration, and intelligent control is called a software and hardware integrated systems (S/HIS). Examples include embedded systems for automotive and avionics applications, telecommunications, wireless ad hoc systems, business applications with an emphasis on web services, etc [1]. However, since the interaction between hardware and software in this type of system [2, 3], to accurately evaluate its reliability, a systematic evaluation method must be established from the perspective of software and hardware integration.

The initial research on the reliability evaluation of S/HIS mainly focused on evaluating the reliability of software and hardware separately. The main task of this was to combine and match various models [4-7]. However, this method did not solve the problem of different hardware and software failure mechanisms. The traditional reliability theory based on probability statistics did not pay attention to the deterministic causes of the system failure; instead, it used statistical methods to analyze the overall reliability level of system. Yet, the limitations of traditional reliability theory of ex post facto feedback had become increasingly prominent. In this case, a reliability theory based on Physics-of-Failure (PoF) has emerged [8], using failure mechanism models to describe the deterministic laws of failures, and using the variability of model parameters to characterize the effects of uncertain factors. However, the variability of model parameters described only aleatory uncertainty (AU). It did not consider the uncertainty of the accuracy of failure mechanism and the selected model, which is affected by the cognitive state of analyst. Obviously, it is necessary to fully consider epistemic uncertainty (EU) to obtain the accurate reliability evaluation results of a S/HIS. In 1990, Apostolakis G, wrote in Science that in addition to the uncertainty of model parameters, there is also

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uncertainty in the model itself caused by incomplete knowledge of the modeler [9], i.e., the EU. In contrast, the uncertainty inherent in the objective world is called AU [10, 11]. Actually, the failure law of system is affected by deterministic causes, AU and EU. Based on this understanding, literature [12] proposed a reliability measure index called belief reliability (BR) that considers the effects of design margin (DM), AU, and EU. Literature [13] further gave the calculation method of the BR and the influence of EU on system reliability quantitatively expressed by the parameter "EU factor". In engineering, a large part of reliability-related engineering activities is aimed at reducing the impact of EU, e.g., performing failure mode and effect analysis (FMEA) [14]. For S/HIS, if not only the effect of hardware failures is considered in the FMEA process, but also the effect of software and hardware comprehensive failures can be fully considered, which can further reduce the EU. Besides, an important type of failure in S/HIS, the time/state-based (TS-based) failure [15], has increasingly become an important factor that plagues developers and users and greatly affects the reliability level of S/HIS. The direct cause of this type of failure is generally unforeseen changes in operating conditions or environmental conditions associated with S/HIS. Therefore, the development of software and hardware comprehensive reliability test (S/HCRT) for such failure will also affect the EU of the system. In summary, the value of the EU factor can be determined based on the results of the above two types of activities.

This paper firstly studied the mechanism of TS-based failure, and presented two kinds of failure mechanism models. Secondly, based on the method proposed in [12, 13, 16], by adding the content related to the TS-based failure during the implementation of FMEA which can determine the first type of EU factor, the EU factor related to the FMEA of the S/HIS can be obtained. Thirdly, based on the second type of EU factor determination method, i.e., S/HCRT, the EU factor related to the S/HCRT can be obtained. These two types of EU factors are further integrated. Finally, considering the DM of the performance parameters of the S/HIS and the influence of the AU factor, the BR of the S/HIS is given.

2. The TS-based Failure of S/HIS

Definition In some cases, unpredictable operations and stresses with physical, chemical or other characteristics act on the hardware part of system directly, further directly or indirectly cause abnormal software operation, and then react to components or systems, which then causes the system behavior to be inconsistent with expectations. The occurrence of a failure has corresponding consequences and can be corrected by some means.

From the above definition, it can be known that the root cause of the TS-based failure is generally the unpredictable changes in operating conditions or environmental conditions, e.g., the SEFI of the single event effect, i.e., the digital logic components lose their original functions under the bombardment of a single charged particle. When a single heavy ion hits an integrated circuit chip, the deposited local dose can damage the silicon region of a channel length range of a MOS tube, resulting in a fixed electrical state. When the running software program reads the above-mentioned fixed-bit values, these values can no longer be read out correctly, leading to catastrophic consequences. Fig. 1 shows the life cycle of the TS-based failure.

