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# THE PROBLEMS OF MODELING THE RELIABILITY STRUCTURE OF THE COMPLEX TECHNICAL SYSTEM ON THE BASIS OF A STEAM-WATER SYSTEM OF THE ENGINE ROOM

*Leszek CHYBOWSKI*
*Maritime University of Szczecin*

**Abstract**:
In the paper the concept of a system structure with particular emphasis on the reliability structure has been presented. Advantages and disadvantages of modeling the reliability structure of a system using reliability block diagrams (RBD) have been shown. RBD models of a marine steam-water system constructed according to the concept of 'multi-component', 'one component' and mixed models have been discussed. Critical remarks on the practical application of models which recognize only the structural surplus have been dealt with. The significant value of the model by professors Smalko and Jaźwiński called by them 'default reliability structure' has been pointed out. The necessity of building a new type of models: quality-quantity, useful in the methodology developed by the author's multi – criteria analysis of importance of elements in the reliability structure of complex technical systems.

***Key words:*** *reliability structure, model of structure, complex technical system, importance of components, reliability block diagram*

## INTRODUCTION

One of the stages of reliability analysis of complex technical systems (CTS) – including the engine room – is the assessment of which events (components) or minimum cross-sections are most relevant to the system in question with regard to ensuring the optimum value of the specified reliability indicator [3].

Usually when the quantitative analysis we want to find items whose reliability must be improved to increase the reliability of the system in an optimal way. This issue is related to the search for so called weak links in the system, that is, the most unreliable elements and element groups in the system as well as components important to safety and quality of operation. In literature on reliability the aspect is named importance analysis. For the sake of quantitative comparative analysis of components importance, so-called importance measures have been introduced. There are many different measures, whose application is conditioned mainly by which aspect of importance appears the most relevant. It should be emphasized that the various measures of reliability lead to different rankings of importance, which is implied by different definitions of measurements.

Due to the limited applicability or non-use of multiple measures of the element importance [5, 7] in the CTS, it was necessary to develop a modern qualitative – quantitative methodology to assign rankings of elements and groups of elements importance in the CTS for the specified importance criteria comprising the following aspects: safety, reliability, economy, availability of spare parts, maintainability. One of the problems in practical use of these measures is sufficiently accurate representation of the system using a model in which the measures will be applied [4, 6].

## SYSTEM STRUCTURE

The concept of the system has been given many definitions, often with a focus on different aspects of the use of facilities during the operation [2, 9]. Aristotle (384-322 BC) observed that 'the whole is more than the sum of the parts' [12]. In general, the system S is <E,R> ordered pair consisting of a set E and the R series, defined as a relationship. In the theory of systems E is called the set of elements, and R the structure of the system [15]. Over the last 40 years, since the introduction of the first importance measure by Z. W. Birnbaum, there have been developed a number of measures describing the importance of element in the structure of the reliability system and the importance of the cross sections of minimum unfitness. However, despite the advanced mathematical (theoretical) ways of importance assessment, they create the mentioned above application problems. CTS, including the engine room systems are difficult to describe herein as they are objects [5]:

- renewable or partially-renewable;
- variable in time structure of the functionality and reliability;
- complex with hierarchical structure and multi-level, often not known, feedbacks;
- with the damages of elements partially or totally dependent;

- for which we know the answer only for a certain extent and nature of extortion and interference;
- with redundancy of unknown relations, which are overlapping sets [14];
- reliability structures of which although their separate basic functional elements are known, however not in whole, nor in substantial part.

Models are tools and forms of representation of reality in human cognition. There are models of the material (similar spatially, physically similar, related mathematically), and mental models (pictorial, symbolic, and mixed). The system is characterized by the constructional, functional, reliability structure, etc. In the reliability analysis of importance it is relevant to build a model for the system of reliability structure. This structure can be modeled using verbal, analytical, logical, visual, and mixed models. When creating models many formal tools are applied (Fig. 1).

