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Component Reliability Importance assessment on complex systems using Credible Improvement Potential

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A R T I C L E I N F O

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A B S T R A C T

Nowadays system reliability performance represents a key issue and being reliable becomes a fundamental requirement of products in many manufacturing fields. The paper is focused on the reliability improvement of fault tolerant complex systems using component Reliability Importance (RI) procedures in order to assess the impact of each component on the overall system reliability. This study is focused on RI assessment during design stage with the aim of optimizing engineers' efforts and focusing on components with the greatest effect on the whole system. The first part of the paper focuses on a particular Reliability Importance measure, the Credible Improvement Potential (CIP), which is the most suitable RI metric for our purpose. The Reliability Importance assessment on a dedicated case study based on fault tolerant complex system is then proposed and results are discussed in detail.

1. Introduction

Reliability is a fundamental requirement of a product, in particular in industrial fields where the number and variety of failures is exponentially growing together with newborn technologies, product complexity and miniaturization of components. This is the reason on the basis of which design engineers focus their attention on both functional performance and RAMS assessment (Reliability, Availability, Maintainability and Safety) in order to meet customer specifications. It is known that the correct approach to consider the RAMS assessment is in the design phase when the feedbacks should be available to modify the starting project and avoid preventable economic loss and time [1–3].

The paper is focused on reliability improvement of complex systems using one of the most trustworthy and efficient procedures, the Reliability Importance (RI). It can be considered as a measure of the impact each component has on the overall system reliability. Taking into account the RI assessment during design stage, engineers can optimize efforts to improve the system reliability focusing on the components that have the greatest effect on the whole system. In fact, thanks to these real-time feedbacks, designers are allowed to found the system advancement on Reliability Importance outcomes, compare different solutions, prove system robustness and reduce time for improvements.

The first steps to achieve RI parameters are represented by the analysis of the system and the reliability assessment that requires a deep knowledge of the system itself; one of the most used technique is Reliability Block Diagram (RBD), that is a top-down technique based on a functional diagram of all the components making up the system. A RBD shows how component reliability contributes to failure or success of the whole system with a one-to-one correspondence between components and each block that is described by a specific failure rate and its connections with the rest of the system.

Once the reliability of the system under analysis has been achieved, the designers can identify the least reliable component in the system in order to improve the whole system reliability. For systems characterized by series functional configuration the Reliability Importance of components is easily achievable because it is just function of the single failure rate. The least reliable component has the biggest effect on the system reliability and system reliability can be enhanced improving the reliability of that component first. This procedure become quite difficult in more complex systems where the importance of each component of the system depends on multiple factors such as location of the component in the system, reliability of the component under analysis and uncertainty in our estimate of the component reliability. Component approach is essential to quantify the contribution of each individual element to the overall system reliability performance.

There are many techniques to assess Reliability Importance parameters but in any case the RI outcomes are an important benefit for designer since they can identify the weakest components with the biggest impact on system performance in order to prioritize re-design actions to be taken (reliability improvement) or suggest the most effective way to operate and maintain system status.

The paper is organized as follows. Section 2 describes the assumptions of the RBD approach used to evaluate system reliability. The Reliability Importance measures are presented and discussed in Section 3. The test case focused on a fault tolerant complex system and its RI

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assessment are described in Sections 4 and 5, respectively. In Section 6, a discussion about the RI evaluation results is presented and, finally, the conclusion is given in Section 7.

2. RBD approach assumptions

The first step to achieve Reliability Importance evaluation is to reduce the whole system to a Reliability Block Diagram. This step is necessary to apply the mathematical methods proposed.

Referring to the international standard IEC 61078 [4], the assumptions to develop the RBD and to calculate the reliability parameters can be summarized as follows:

- System components have only two valid states: working ("up" state) or failed ("down" state); intermediate or partial working is not allowed. On the basis of this assumption, the system state can be considered as a discrete random variable.
- Failures are independent each other so the faulty condition of a component does not affect the probability of failure of any other item within the system. On the basis of this assumption, the probability of failure of the block A, $P(A)$ – for example – is not related (i.e. independent) with the probability of failure $P(B)$ of the block B, and vice versa.

$$P(A|B) = P(A); \quad P(B|A) = P(B) \tag{1}$$

- Sequential events are not taken into consideration and the system analysis stops when the first fault occurs. For this reason, this approach is not suitable for order-dependent or time-dependent modeling.
- System items are considered in "useful life" so failures can be considered random events and the failure/hazard rate λ_i is assumed as constant in the time, that is:

$$\lambda_i(t) = \lambda_i, \text{with i} = 1 \ldots n \tag{2}$$

being n the number of items of constituting the system.