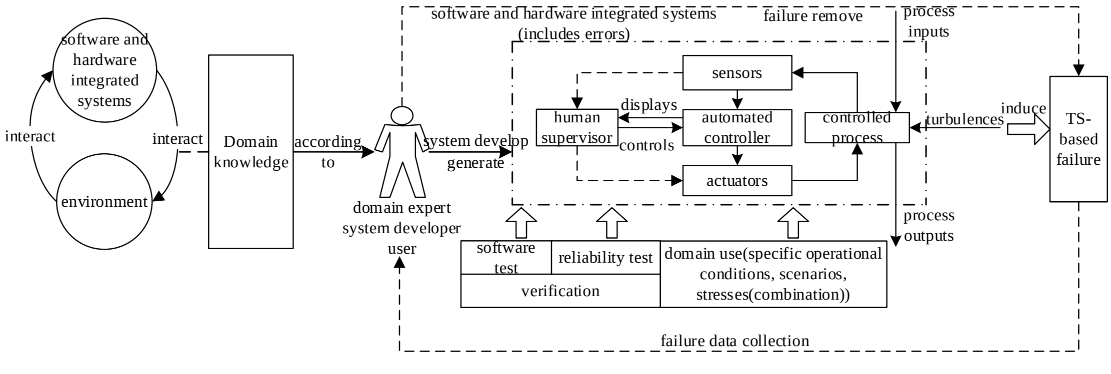

Fig. 1: The life cycle of the TS-based failure

As can be seen from Fig. 1, the failure mechanism of the TS-based failure is very different from the simple hardware or software failure mechanism. The hardware failure is usually triggered by certain stress type and stress level over time; the software failure is usually caused by certain operating conditions, depending on whether the code containing the software error is run, thus it is space-based and theoretically independent of time. However, the TS-based failure is related to both time and space.

Nowadays, almost all failure mechanism analysis of engineering systems is based on the causal chain or tree model of failure events, which can only describe the direct and linear relationship between events. It is therefore impossible to characterize the TS-based failures caused by environmental disturbances that occur over time. To overcome the deficiency, it is necessary to use the model which is based on cybernetics and can describe indirect, non-linear relationships and state transitions. And it can characterize the TS-based failures caused by environmental disturbances that occur over time.

3. The Definition of BR

The BR is a kind of reliability metric suitable for describing the failure laws of systems under the combination of aleatory and EU. It is defined as [13],

$$R_B = \Phi(M_d/(U_a + U_e)) \tag{1}$$

$$\Phi(x) = (1/\sqrt{2\pi}) \int_{-\infty}^{x} \exp(-t^2/2)\, dt \tag{2}$$

where, M_d is the DM (the average of system performance margin distribution), $-\infty < M_d < +\infty$. It is a representation of the deterministic cause of failure. U_a represents the AU which is used to characterize the impact of AU on system reliability. $U_a \geqslant 0$. Generally, the U_a is measured by the standard deviation of the performance margin distribution. U_e represents the EU, which is used to characterize the impact of EU on system reliability. $U_e \geqslant 0$. The U_e can be determined by evaluating the application effects of engineering activities related to the EU. To facilitate the calculation, the AU and EU of the performance margin are
usually normalized, and the AU factor α_a and EU factor α_e are defined as,

$$\alpha_a = U_a/|M_d| \geq 0 \tag{3}$$

$$\alpha_e = U_e/|M_d| \geq 0 \tag{4}$$

then the BR can be calculated according to the following equation,

$$R = \begin{cases} \Phi(1/(\alpha_a + \alpha_e)), M_d \geq 0 \\ 1 - \Phi(1/(\alpha_a + \alpha_e)), M_d < 0 \end{cases} \tag{5}$$

4. The Determining of EU Factor Of S/HIS

4.1 The Evaluation Method of FMEA Application Effect

The variable E is defined to characterize the application effect of FMEA. Regulation: The larger the E, the better the application effect of FMEA. The main factors affecting E are divided into the following four aspects [16], the degree of failure mode cognition, cause cognition, effect cognition, and the effectiveness of improvement measures. Evaluation criteria are established for each aspect to evaluate the influence of these factors on E, as shown in Tab. 1. E_1~E_4 in Tab. 1 respectively reflects the above four aspects, and $E_i \in [0, 1], i = 1, 2, 3, 4$, Regulation: The closer the E_i is to 1, the better the completion of this aspect is.