Because of the characteristics of complex technical systems, listed in the introduction, constructing a model of structure reliability may be a serious problem. In the further part of the paper the selected ways of modeling the system reliability structure were assessed.

## RDB MODELS OF STRUCTURE

System reliability structure is often represented in the form of reliability block diagrams RBD (Reliability Block Diagrams), which can be easily converted into equivalent models such as: Fault Tree, binary models (Boolean models), and others.

The assumptions in the construction of the model condition obtaining an adequate simplification in their analysis and affect the accuracy of the analysis results. In the following section three concepts to build the reliability structure of a complex technical system by RBD models along with a brief discussion of their advantages and disadvantages have been presented. The example of its application will be a steam-water system of the engine room of 6500 TEU Class Container Carrier [14] shown in Fig. 2.

System components, not reserved (but involved in a series into a reliability structure) were determined for models 1, 2 ... m, and the reserved blocks (feed pumps, circulating pumps and leading valves) were determined: 1 ', 2' and 3 '. Moreover, in each of the reserved blocks (mirrored) the basic element was marked 0 and a reserved element 1.

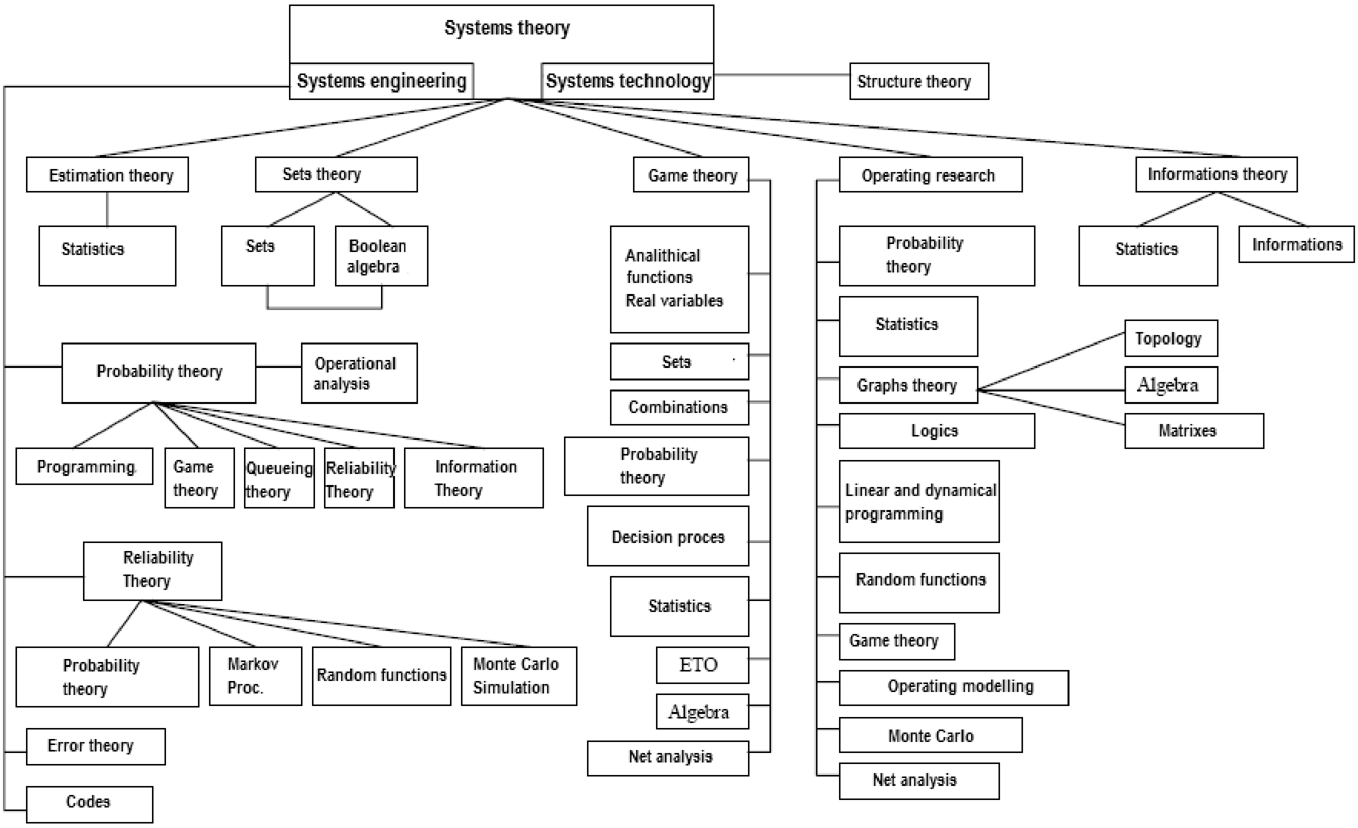


*Fig. 1. Tree of CTS formal modeling tools [1]*

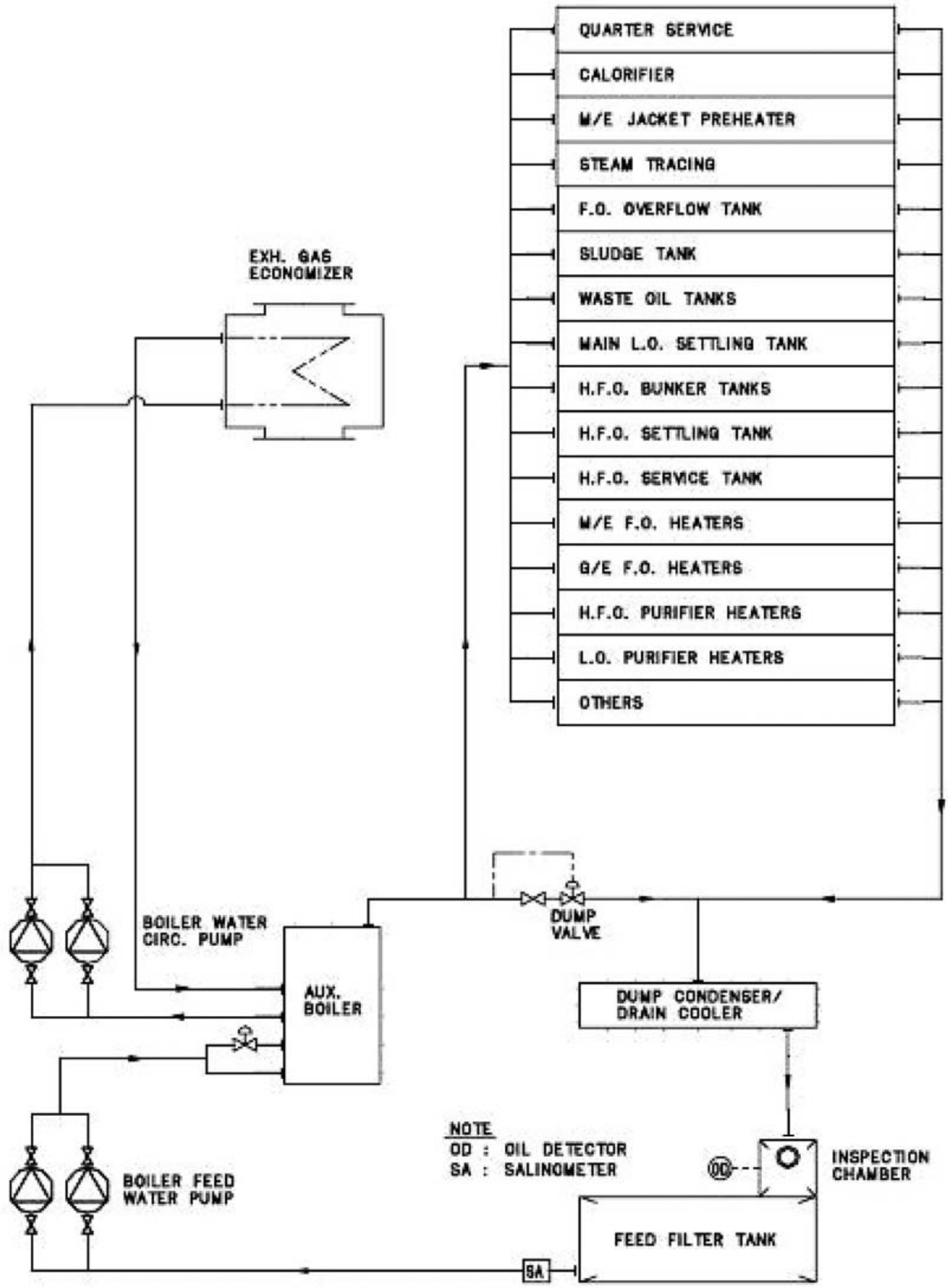


***Fig. 2. Steam, drain and feed water system of 6500 TEU Class Container Carrier***

*Multi-component' model*

One of the concepts of modeling of complex structures, such as engine room systems is the 'multi-component' model in which the analyst tries to map all the elements of the system. This approach was proposed in [8]. For the above mentioned power station the RDB model can be represented as shown in Fig. 3.

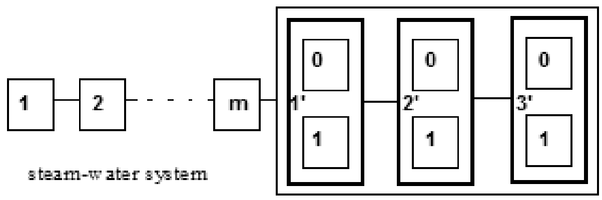


***Fig. 3. 'Multi-component' RDB model of a steam-water system***

Periodic damages to the engine room components (steam-water system) will make certain elements reliability function take values less than 1 Depending on the level of decomposition of the system assumed by the analyst, the number of the items of an example auxiliary system of the engine room is a few dozens to several thousands. This approach, despite a seemingly very accurate representation of the reliability structure of the system causes the system model become very often too complex, and obtained values of the system reliability calculated on the basis of such a model do not reflect the CTS real working conditions. In Fig. 4 R reliability value of a serial system consisting of 100 elements of reliability values R which equal: 0.995, 0.990, 0.980 and 0.950, have been shown.

