14th IMEKO TC10 Workshop Technical Diagnostics
New Perspectives in Measurements, Tools and Techniques
for system's reliability, maintainability and safety
Milan, Italy, June 27-28, 2016

Credible Improvement Potential index for Reliability Importance assessment

Marcantonio Catelani, Lorenzo Ciani, Matteo Venzi
Department of Information Engineering,
University of Florence,
via di S. Marta 3, 50139, Florence (Italy)
lorenzo.ciani@unifi.it

Abstract **– System reliability represents a key performance of modern products and nowadays being reliable is one of the most important requirements, in particular in the industrial field.**

This paper is focused on the reliability improvement of complex systems containing redundant architectures through Reliability Importance (RI): starting from the single component reliability, RI procedures are used to evaluate their impact on the whole system.

This practice is particularly helpful during the design stage of complex systems since it allows design engineers to have reliability feedbacks before the realization of the product in order to focus the efforts on the components that have the greatest effect on the whole reliability performance.

The paper is organized as follows: the first section describes the Credible Improvement Potential (CIP) that is the most suitable RI metric for our purpose. The second section, instead, shows the application of the method on a generic complex system containing standby redundant blocks.

Keywords **– Reliability Importance, Credible Improvement Potential, Complex systems, Reliability Block Diagram, Standby redundancy**

I. INTRODUCTION

The introduction of new-born technologies together with the increase of product complexity and the miniaturization of components are some of the reasons that lead to a growth of failure variety and number: this trend is particularly significant in industrial fields and explain the interest in reliability assessment and performance.

This study focuses on reliability improvement of complex systems using one of the most trustworthy and efficient procedures, the Reliability Importance (RI), which is a measure of the impact each component has on the overall system reliability. Thanks to RI assessment, in particular during design stage, engineer can optimize efforts to improve the system reliability focusing on the components that have the greatest effect on the whole system [1].

Cost and time saving are the principal strong points of this procedure: complete prediction of reliability importance parameters are real-time feedbacks achievable in the early stages of industrial product development and they allow designers to found the system advancement on reliability importance outcomes, furthermore they can compare different solutions, prove system robustness and reduce time for improvements [2-4].

The develop procedure that is shown in this paper is focused on "component" Reliability Importance with the aim of analyze the system at the lowest level: this feature is important not to sub-optimize the reliability assessment considering sub-systems. Component approach is essential to quantify the contribution of each individual element to the overall system reliability performance.

The first step to achieve RI parameters is the analysis of the system and the reliability assessment using Reliability Block Diagram (RBD) method; design engineers can identify the least reliable component in the system after a preliminary system reliability assessment in order to improve the whole system reliability.

In series systems 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 and its 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 in the system depends on multiple factors: location of the component in the system, reliability of the component under analysis and uncertainty in our estimate of the component reliability [1].

The paper is organized as follows: the first section describes the Credible Improvement Potential (CIP) that, after many tests, revealed to be the most suitable RI metric for our purpose. The second section, instead, shows the application of the method on a generic complex system containing standby redundant blocks.

II. RELIABILITY IMPORTANCE METRICS

In literature there are many reliability importance metrics and all these methods were tested on different test cases within the Department of Information Engineering of the University of Florence: this huge work revealed that Improvement Potential (IP) and Credible Improvement Potential (CIP) are the most suitable measures for Reliability Importance assessment of complex systems with redundant architectures.

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:

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

where:

$I_I^{IP}(t)$ is Improvement Potential index of component *i* at time *t*;

$R_S(t)$ is system reliability at time *t*;

$R_i(t)$ is reliability of component *i* at time *t*;

The most important weakness of this Reliability Importance metric is that it is not actually possible improving component reliability $R_i(t)$ to 100% so the supposed improvement is not physically achievable [1].

For this reason another reliability importance measure was developed, the *Credible Improvement Potential*.

It 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 [4-6].

CIP definition is shown below:

$$I_i^{CIP}(t) = R_s\left[t; R_i(t) = R_i^+(t)\right] - R_s(t) = \Delta R_s(t) \tag{2}$$

where:

$I_I^{CIP}(t)$ is Credible Improvement Potential index of component *i* at time *t*;

$R_S(t)$ is system reliability at time *t*;

$R_i(t)$ is reliability of component *i* at time *t*;

$R_i^+(t)$ is the improved reliability of component *i* at time *t*.