Table.1: The evaluation criteria of the FMEA application effect of S/HIS

Effect factor	Evaluation criteria		Scoring criteria	
	Evaluation point	Evaluation requirement		
the degree of failure mode cognition E_1	the quality of failure criterion definition E_{11}	E_{111} the definition of failure criteria is clear	can very clearly determine whether the system has failed according to the failure criteria	$E_{111}=3$
			can clearly determine whether the system has failed according to the failure criteria	$E_{111}=1$
			cannot clearly determine whether the system has failed according to the failure criteria	$E_{111}=0$
		E_{112} the definition of failure criteria is complete	failure criteria can support a very comprehensive analysis of failure modes, considering the hardware and software factors	$E_{112}=3$
			failure criteria can support a comprehensive analysis of	$E_{112}=1$

			failure modes, considering the traditional hardware factor only	
			failure criteria cannot support comprehensive analysis of failure modes	E_{112}=0
	the completeness of failure mode analysis E_{12}	E_{121} the failure mode analysis should consider all functions that the system needs to complete	expert review confirms functional coverage is complete	E_{121}=3
			expert review finds that some non-critical functions are missing	E_{121}=1
			expert review finds that a large number of critical functions are missing	E_{121}=0
		E_{122} the failure mode analysis should cover the various use and environmental conditions that the system may experience	expert review confirms that the coverage of use and environmental conditions is complete. The meaning of “completeness” here includes not only the traditional use and environmental conditions, but also the operating conditions and use environments corresponding to the TS-based failure, i.e., the software factor needs to be considered	E_{122}=3
			expert review confirms the coverage of traditional use and environmental conditions related to failure is complete, yet the operational and environmental conditions of TS-based failure not considered, i.e., the software factor not considered	E_{122}=1
			expert review confirms the traditional use and environmental conditions related to failure is partly considered, yet the operational and environmental conditions of TS-based failure not considered, i.e., the software factor not considered	E_{122}=0.6
			expert review confirms that a large number of traditional use and environmental conditions related to failure not considered, and the operational and environmental conditions corresponding to TS-based failure not considered	E_{122}=0
		E_{123} the failure mode should include complete loss of function and degraded function	the loss of function and degraded function are both considered	E_{123}=3
			only one type of failure mode is analyzed	E_{123}=1
			neither type of failure mode is analyzed	E_{123}=0
	the trust degree of failure mode source E_{13}	E_{131} the failure modes considered in the analysis should have a trusted source	the failure mode is derived from the historical data of this system or similar system	E_{131}=3
			the failure mode is derived from authoritative literature, standards, manuals	E_{131}=1
			the failure mode is derived from experts’ experiences	E_{131}=0
the degree of failure cause cognition E_2	the completeness of failure cause analysis E_{21}	E_{211} the failure causes considered in the analysis should cover all possible situations	expert review confirms the cause coverage is complete and comprehensively considers the hardware and software factors	E_{211}=3
			expert review confirms the comprehensive coverage of hardware failure causes; yet, failure causes corresponding to the failure mechanism model of the S/HIS not considered	E_{211}=1
			expert review confirms that some non-critical hardware failure causes are missing, and the failure causes corresponding to the S/HIS failure mechanism model not considered	E_{211}=0.6
			expert review confirms that a large number of critical failure causes are missing	E_{211}=0
	the completeness of	E_{221} the failure transitivity analysis should	The horizontal and vertical transitivities are fully analyzed. The vertical transitivity refers to the effect of failures on the previous level; the horizontal	E_{221}=3