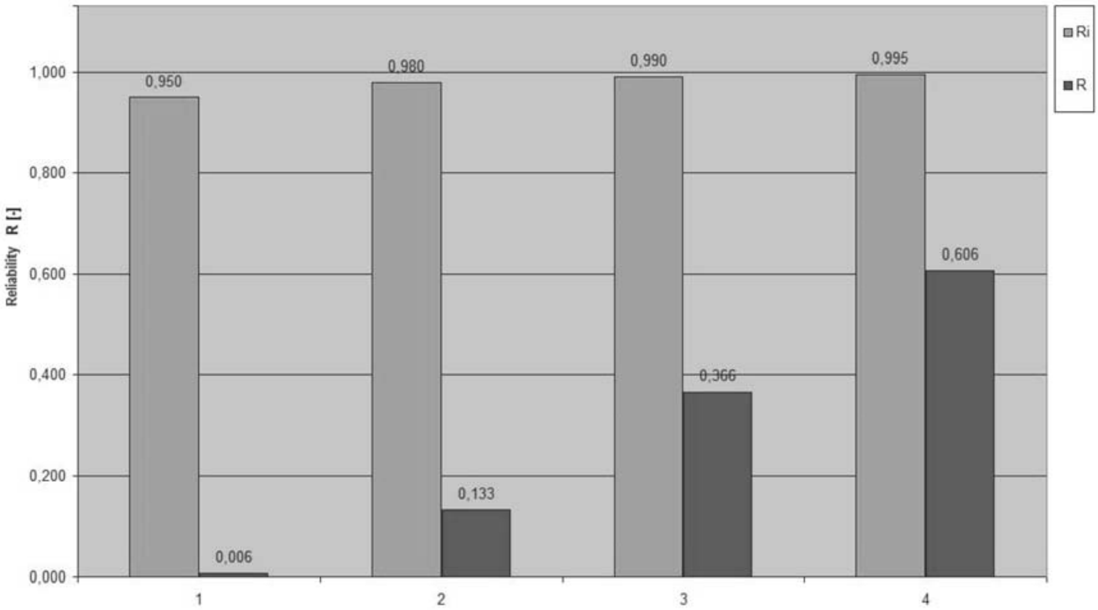


*Fig. 4. Reliability of 100 element series system with specified reliability values of components*

In the first case, the overall reliability of this system is ca. 0.6, which is very low. One might conclude that such a system with virtually similar (almost equal) probability will be fit or in the state of unfitness. In subsequent cases, the reliability of the system is even smaller. In addition, multi-component model describes in a limited way time variability of the reliability structure resulting from the damage to the switching on and switching reserve elements. Therefore, the use of RBD models in this concept is useful only for simple systems and for CTS is completely impractical and gives results inconsistent with reality.

*'One-component' model*

To avoid the problems of modeling the changes in functional and reliability structures of the system during its operation, Matuszak [11] proposed a model which treats the system as a single item. According to this study concept any damage in the analyzed system was recorded as a failure of the system [13]. Schematically this model can be represented as shown in Fig. 5.

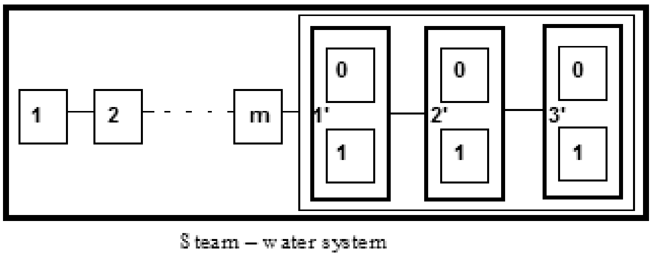


*Fig. 5. 'One-component' RBD model of a steam – water system*

This approach results in underestimation of reliability due to the removal of reserved items and considering in the analysis damages causing only reduced functionality of the system without its total damage (failure), and also recognizes a failure of components that do not affect the operation of the system, i.e. passive components [1]. A sample assessment of steam-water system reliability using this concept according to [11] is shown in Fig. 6.