Therefore $I_I^{CIP}(t)$ express the system reliability improvement that designers achieve using a component with reliability $R_i^+(t)$ in place of the starting one defined by $R_i(t)$.

In order to improve component reliability to the state of art, CIP metric requires the introduction of the Improvement Factor *n* that is not a fixed value but concerns the quality, the application and the effort that designers would accept to improve system reliability [1].

In this study the quality factor π_Q in MIL-HDBK-217 [7] was chosen to set a range of suitable values for *n*: in the Military Handbook π_Q is one of the parameter used to calculate the failure rate of a specific item and it assumes different values depending on the quality of the equipment.

Therefore, following the definition and the range of values of π_Q defined in [7], in this study the Improvement Factor *n* is set at value of 4: this assumption is justified for many industrial systems with high quality standards and requirements [1].

In many applications the Quality factor is greater than 4 since it compares a low quality equipment and a top quality one; anyway in most of industrial applications low quality equipment are hardly ever used so the chosen value is quite realistic to quantify the improving failure rate from standard/mid-quality to top-quality.

Eq. 3, 4 and 5 shows the standard component reliability function, the improved reliability function and the Improvement Factor definition:

$$R_i(t) = e^{-\lambda_i t} \tag{3}$$

$$R_i^+(t) = e^{-\frac{\lambda_i}{n}t} \tag{4}$$

$$n = \frac{\lambda_{old}}{\lambda_{new}} = \frac{\lambda_i}{\lambda_i^+} \tag{5}$$

In any case there are no restrictions in the choice of Improvement Factors so the Credible Improvement Potential measure is suitable for a wide range of applications that requires custom *n*-values for each item: in this case, in order to have comparable and consistent results, the only prerequisite is to use a uniform allocation method.

With this feature CIP measure solves the issue arisen with Improvement Potential metric; furthermore it can be used to assess Reliability Importance of complex systems and in presence of standby redundancy architectures, which is the roadblock of many other RI techniques [1].

CIP metric offers a also different interpretation since it represents the achievable per cent improvement using a better component in terms of reliability performance.

It may assume values in the interval [0;1):

$$0 \le I_i^{CIP}(t) < 1 \qquad (6)$$

where:

$I_I^{CIP}(t)=0$ means that there is no improvement, $R_i(t)=R_i^+(t)$ and system reliability is the same then before.

$I_I^{CIP}(t)\rightarrow 0$ low CIP values corresponds to little reliability improvements.

$I_I^{CIP}(t)\rightarrow 1$ high CIP values corresponds to high reliability improvements.

$I_I^{CIP}(t)=1$ is not included in the CIP range because it corresponds to a 100% system reliability improvement and it is possible only in case of $R_i(t)=0$ and $R_i^+(t)=1$.

Naturally, system reliability will improve in case of component upgrade with another one offering a higher reliability performance: design engineers must repeat this procedure for all the items making-up the system so they'll be able to know which item has the greatest impact on the whole system reliability.

Credible Improvement Potential measure was tested with different RBDs and the most interesting model is shown in Section III.

III. RELIABILITY IMPORTANCE ASSESSMENT

Figure 1 shows a generic complex system containing standby redundant blocks that was chosen to test and validate the Credible Improvement Potential measure: the red nodes represent hot standby architectures while blue ones are in cold standby configuration.

The first step is the system reliability assessment using *RBDesigner*®, a dedicated tool developed in the Department of Information Engineering of the University of Florence that allows design engineers to achieve a reliability prediction of a complex industrial system in the early product design stages [2-3].

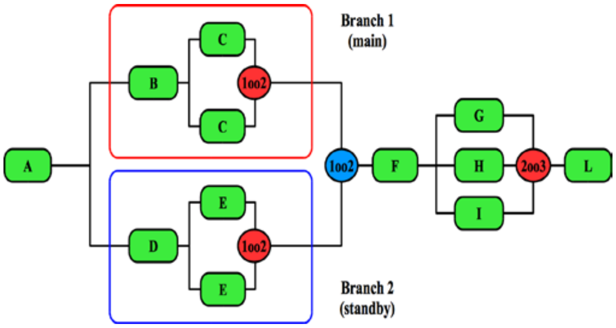

Fig. 1.Case study Reliability Block Diagram

Component failure rates and corresponding MTBFs are shown in Table 1 while in Fig. 2 shows the system reliability considering a single component upgrade at once: each curve in the chart corresponds to the reliability function of the system where the selected item was replaced with the improved one; obviously the improvement is in terms of reliability performance [1].