- The probability density function of failure $f(t)$ is an exponential distribution. Considering the useful-life period and assuming random failures, $f(t)$ and reliability function $R(t)$ can be written as follows:

$$f(t) = -\frac{dR(t)}{dt} = \lambda e^{-\lambda t} \tag{3}$$

$$R(t) = \exp\left\{-\int_0^t \lambda(t)dt\right\} = e^{-\lambda t} \tag{4}$$

- Components are defined by the Mean Time To Failure (MTTF) as:

$$MTTF = \int_0^\infty t \cdot f(t)dt = \int_0^\infty R(t)dt \tag{5}$$

This definition is valid also for Mean Time Between Failures (MTBF) when referred to systems composed by two or more components.

These hypotheses are mandatory to achieve a reliability prediction and consequent importance measure; otherwise the proposed RBD approach would not be put in practice.

3. Reliability Importance measures

Many different Reliability Importance indices developed for different purposes are proposed in literature but most of them are specific methods for dedicated applications and they are not suitable for a generic complex system [5–10]. In this paper are described the two metrics that turned out to be the best Reliability Importance measures for our purpose after many test on different test cases. These methods are Improvement Potential (IP) and Credible Improvement Potential (CIP).

Improvement Potential index establish how much the system reliability would benefit from making one component completely reliable; in other words it assess the maximum potential in improving a specific component reliability [5]. IP measure is the difference between the system reliability with a perfect component i and the system reliability with the actual component, as follows:

$$I_i^{IP}(t) = R_s[t; R_i(t) = 1] - R_s(t) \tag{6}$$

where $I_i^{IP}(t)$ is the Improvement Potential index of component i at time t, $R_S(t)$ is system reliability at time t and $R_i(t)$ is reliability of component i at time t.

A weakness of this reliability index is that is not actually possible improving component reliability $R_i(t)$ to 100% so the supposed improvement is not physically achievable.

For this reason a new Reliability Importance measure was introduced, the Credible Improvement Potential metric.

CIP solves the issue described above improving $R_i(t)$ to a new value $R_i^+(t)$ that represents the reliability corresponding to the state of the art for this type of components [5,7,11–14]. CIP definition is shown below:

$$I_i^{CIP}(t) = R_s\left[t; R_i(t) = R_i^+(t)\right] - R_s(t) = \Delta R_s(t) \tag{7}$$

where $I_i^{CIP}(t)$ is Credible Improvement Potential index of component i at time t and $R_i^+(t)$ is the improved reliability of component i at time t.

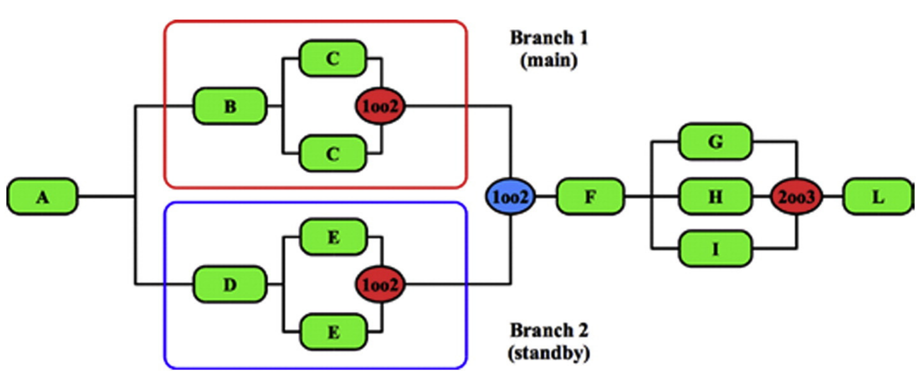

Fig. 1. Case study Reliability Block Diagram.

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