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A NOTE ON MODIFICATIONS TO THE METHODOLOGY FOR COMPONENTS IN THE COMPLEX TECHNICAL SYSTEMS RELIABILITY STRUCTURE IMPORTANCE EVALUATION

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Abstract

The paper presents State-of-the-Art in topic of reliability importance analysis for components and groups of components in complex technical systems (CTS). Basic importance evaluation measures for finding so called "weak links" in system structure have been discussed. Quantitative and qualitative importance analysis methods have been presented. Range of applicability of these methods have been pointed out. Some results of importance evaluation with use of Birnbaum's and Vesseley-Fussell's measures based on the example of 2-phased complex marine system have been shown. Critically conclusions on currently known importance analysis methods have been presented.

Keywords: *importance analysis, sensitivity analysis, importance measure, weak links, reliability structure*

1. Introduction

Dependability theory both in the statistical approach as well as physics of damage is mostly being concentrated on the functioning of systems and effectively allow to calculate of different measures of reliability, availability and safety of the systems. Basic reliability measures for the system are providing important information on a given system but for the evaluation of system components reliabilities this measures are providing only general information in the aspect correct operation of the system. Apart from the case of the serial reliability structure this measures are not giving information on influence of component reliability (component state) onto system reliability (system state). The tolerance of components failures by system depends on the reliability of components and the system reliability structure, in which the given component is located.

2. State-of-the-Art

From the dependability point of view, the importance of given component in the system depends on two factors:

- reliability characteristics of the component,
- reliability structure in which the component is located.

The influence of first factor is obvious. In relation to the component location in reliability structure, the component is the more important, if its location is more similar to the single component inserted to serial reliability structure of system. Component importance (influence on the change of the system reliability) is decreasing together with the increase in the level of redundancy of this component.

2.1. Quantitative importance evaluation

In 1969 Z.W. Birnbaum in the work [3] published the first quantitative measure of the importance of components in the reliability structure of the system, which he defined as the difference between the system reliability, when the *i*-th component is in up state at the time *t* and with the system reliability, when the *i*-th component is in down state at the time *t*. Birnbaum measure depends only on the structure in which the component is localized and from the reliability characteristics of all other (remaining) components. Birnbaum's measure do not depends on the reliability of considered the component. The process of quantitative analysis of the importance of components and groups of components was described schematically in the Fig.1.

In 1975 H.E. Lambert implemented term of the critical component of the system, which one if is in down state will cause system down state. He introduced the measure of the criticality which it is possible to define as, the probability, that the *i*-th component is critical for the system and is failed at time *t*.

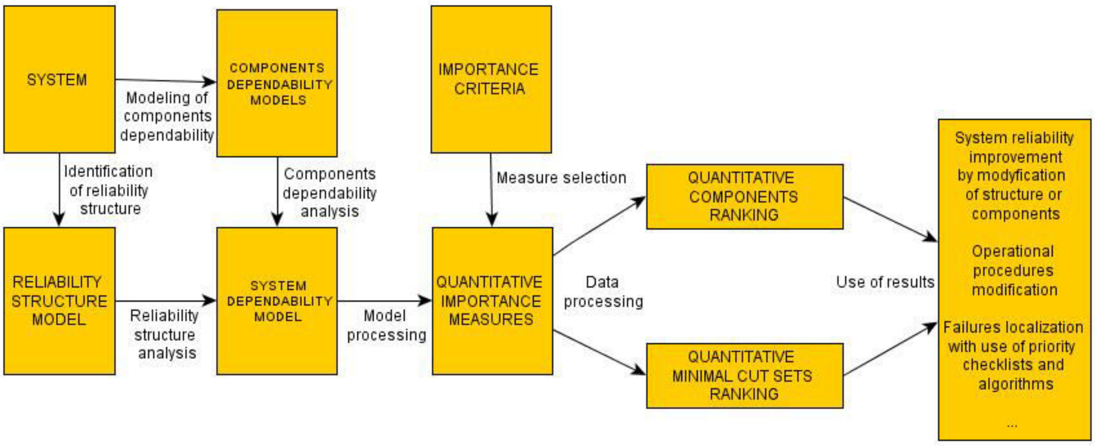

Fig. 1. Quantitative importance analysis of components and groups of components in the system reliability structure

In subsequent years new measures of the importance have been introduced, including measures drawn up by R.E. Barlow and F. Proschan [2]. Barlow-Proschan's measure is equal to the probability that the system failure is an effect if the *i*-th component failure. This measure can be treated as the average Birnbaum measure in reference to the unreliability of the *i*-th component.

At the end of 70's B. Natvig drew up a new reliability measure of the importance [15], in which he made the importance of the component conditional on loss of the remaining time to failure of the system caused by the transition of the considered component into down state. B. Bergman in 1987 suggested the next more widely known measure.

Issues of the evaluation of the importance were elaborated in subsequent years, importance measures have been developed for renewable systems by replacing the reliability and unreliability functions with functions of availability and unavailability [11,16]. A Vesely-Fussell's measure $I_i^{VF}(t)$ is one of commonly used quantitative measures of the importance for renewable systems and for the *i*-th component, and is defined as the conditional probability that an at least one minimal cut set containing the *i*-th component will occur at time *t*, assuming that the system is down at time t.

One should emphasize the fact, that different reliability importance measures are leading to different importance rankings because of different definitions of measures, therefore one should take characteristics of the given measure into consideration making interpretations during the analysis of the results. For finding components of the system, of which reliability characteristics should be corrected in order to increase the system reliability the most useful are reliability Birnbaum's measure and Barlow-Proschan's measure. However at seeking components which failures with the greatest probability will cause the breakdown of the system is recommended to use of the Vesely-Fussell's measure and the criticality measure. Example rankings of component importance [11] for vessel propulsion plant sea water cooling system for two different phases of operation based by two different measures have been shown in Fig. 2.