These curves are compared with the standard reliability function of the system (green curve). The enhancement is based on the Improvement Factor n (Eq. 5).

TABLE I. FAILURE RATES AND MTBF

Component	Failure rate [failures/10^6h]	MTBF [h]
Item A	1,51	662252
Item B	7,05	141844
Item C	8,10	123457
Item D	5,31	188324
Item E	40,42	24740
Item F	1,11	900901
Item G	5,23	191205
Item H	6,12	163399
Item I	2,26	442478
Item L	3,11	321543

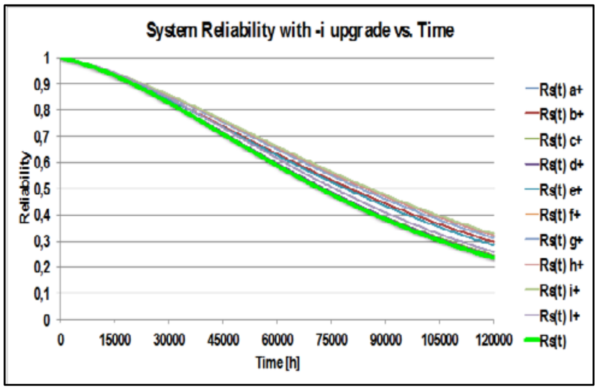

Fig. 2.System Reliability with single item upgrade vs. Time

Figure 3 shows the time-dependent Reliability Importance curves: this plot is function of time and it was achieved using CIP equations described above (Eq. 2, 3 and 4). Each curve in the chart corresponds to the Credible Improvement Potential measure of each component in function of time and each line represents the per cent improvement achievable at any time considering the upgrade of that particular component.

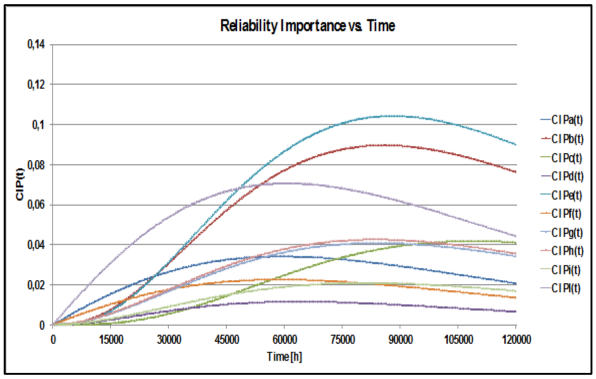

Fig. 3.Component Reliability Importance vs. Time

Static Reliability Importance is a different plot-type introduced to focus on the behaviour of the system at a specific time. It is a sort of reliability snap-shot of the system using histograms and pie charts [1].

Figures 4 and 5 show CIP indices at 24000 and 48000 hours respectively and it is possible to notice the different contribution of each component to system RI.

The two representations of CIP in time-dependent and static plots offer a clear overview of Reliability Importance trend of each component in the system; in order to give to the reader the correct interpretation of the results and show the achievable benefits of RI assessment on the case study, a comparison between two components is described below.

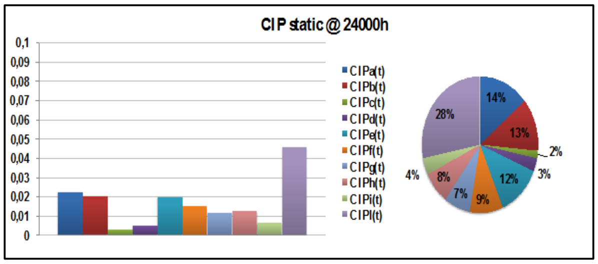

Fig. 4.Static Component Reliability Importance at 24000h

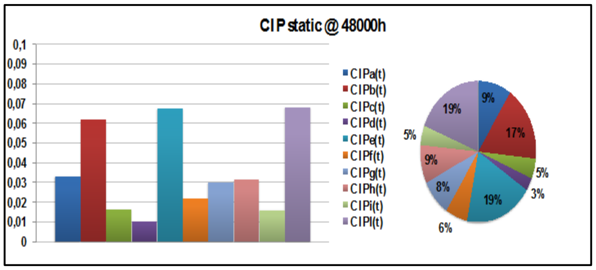

Fig. 5.Static Component Reliability Importance at 48000h

For this purpose the comparison is restricted to two components, in the case item *E* and item *L*, which differs for the following characteristics:

