MEGBÍZHATÓSÁGI BLOKKDIAGRAM HIERARCHIKUS ÉRZÉKENYSÉGVIZSGÁLATA

HIERARCHICAL SENSITIVITY ANALYSIS OF RELIABILITY BLOCK DIAGRAM

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KIVONAT
A kanonikus rendszerek és azok megbízhatóságának elméleti és gyakorlati vizsgálata számos járműmérnöki területen fontos szerephez jut. Az egyik legfontosabb kérdés a teljes rendszer megbízhatóságának érzékenysége. A tanulmány célja a repülőgépek és a gázturbina motorok matematikai diagnosztikai módszertanának adaptálása a véges kanonikus rendszer megbízhatóságának meghatározására. Tanulmányunk egy egyszerű példán mutatja be a javasolt a megbízhatósági blokkdiagram hierarchikus érzékenységi modellt.

ABSTRACT
Theoretical and practical investigation of canonical systems and their reliability has become important in several fields of vehicle engineering. One of the most important questions is the sensitivity of their reliability. The main aim of this paper is to show adaptation of mathematical diagnostic methodology of aircraft systems and gas turbine engines to determine sensitivity of reliability of finite canonical system. The proposed method is named Hierarchical Sensitivity Model of Reliability Block Diagram (HSMoRBD). The paper shows the proposed method theoretically and its applicability by a simple example.

1. INTRODUCTION

Reliability – that often means dependability –, has a broad meaning in our daily life [7]. Reliability analysis methods are defined by international standard IEC 60300-3-1. The most widely used quantitative analyses are Fault Tree Analysis (FTA) and Analysis of Reliability Block Diagram (RBD) [3].

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During of the project mentioned above Nagy and Tuloki explored [4] a real sensor and commutation network system of fully electric vehicle (Nissan Leaf Z0) and depicted its block diagram. Zentai proposes an algorithm that classifies the vertices of a graph (e.g. vehicles, or road side units) based on their risk value [12].

Szakács introduced a model of a pneumobil vehicle developed at the University of Óbuda [9]. The goal of his modelling is to describe the air pressure and flow, force, and speed behavior of the piston, in order to optimize drive power, and gas consumption. Further goal of the modelling is to develop functional block model of driving system of pneumobil for optimizing its control strategies, in special attention on maximizing vehicle power, and traveling range [10].

In the reliability engineering literature, there are many studies books as well as papers dealing with reliability theory from theoretical and practical points of view.

The aim of Boucerredj's work is to propose a dependability evaluation of system controlled by computer using a new approach based on optimization qualitative and quantitative analysis [1]. This qualitative analysis optimization based on Truth Table method combined with Karnaugh Table used for focus the search of failure on the system study (or parts of the system) that are interesting for dependability analysis, the objective is to determine the causality events between nominal states, degraded state and feared state for deriving Minimal Feared State (MFS).

The paper of Pan investigates a Bayesian approach to system reliability prediction using multilevel incomplete data [5].

In paper of Catelani et.al sensitivity analysis is carried out to assess propagation of uncertainty from nominal values of failure rates taken from reliability data handbooks to system reliability outcome of a generic Safety Instrumented System [2].

In paper [11], the complete process and method of ship reliability analysis are studied. The whole ship is divided into three (equpment; subsystems; system) levels and analysis from bottom to top.

Pokorádi developed a modular approached sensitivity models named as Linear Fault Tree Sensitivity Model (LFTSM) [6][8]; the Linear Sensitivity Model of System Reliability (LSMoSR) and Linear Sensitivity Model of System Unreliability (LSMoSU) [7]. These modular approach tools that use matrix-algebraic method based upon the mathematical diagnostic methodology of gas turbine engines.

Most advantages of the modular approach methods mentioned above are the followings:

- it is an easy-used algorithm;
- elements of coefficient matrices can be easily determined because of they are typical ones;
- sensitivity matrix shows sensitivity coefficients not only for entire system or process but for the subsystems or sub-processes as well;
- sensitivity coefficient's structure is similar, thus substituting parameters makes the whole system typical or typified [8].

The present article follows in the spirit of these works and proposes a new Hierarchical Sensitivity Model of Reliability Block Diagram (HSMoRBD).

The paper is organized as follows; Section 2 represents the Reliability Block Diagram method theoretically and in practice. Section 3 explains the methodology of hierarchical sensitivity analysis of RBD firstly theoretically and then by a case study. Finally, Section 4 concludes the article, summarizes and proposes some future research directions.