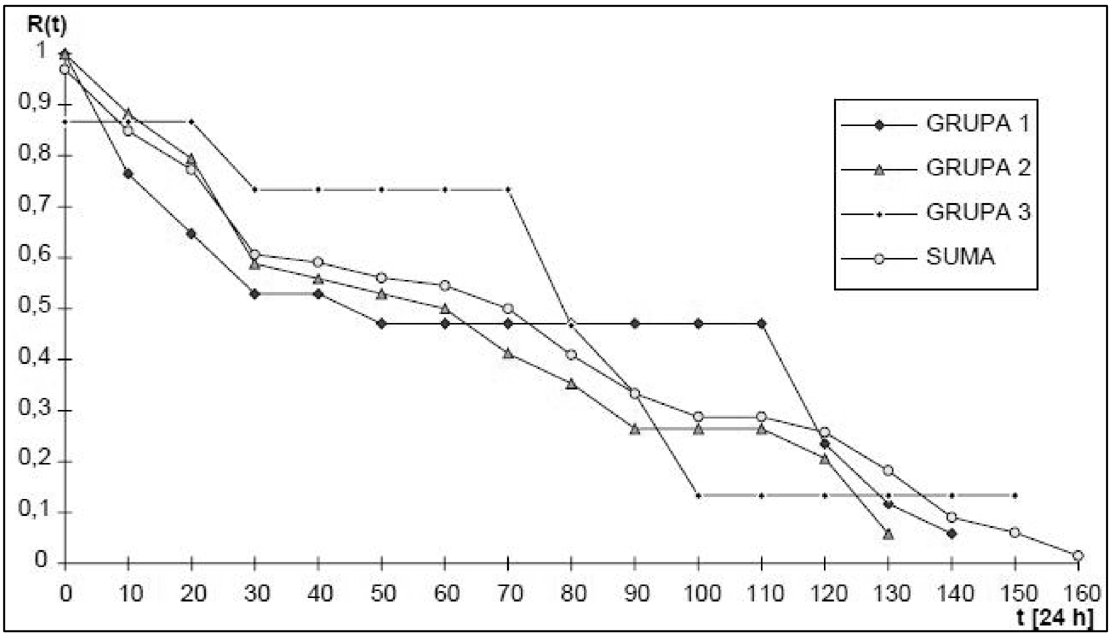


*Fig. 6. The course of the reliability function for the sum of damages and each group of observed damages in steam system*

The presented in Fig. 6 summary (averaged from three groups of observations) course of the reliability function that achieves the steam system reliability equals approximately 0.6 after 30 days of operation, which does not reflect the actual working conditions of the analyzed system. The steam-water systems belongs to the relevant ones for the operation fueled by residual oil because of the need for heating fuel and which is associated with it to provide propulsion for the vessel (this situation applies to the vast majority of seagoing ships). Furthermore, the proper operation of a steam-water system is significant factor in the safe operation due to the potential for an explosion of the boiler, the fire in the main engine exhaust manifold, the possibility of burning machine crew, etc. Therefore, the presented model, apart from academic studies, can not be applied in practice.

*Mixed model*

An alternative to the previously mentioned concept of modeling the steam-water system due to RBD diagrams, can be a mixed model (using the approach shown in sections 3.1 and 3.2), in which part of the reliability structure consisting of blocks connected in series to be modeled by means of a replacement block, whereas reserved blocks remain in the model included in the form of parallel substructures or cold spare substructures. Such a model can be schematically represented as shown in Fig. 7.

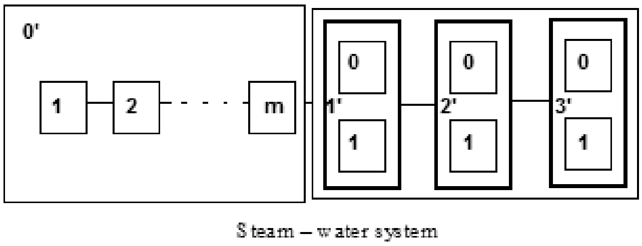


***Fig. 7. Mixed RBD model of a steam – water system***

The proposed approach reduces the complexity of the reliability structure model while maintaining the model elements which can be spares, thus, the underestimation of system reliability shall be minimized. For the case presented, reliability of steam-water system with four blocks of exponential probability distribution of the length of time to damage, the damage intensity equal to 10 failures per million hours of operation of the block and the operating time equal to one year is shown in Fig. 8.

In the presented case the obtained estimation is much closer to actual operating conditions than in the previous two cases.

**FINAL CONCLUSION**

In this paper the classical approach to modeling system reliability structure has been presented. The approach does not recognize a lot of internal feedback, hierarchical system structure, and spares. The obtained results of the analysis may be underestimated and may not recognize many types of surpluses (structural, parametric, time, strength, functional, element, etc.).

CTS reserving may have a different character and in practice is not known to the designer, operator and analyst of the system due to many internal often overlapping in their operation surpluses in each system [10].

The default structure of CTS reliability in a 'black box' proposed by professors Jaźwiński and Smalko seems, according to the current state of science, to be the best model describing the redundancy in the system, at the same time not representing explicitly the actual relationships between system components, which severely limits its application.