	transitivity analysis E_{22}	include vertical and horizontal transitivity analysis	transitivity refers to the failure transitivity between products at the same level	
			Considering vertical transitivity only	$E_{221}=1$
			No transitivity analysis is conducted	$E_{221}=0$
the degree of failure effect cognition E_3	the completeness of failure effect analysis E_{31}	E_{311} failure effect analysis should cover local effect, previous level effect and final effect	expert review confirms that failure effect analysis is complete	$E_{311}=3$
			expert review confirms that some of failure effect is missing	$E_{311}=1$
			expert review confirms that a large number of failure effect is missing	$E_{311}=0$
	E_{32} the accuracy of criticality analysis	E_{321} the data source of criticality analysis should be reasonable and credible	derived from actual data	$E_{321}=3$
			derived from authoritative literature or standards, manuals	$E_{321}=1$
			derived from experts' experiences	$E_{321}=0$
		E_{322} the method of criticality analysis should be reasonable	adopt the improved criticality analysis methods	$E_{322}=3$
			adopt the traditional criticality analysis method, i.e., RPN	$E_{322}=0$
the effectiveness of improvement measures E_4	E_{41} the extent to which the failure mode has been eliminated	E_{411} the improvement measures can eliminate the failure modes analyzed or reduce the probability of happening without introducing new failures	After expert review, all the analyzed failure modes have been improved, including hardware failure modes and software and hardware comprehensive failure modes	$E_{411}=3$
			After expert review, all the hardware failure modes have been improved, but the software and hardware comprehensive failure modes have not been improved	$E_{411}=1$
			After expert review, some hardware failure modes have been improved, but software and hardware comprehensive failure modes have not been improved	$E_{411}=0.6$
			After expert review, a large number of hardware failure modes and software and hardware comprehensive failure modes have not been improved	$E_{411}=0$
	E_{42} the extent to which the failure cause has been eliminated	E_{421} the improvement measures can eliminate the failure causes analyzed or reduce the probability of happening without introducing new failures	After expert review, all the analyzed failure causes have been improved, including hardware failure causes and software and hardware comprehensive failure causes	$E_{421}=3$
			After expert review, all the hardware failure causes have been improved, but the software and hardware comprehensive failure causes have not been improved	$E_{421}=1$
			After expert review, some hardware failure causes have been improved, but software and hardware comprehensive failure causes have not been improved	$E_{421}=0.6$
			After expert review, a large number of hardware failure causes and software and hardware comprehensive failure causes have not been improved	$E_{421}=0$
	E_{43} the extent to which the failure effect has been reduced	E_{431} the improvement measures can eliminate the failure effects analyzed or reduce the probability of happening without introducing new failures	After expert review, all the analyzed failure effects have been improved, including hardware failure effects and software and hardware comprehensive failure effects	$E_{431}=3$
			After expert review, all the hardware failure effects have been improved, but the software and hardware comprehensive failure effects have not been improved	$E_{431}=1$
			After expert review, some hardware failure effects have been improved, but software and hardware comprehensive failure effects have not been improved	$E_{431}=0.6$
			After expert review, a large number of hardware failure effects and software and hardware comprehensive failure effects have not been improved	$E_{431}=0$

Using the evaluation criteria established in Tab. 1, E_1~E_4 can be evaluated, and then the evaluation of the FMEA application effect can be completed. The specific method is as follows, Firstly, according to the evaluation criteria given in Tab. 1, the degree of failure mode cognition, cause cognition, effect cognition and the effectiveness of improvement measures of FMEA are evaluated to determine the values of E_1~E_4. In Tab. 1, several evaluation points are given for each effect factor; moreover, corresponding evaluation requirements are given for each evaluation point. To facilitate the expert to make judgments, the scoring items are refined according to the evaluation requirements. For each item (the k^{th} evaluation requirement of the j^{th} evaluation point of the i^{th} effect factor), E_{ijk}, the experts give a score of 3, 1, 0.6, or 0 according to the degree of compliance between the evaluation object and requirements. After collecting the expert scoring results, determine the values of E_1 ~E_4 through equations (6) and (7),

$$E_{ij} = (1/n_k)\sum_{k=1}^{n_k}(E_{ijk}/3) \tag{6}$$

$$E_i = (1/n_j)\sum_{j=1}^{n_j}E_{ij} \tag{7}$$

where, n_k is the number of evaluation requirements included in the j^{th} evaluation point of the i^{th} effect factor; n_j is the number of evaluation points included in the i^{th} effect factor.