2. RELIABILITY BLOCK DIAGRAM

Reliability Block Diagram is easy to evaluate and understand. It has been widely used in reliability engineering for many years Its general methodology is depicted by international standard IEC 60300-3-1 [3]. The RBD has equivalent mathematical characteristics to FTA. The method provides a perspicuous graphical representation of the redundancy inherent within the investigated system.

2.1. Theoretical Solution

The RBD can be used only reliability investigation of simply system. A simply system does not have so-called complex interconnections, therefore it can be represented as a network in which components and subsystems are connected in series, in parallel, or a combination of these.

The serial system means that all of its components must work for the system to be successful (see figure 1). Its reliability can be determined by

$$R_{sys} = \prod_{j=1}^{n} R_j \qquad (1)$$

equation, where:

R_j – reliability of j^{th} element;
n – number of elements.

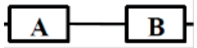

Figure 1 Series System

In case of a parallel system success requires that either one (or more) element must operate successfully. So, the reliability of parallel system:

$$R_{sys} = 1 - \prod_{j=1}^{n} \left(1 - R_j\right) \qquad (2)$$

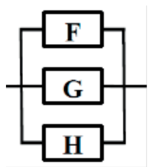

Figure 2 Parallel System

It is important to mention, that serial or parallel system from point of view of reliability do not mean in any case serial or parallel connections from technical, technological points of view.

The combined RBDs can be serially-parallel or in parallel-serial combination. These models include combination of the redundant and no redundant elements or subsystems. In this case we should define different layers of the RBD.

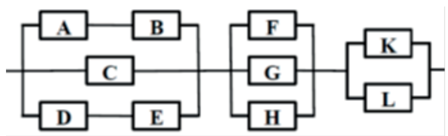

Figure 3 The investigated system

3.2. Case Study

Layer 1: The investigated system (see Figure 3) has been modelled as subsystems X; Y and Z with series connections.

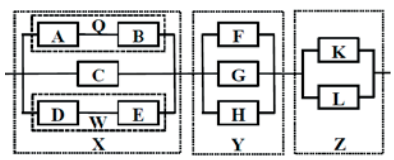

Figure 4 Layers of the Investigated System

The reliability of system can be determined by

$$R_{sys} = R_X R_Y R_Z \qquad (3)$$

equation.

Layer 2: The subsystem X has been modelled as blocks Q; C; W with parallel connection:

$$R_x = 1 - \{(1 - R_Q)(1 - R_C)(1 - R_W)\} \qquad (4)$$

The subsystem Y has been modelled as elements F; G and H with parallel connection:

$$R_Y = 1 - \{(1 - R_F)(1 - R_G)(1 - R_H)\} \qquad (5)$$

The subsystem Y has been modelled as elements K and L with parallel connection:

$$R_Z = 1 - \{(1 - R_K)(1 - R_L)\} \qquad (6)$$

Layer 3: The subsystem Q has been modelled as elements A and B with series connection:

$$R_Q = R_A R_B \qquad (7)$$

The subsystem W has been modelled as elements D and E with series connection:

$$R_W = R_D R_E \qquad (8)$$

Then – using equations (3) – (8) backwards – the reliabilities of intermediate blocks in the layers and at last reliability of system should be determined.

The Figure 5 shows system reliabilities R_{sys} in case of different reliabilities of all components R_i.

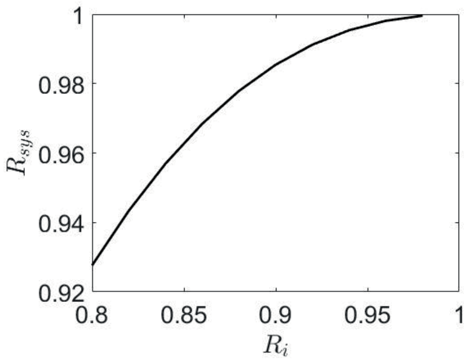

Figure 5 System Reliabilities in Cases of Different Reliabilities of Components

2.3. Simulation-based Sensitivity Analysis

To investigate sensitivities of system reliability the reliabilities of components have been changed severally. During simulation all elements have same r_i = 0.9 reliability, only the reliability of the investigated component is changed from 0.8 to 0.98.

Figures 6 – 9 show the results of simulations, which depict the changing of system reliability and subsystem in layer 1 that comprises the investigated element.