With reference to the evaluation of groups of components it is possible to consider the importance of minimal cut sets (minimal sets of components which simultaneous down state will cause the system down). The importance of the minimal cut sets is being interpreted as the conditional probability, that the *k*-th minimal cut set will appear at time *t*, assuming that the system is down at time *t*.

Fig. 2. Example CTS components importance rankings based on Birnbaum's and Vesseley-Fussell's measures [11]

2.2. Qualitative importance evaluation

The applicability of mentioned measures is very limited, because it requires the accurate knowledge of reliability characteristics of individual components and the entire system [11,15]. With reference to CTS an information about the probability density of time to component failure, reliability, time to failure functions etc. is usually unknown.

Partly solution in case of lack of full information on system is an application of qualitative importance analysis. In this method the importance of the given component is evaluated only with reference to the location of this component in the system reliability structure. However not considering by qualitative methods the information about components reliabilities causes that these measures have a limited applicability. The process of qualitative analysis of the importance was described in the Fig. 3.

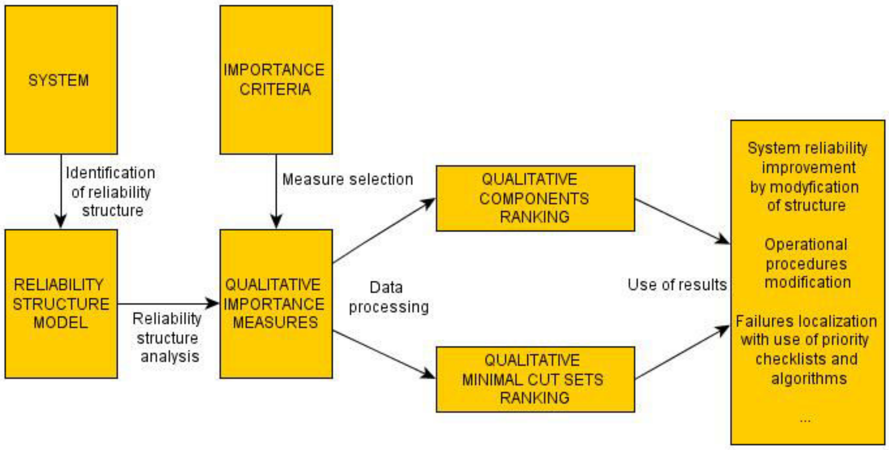

Fig. 3. Qualitative importance analysis of components and groups of components in the system reliability structure

As example of the qualitative measure of the component importance (dependent only on the system reliability structure, which the component is located in) is a structural measure of Birnbaum, which for the *i*-th component is being defined as the relative number of *n*-component system states for which the *i*-th component is critical for the system (states in which component down state will cause the system down).

L. Chybowski and Z. Matuszak suggested the normalised measure of streams [6,11] based on M. Kołodziejski and Z. Matuszak stream measure, which takes into consideration the participation of the *i*-th component in the reliability structure of a few subsystems at time *t*.

Qualitative importance measure for system cut sets is number of set components (cut set order). The cut set is usually the more important if it contains fewer components.

Creating rankings of components and events leading to components failures in the system is one of issues of the evaluation of the importance of components. The ranking of events can work on the assumption that human errors appear much more often than failure of active components, and failures of active components are more frequent than failures of passive components. For example the working pump will fail more likely than the standby pump.

3. Final conclusions

In 90's and in the last decade many theoretical works concerning analysis of the importance and connected issues came into existence, including works of: E. Zio, G. E. Apostolakis, E. Borgonovo, A. Brandowski, T. Aven, J. Jaźwiński, Z. Smalko, K. Kołowrocki, F. C. Meng, J. Z. Czajgucki, W. E. Vesely, J. Vatn, Z. Matuszak, P. J. Boland. Amongst the tendency in analysis it is possible to distinguish papers on: developing new measures importance of components [4,5,11, 18], describing specific applications of importance measures of the given class of systems in the assessment of the safety [5,10,11,12, 15.18] and far-reaching analyses of connections between different importance measures and getting of importance rankings [1,11,17] among others.

In the 21st century new importance analysis issue appeared taken up by researchers (among others S. Beeson, J. D. Andrews), which is the importance analysis of noncoherent systems components (systems, in which component fault can cause change system state from down into up state). Analysis of the importance for such systems was connected with a significant complication of mathematical models, because for every component one should appoint two measures associated with being of the component appropriately the condition of the up and down state. Such an approach makes difficulties of an interpretation of the achieved analysis results. However in spite of the developed models these methods are good for theoretical analysis, due to the fact that apart from few coincidences, CTS are coherent systems.

During last over 40 years from introducing the first measure of the importance by Z.W. Birnbaum many importance measures of the components and minimal cut sets have been introduced. However in spite of the theoretical models of the evaluation of the importance, they are creating quoted appliqué problems. CTS including vessel propulsion plant are systems difficult in the description (analysis) [7,8,9,13] due to CTS are systems:

- renewable or partial-renewable;
- with time dependent functional and reliability structure of the system;
- with hierarchical structure and multidimensional often not known feedbacks;
- with components failures partly or entirely dependent;
- for which replies only to the defined scope and character of inputs and disturbances are known;
- with unknown redundancy kinds and connections [14];
- for which the reliability structure in spite of known allocation of basic functional components is not often known entirely or in considerable parts.

In view of the described CTS features application of known measures of the importance is often limited or impossible because of the lack of complete information on relations in the system and components reliabilities, what makes that “classical importance measures” have limited application for CTS analysis.

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