Secondly, the value of E is finally determined by considering the comprehensive effect of the degree of failure mode cognition, cause cognition, effect cognition, and the effectiveness of the improvement measures.

Equation (8) is used to characterize the comprehensive effect of E_1~E_4 on E. The value of E can be determined to complete the evaluation of the effect of FMEA through equation (8),

$$E = E_4 \cdot \sum_{i=1}^{3}(\omega_i \cdot E_i) \tag{8}$$

where, ω_i represents the weight occupied by E_i. It is obviously that, $0 \le \omega_i \le 1$ and $\sum_{i=1}^{3}\omega_i = 1$. Here, assume that the contributions of the degree of failure mode cognition, the degree of failure cause cognition, and the degree of failure effect cognition are the same. Thus, $\omega_1 = \omega_2 = \omega_3 = 1/3$. It can also be seen that when E_4=0, then, E=0, i.e., if only FMEA is carried out without corresponding design improvement, such work is not meaningful for improving the reliability of system.

4.2 The Evaluation Method of S/HCRT Application Effect

The TS-based failure is both time and space dependent, resulting from the dual effects of stress and operation. Thus, it is necessary to adopt the mode of "reliability test + software test" [15] for S/HCRT. This paper chooses reliability demonstration test (RDT) as the test type, which is generally performed on a higher-level system to fully evaluate the condition of interface and improve the authenticity of test. The timing of this type of test also meets the prerequisites for detecting the TS-based failures.

The test process needs to select some failure types from the existing TS-based failure type set to constitute the set for test verification. This paper selects temperature failure, vibration failure and electricity failure. Moreover, the instances corresponding to the failure types in the set are given. And the stress levels of various types of stresses corresponding to the failure instances are given. The evaluation indexes of S/HCRT in this paper include the quality of test mode, test implementation, and test results. The evaluation process is shown in Fig. 2. The quality measurement level can be obtained and the specific process refers to the next section. Here, T is defined to characterize the application effect of the S/HCRT. Regulation: The larger T, the better the application effect, and $T \in [0,1]$. The corresponding relationship between the test quality level and test application effect (EU factor value) is, Excellent-0.9; Good-0.8; Average-0.6; Poor-0.1.

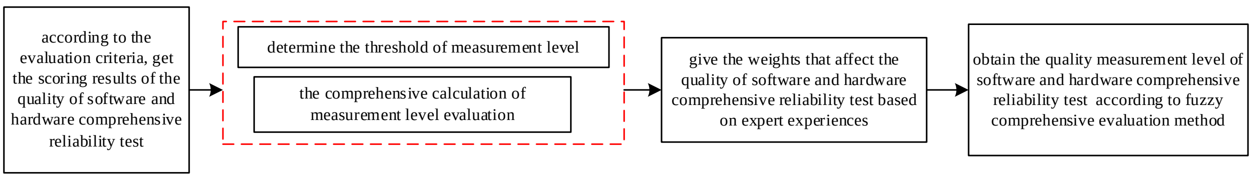

Fig. 2: The quality evaluation process of S/HCRT

4.3 The Calculation of Eu Factor

This paper considers the following factors that affect the EU, the EU related to the FMEA, and the EU related to the S/HCRT. Thus, the α_e is determined by the E and T. From the literature [13], $\alpha_e \in [0,+\infty)$, $\alpha_e = 0$, $\alpha_e = +\infty$ represents the state of minimum and maximum EU, respectively. In this paper, the relationship between the α_e and E and T is described as,

$$\alpha_e = d/(\beta * E + \gamma * T)^2 \tag{9}$$

where, d is a proportional constant, usually d = 0.5 [16]. β and γ are two proportionality coefficients, deriving from experience. Take 0.65 and 0.35 respectively.