2.4. Discussions

The following conclusions can be drawn from the results of RBD reliability analysis and simulation:

A1: The reliability of system is approaching 1 asymptotically when reliabilities of components increase (see Figure 5)

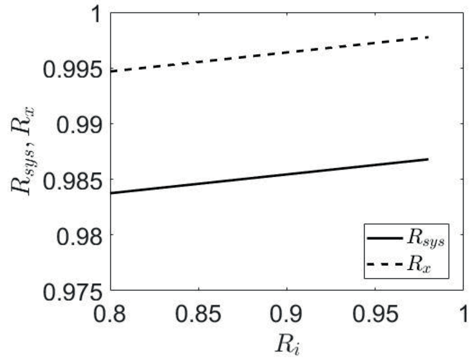

Figure 6 System and Subsystem X Reliabilities in Cases of Different Reliabilities of Components A; B; D and E

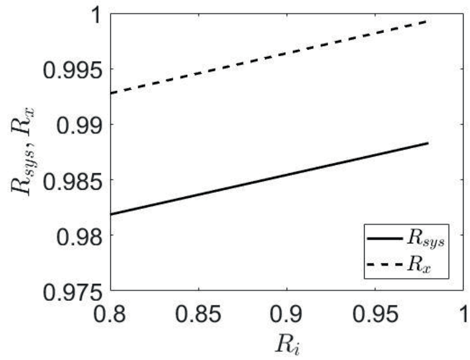

Figure 7 System and Subsystem X Reliabilities in Cases of Different Reliabilities of Component C

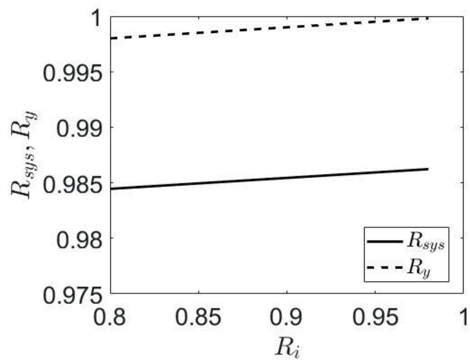

Figure 8 System and Subsystem Y Reliabilities in Cases of Different Reliabilities of Components F; G and H

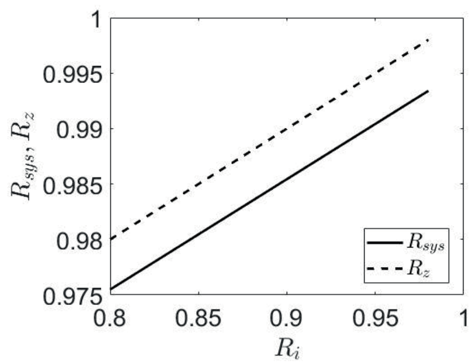

Figure 9 System and Subsystem Z Reliabilities in Cases of Different Reliabilities of Components K and L

B1: The decreasing order of rises of curves is

following:
- K and L (see Figure 9);
- C (see Figure 7);
- A, B, D and E (see Figure 6);
- F, G and H (Figure 8).

B2: The function curves of components K and L have the most rise.

B3: The function curves of components F, G and H have the list rise.

It can be stated that increasing of component reliability K or L results in the biggest increase of system reliability.

3. HIERARCHICAL SENSITIVITY ANALYSIS

For sensitivity investigation, the linear sensitivity model of the discussed RBD should be set-up. In this chapter the method of modular approach sensitivity model setting up will be depicted theoretically and demonstrated practically by the example of the sample RBD mentioned above (Figure 3).

3.1. Theoretical Solution

The sensitivity analysis shows how sensitive the system's output parameter is while changing in any elements of the input parameters. In other words the sensitivity coefficient characterizes measurement of the investigated output system parameter's dependence upon given input one.

Using the mathematical model of investigated system or process relative changing of output parameters can be determined in case of changing of input one (or ones). By literatures [6] and [7], the sensitivity coefficient by input parameter x_i of general function $y = f(x_1, \ldots, x_n)$ can be determined analytically by the coefficients:

$$K_{y,x_i} = \frac{\partial f(x_1;x_2;\ldots x_m)}{\partial x_i}\frac{x_i}{f(x_1;x_2;\ldots x_m)} \quad (9)$$

a short sign is K_{yi}, and

$$\frac{d\eta}{\eta} \approx \frac{\Delta\eta}{\eta} = \delta\eta \quad (10)$$

equation, the following linear system can be achieved:

$$\delta y = K_{y1}\delta x_1 + K_{y2}\delta_{x2} + \ldots + K_{ym}\delta x_m \quad (11)$$

Using equation, mentioned above, how sensitive dependent system output parameters will be to uncertainties of input ones.