- Components have different failure rates, *E* is one order of magnitude greater than *L*;

$$\lambda_E = 40,42 \cdot 10^{-6}\ failures/h$$

$$\lambda_L = 3,11 \cdot 10^{-6}\ failures/h$$

- Components are linked to the rest of the system with different connections; *L* is connected in series whereas *E* is involved in 1oo2 hot redundancy that, in turn, is inside the standby branch of a 1oo2 cold standby architecture.

As shown in Figure 4, at 24k hours the Reliability Importance of *L* is greater than the other item: *L* partecipate with a contribution of 28% to system RI and allows a 5% improvement to the whole reliability. At that time item *E* has a reduced weight (12%) and a corresponding 2% upgrade on system reliability.

At 48k hours (Fig. 5) the impact of the two components is the same: both items have 19% significance and ensure approximately 7% gain in terms of system reliability performance.

These results achieved from the analysis of the component Reliability Importance measures underline the time-dependency behavior and, at the same time, the significance of RI assessment: CIP outcomes are fundamental during design stage to focus on the "right" components and take the best decisions for money and time saving.

IV. CONCLUSIONS

This paper shows the generic procedure of Reliability Importance and focuses on a particular method named Credible improvement Potential that has turned out to be the most flexible and efficient to measure the impact of each component on the overall system reliability; CIP is particular effective in applications involving complex systems with different and composite redundant architectures such as the presented case study.

Reliability Importance assessment is particularly useful if hold with continuity during all the design stages of a product and this feature is fundamental to allow design engineers to take structural decisions and select the best items to complete the mission. Using the described procedure, the product design may take into account the system reliability performance and this is a huge improvement in industrial applications because design can be based on reliability assessment.

The results achieved in the third paragraph underlines the time-dependency behavior and the significance of Reliability Importance assessment that is fundamental to focus on the components with the greatest impact on the overall system reliability.

Finally, the future development of this study will be the introduction of a modular Improvement Factor: as said before, items with different reliability performances and room for improvements (such as electronic devices and mechanical equipment) may require different *n*-factors to achieve the best-fitting of the Reliability Importance assessment. The final step to improve CIP method is the introduction of a cost-based metric considering both the reliability performance and the cost of each improvement to give design engineers more thorough feedbacks.

REFERENCE

[1] Marcantonio Catelani, Lorenzo Ciani, Matteo Venzi, “Component Reliability Importance assessment on complex systems using Credible Improvement Potential”, European Symposium on Reliability of Electron Devices, Failure Physics and Analysis (ESREF) - Halle (Germany) - September 19-22, 2016

[2] Marcantonio Catelani, Lorenzo Ciani, Matteo Venzi, "Improved RBD analysis for reliability assessment in industrial application", Proc. Of IEEE - International Instrumentation And Measurement Technology Conference (I2MTC) - Montevideo (Uruguay) - May 2014, pp. 670-674

[3] Catelani, M., Ciani, L., Venzi, M. “Reliability assessment for complex systems: A new approach based on RBD models” Proc of (2015) 1st IEEE International Symposium on Systems Engineering, ISSE 2015 - Proceedings, art. no. 7302771, pp. 286-290.

[4] IEC 61078. Analysis techniques for dependability - Reliability block diagram and Boolean methods, 2006.

[5] M. Rausand, System Reliablity Theory, (2nd edition), Wiley, 2003.

[6] W. Wang, J. Loman, P. Vassiliou, Reliability Importance of Components in a Complex System, Proc. Annual RELIABILITY and MAINTAINABILITY Symposium," Los Angeles, California, USA, January 26-29, 2004.

[7] MIL-HDBK-217FN2, Military handbook: reliability prediction of electronic equipment, 1995.