5. Application case

In this section, the subsystem of a S/HIS is selected as the experimental object for application case. The subsystem contains temperature sensors and related software. The simulation modeling of the experimental object yields a DM M_{design} = 0.0254 and an AU factor α_a=0.4538 according to the method proposed in [16]. The calculation process of the EU factor is given below, and the system BR value is further given.

5.1 Determine the EU factor

1) The calculation of the EU factor related to FMEA

Three experts were invited to evaluate the FMEA application effect of the system based on the system's FMEA report according to the evaluation criteria in Tab. 1. Substituting the evaluation results into equation (8), the evaluation results are shown in Tab. 2.

Table. 2 The application effect evaluation of a system

Effect factor	Expert A	Expert B	Expert C
the degree of failure mode cognition	0.7	0.8	0.7
the degree of failure cause cognition	0.8	0.8	0.7
the degree of failure effect cognition	0.7	0.7	0.6
the effectiveness of improvement measures	0.9	0.8	0.9
scoring results	0.66	0.61	0.60

The average value of results of the three experts was used as the final score, $E = (E_A + E_B + E_C)/3 = 0.62$.

2) The calculation of the EU factor related to S/HCRT

Set the value range of each level, poor(0.0,0.8), average(0.8,0.9), good(0.9,0.95), excellent(0.95,1.0). Acquire that, C_1=0.4, C_2=0.85, C_3=0.925, C_4=0.975. Substituting them into the equation,

$$A_1(r) = \begin{cases} 1 & v_1 = 0 \le r \le v_2 = 0.8 \\ (r - c_2)/(v_2 - c_2) = (0.85 - r)/0.05 & 0.8 < r < 0.85 \\ 0 & \text{other} \end{cases} \quad A_2(r) = \begin{cases} 1 & v_2 = 0.8 \le r \le v_3 = 0.9 \\ (r - c_1)/(v_2 - c_1) = (r - 0.4)/0.4 & c_1 = 0.4 < r < v_2 = 0.8 \\ (r - c_3)/(v_3 - c_3) = (0.925 - r)/0.025 & v_3 = 0.9 < r < c_3 = 0.925 \\ 0 & \text{other} \end{cases}$$

$$A_3(r) = \begin{cases} 1 & v_3 = 0.9 \le r \le v_4 = 0.95 \\ (r - c_2)/(v_3 - c_2) = (r - 0.85)/0.05 & c_2 = 0.85 < r < v_3 = 0.9 \\ (r - c_4)/(v_4 - c_4) = (0.975 - r)/0.025 & v_4 = 0.95 < r < c_4 = 0.975 \\ 0 & \text{other} \end{cases} \quad A_4(r) = \begin{cases} 1 & v_4 = 0.95 \le r \le v_5 = 1.0 \\ (r - c_3)/(v_4 - c_3) = (r - 0.925)/0.025 & c_3 = 0.925 < r < v_4 = 0.95 \\ 0 & \text{other} \end{cases}$$

Assume that there are M experts, and the K^{th} expert's qualitative score of its level according to the calculated value of the measurement u_i is recorded as r (i, k). A total of M scoring results is obtained, and the algebraic average value could be used as the comprehensive evaluation value for measuring the u_i level, and recorded as, $R(i) = (1/M)\sum r(i,k)$. Substituting R(i) into the above membership function, the fuzzy comprehensive evaluation results of each metric are obtained. After normalizing the above results, an evaluation matrix is constructed. Three experts were invited to evaluate the application effect of the S/HCRT from the aspects of quality of test mode, test implementation, and test result. The results are shown in Tab. 3.