The sensitivity coefficients of RBD can be determined by the following ways:

In case of serial systems (or subsystems) – using equation (1)

$$R_{sys} = \prod_{j=1}^{n} R_j \quad \Rightarrow \quad K_i = 1 \quad (12)$$

In case of parallel systems (or subsystems) – using equation (2):

$$R_{sys} = 1 - \prod_{j=1}^{m}\left(1 - R_j\right) \quad \Rightarrow \quad K_i = \frac{R_i}{R_{sys}}\prod_{\substack{j=1 \\ j\neq i}}^{m}\left(1 - R_j\right) \quad (13)$$

Next task is to separate events of block diagram into elements and blocks (system and subsystems). Their reliabilities should be arranged into vectors x and y. Then, the connection between reliabilities of elements blocks can be described by

$$\mathbf{A}\delta\mathbf{y} = \mathbf{B}\delta\mathbf{x} \quad (14)$$

where A and B are coefficient matrices of blocks and elements. If matrix A is invertible, using

$$\mathbf{S} = \mathbf{A}^{-1}\mathbf{B} \quad (15)$$

relative sensitivity coefficient matrix of investigated RBD, the equation

$$\delta\mathbf{y} = \mathbf{S}\delta\mathbf{x} \quad (16)$$

can be used for relative sensitivity investigation.

3.2. Case Study

To demonstrate methodology mentioned above, lets' study the RBD shown by figure 3.

The vectors of reliabilities of blocks and elements:

$$\mathbf{y}^T = \begin{bmatrix} R_{sys} & R_Z & R_Y & R_X & R_Q & R_W \end{bmatrix} \quad (17)$$

$$\mathbf{x} = \begin{bmatrix} R_A \\ R_B \\ R_C \\ R_D \\ R_E \\ R_F \\ R_G \\ R_H \\ R_K \\ RL \end{bmatrix} \quad (18)$$

$$\mathbf{A} = \begin{bmatrix} 1 & -1 & -1 & -1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -K_{XQ} & -K_{XW} \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (19)$$

$$\mathbf{B}^T = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & K_{XC} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & K_{YF} & 0 & 0 & 0 \\ 0 & 0 & K_{YG} & 0 & 0 & 0 \\ 0 & 0 & K_{YH} & 0 & 0 & 0 \\ 0 & K_{ZK} & 0 & 0 & 0 & 0 \\ 0 & K_{ZL} & 0 & 0 & 0 & 0 \end{bmatrix} \quad (20)$$

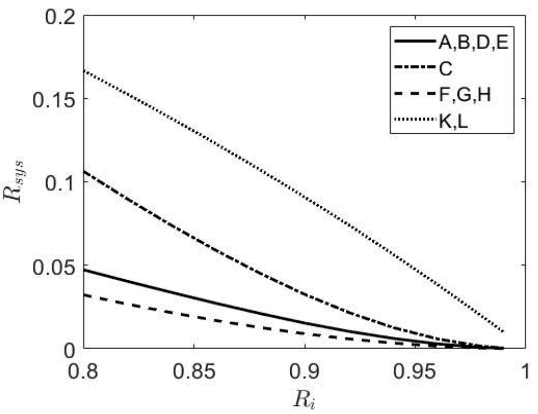

Figure 10 Sensitivities of System Reliability Depends on Reliabilities of Components

The sensitivity coefficients of the investigated RBD can be determined using equations (3) – (8) by equations (12) and (13).

Figure 10 shows sensitivities of system reliability depends on reliabilities of components.

3.3. Discussions

The following conclusions can be drawn from the results of RBD sensitivity analysis:

C1: The relative sensitivity of system reliability decreases if reliabilities of elements increase

C2: Using same reliabilities of components, the relative sensitivity of system reliability to reliability of components are the same in cases of elements A; B; D; E and F; G; H and K ; L..

The conclusions C1 and C2 are in accord with conclusions B1; B2 and B3.

D1: From Conclusions B1; B2; B3 and C2, the authors introduce the terms "***structural sensitivity***" and "***structural sensitivity coefficient***".

The structural sensitivity coefficient characterizes the effect of a given component from constructional point of view. Its value is determined only by localization in the system – not a value – of the given component.

E1: The proposed method can be used to analyze sensitivity of the reliability of the RBD.

E2: Elements of coefficient matrices can be easily determined.

E3: Sensitivity parameters of the possible system states can be used in cases with separate professional meaning (for example road traffic or logistical management).

4. CONCLUSIONS, FUTURE WORK

In this paper a new modular approach method named Hierarchical Sensitivity of Reliability Block Diagram (HSoRBD) was proposed. The Authors' proposed prospective future research direction is the study of sensitivity and uncertainty analysis methodologies of technical systems, such as vehicle sensory network, reliability.

5. ACKNOWLEDGEMENT

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