The author suggests using quantitative – qualitative models, in which on a given level of decomposition the emphasis will not be placed on a combination of elements, but their number, characteristics and the issue concerning the multiplied (reserved) elements in order to increase system

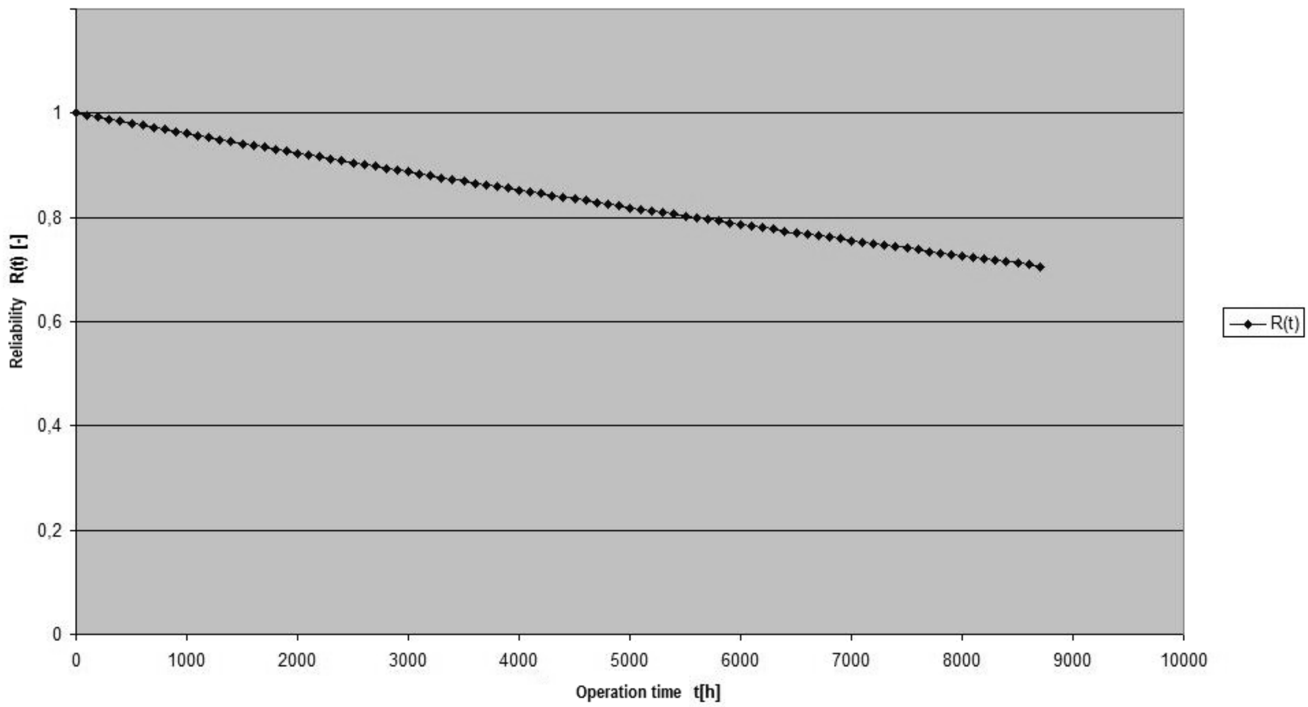


***Fig. 8. Reliability of steam – water system assessed by the use of RDB mixed model***

reliability. Within the mentioned topic further study is carried out, which is expected to contribute to the development of useful practical multi-criteria methodology for assessing the relevance of items in the CTS, such as the engine room.

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dr inż. Leszek Chybowski
Maritime University of Szczecin
Institute of Ship Power Plant Operation
Faculty of Marine Engineering
ul. Wały Chrobrego 1-2, 70-500 Szczecin, POLAND
e-mail: l.chybowski@am.szczecin.pl

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