Table. 3 The application effect evaluation of the S/HCRT

Measurement index	test mode quality	test implementation quality	test result quality
Expert 1	0.8	0.8	0.9
Expert 2	0.8	0.7	0.8
Expert 3	0.9	0.9	0.9

It shows that R_1=0.83, R_2=0.80, R_3=0.87; thus, the degrees of membership of the above application effect level are, R_1: $A_1(r)$=0.4, $A_2(r)$=1, $A_3(r)$=0, $A_4(r)$=0; R_2: $A_1(r)$=1, $A_2(r)$=1, $A_3(r)$=0, $A_4(r)$=0; R_3: $A_1(r)$=0, $A_2(r)$=1, $A_3(r)$=0.4, $A_4(r)$=0, i.e., $U_1|\rightarrow$(0.4,1,0,0), $U_2|\rightarrow$(1,1,0,0), $U_3|\rightarrow$(0,1,0.4,0). After normalization, $U_1|\rightarrow$(0.2857,0.7143,0,0), $U_2|\rightarrow$(0.5,0.5,0,0), $U_3|\rightarrow$(0,0.7143,0.2857,0). The evaluation matrix is as follows,

$$R = \begin{bmatrix} 0.2857 & 0.7143 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0.7143 & 0.2857 & 0 \end{bmatrix}$$

Assume that the three application effect level weights are all 1/3, then, the quality measurement level is obtained according to the equation in the fuzzy comprehensive evaluation method.

$$RU(i) = W \circ R = \{w_{i1}, w_{i2}, \cdots, w_{in}\} \circ \begin{bmatrix} r'_{11} & r'_{12} & r'_{13} & r'_{14} \\ r'_{21} & r'_{22} & r'_{23} & r'_{24} \\ \vdots & \vdots & \vdots & \vdots \\ r'_{n1} & r'_{n2} & r'_{n3} & r'_{n4} \end{bmatrix} = \{RU_i^{\ 1}, RU_i^{\ 2}, RU_i^{\ 3}, RU_i^4\}$$

$$= [1/3 \quad 1/3 \quad 1/3] \begin{bmatrix} 0.2857 & 0.7143 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0.7143 & 0.2857 & 0 \end{bmatrix} = [0.2619 \quad 0.6429 \quad 0.0952 \quad 0]$$

The significance of RU is, the degree of membership of fuzzy comprehensive evaluation of the quality level of the S/HCRT at the “poor”, “average”, “good” and “excellent” level are 0.2619, 0.6429, 0.0952 and 0, respectively. According to the principle of maximum membership, the quality level of evaluation object is “average”. According to the corresponding relationship in Tab. 3, the corresponding EU factor value is 0.6.

3) The calculation of comprehensive EU factor

Substituting E = 0.62 and T = 0.6 into equation (9), $\alpha_e = d/(\beta * E + \gamma * T)^2 = 1.3306$.

5.2 The Calculation of System BR

Substituting M_{design}=0.0254>0, α_a=0.4538 and α_e=1.3306 into equation (1) and (2), the BR of the system can be obtained as follows, $R_B = \Phi(1/(\alpha_a + \alpha_e)) = 0.7124$. If the influence of EU is not considered, i.e., $\alpha_e = 0$, the reliability of the system is, $R = \Phi(1/\alpha_a) = \Phi(1/0.4538) = 0.9862$. Comparing the calculation results, the BR considering the influence of EU is significantly lower than the BR not considering the influence of EU. The reason for this difference is, the effects of the system’s FMEA and S/HCRT need to be further improved; therefore, the influence of EU on the system is significant. In all, in the design process of system, on one hand, it is necessary to control the influence of AU; and on the other hand, it is necessary to further improve the reliability work of FMEA, S/HCRT, etc. to continuously reduce the EU and improve system reliability.

6. Conclusion

The system reliability is determined by the DM, AU, and EU. Existing reliability measures ignore the impact of EU. This paper proposed a calculation method of EU factor of S/HIS based on FMEA application effect and S/HCRT application effect. Furthermore, a BR evaluation method with comprehensive consideration of the DM, AU and EU was presented. Finally, the proposed method was demonstrated and verified through application case. The results show that the existence of EU will reduce people’s trust in “system reliability”. Thus, in the system design process, the reliability design goal should be achieved by continuously reducing the EU and controlling the AU. The FMEA and S/HCRT are just two of the common reliability engineering activities that can reduce the EU. Subsequent research can also consider integrating other engineering activities that can reduce EU to further improve the method for determining the EU factor.

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