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Integrated software tools supporting decision making on identification, prediction and optimization of complex technical systems operation, reliability and safety
Part 1
Integrated software tools description

Keywords

reliability, identification, prediction, optimization, technical systems, software tools

Abstract

The paper is composed of six parts and presents the software tools created in the scope of the Poland-Singapore Joint Research Project, the Integrated Safety and Reliability Decision Support System - IS&RDSS. In the paper first part, there are briefly described all computer programs with pointed aims. Dependencies between computer programs and possible transitions using this integrated package of software tools are presented at the scheme-algorithm. In the remaining paper parts, there is presented the application of the computer programs, being in the package of software tools, to the reliability analysis of an exemplary complex technical system.

1. Introduction

One of the project result stages is integrated package of tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Included computer programs CP 8.1-8.16 are supplemented by Tasks 8.1-8.16, [6]-[21] of the Workpackage WP8.

2. Description of the integrated package of software tools

The computer programs CP 8.1-8.16 are used in tasks of package WP9 in particular cases for real technical systems i.e. port, shipyard and maritime transportation systems. The computer programs along with the description are also included into the training courses directed to industry in the scope of WP11.

In *Figure 1* there is presented the scheme of the integrated package of software tools.

The computer program CP 8.1 is used for identification of the operation processes of complex technical systems. The aims of the program CP 8.1 are:

- identification of the unknown basic parameters of the system operation processes;
- verification the hypotheses concerning the unknown forms of the distribution functions of the conditional sojourn times in the particular operation states on the basis of empirical data coming from the operation processes of complex technical systems;
- determining the probabilities of the initial operation states of the system operation process and the probabilities of the system operation process transitions between the operation states;

- estimation the unknown parameters of the distributions of the conditional sojourn times of the system operation process in the particular

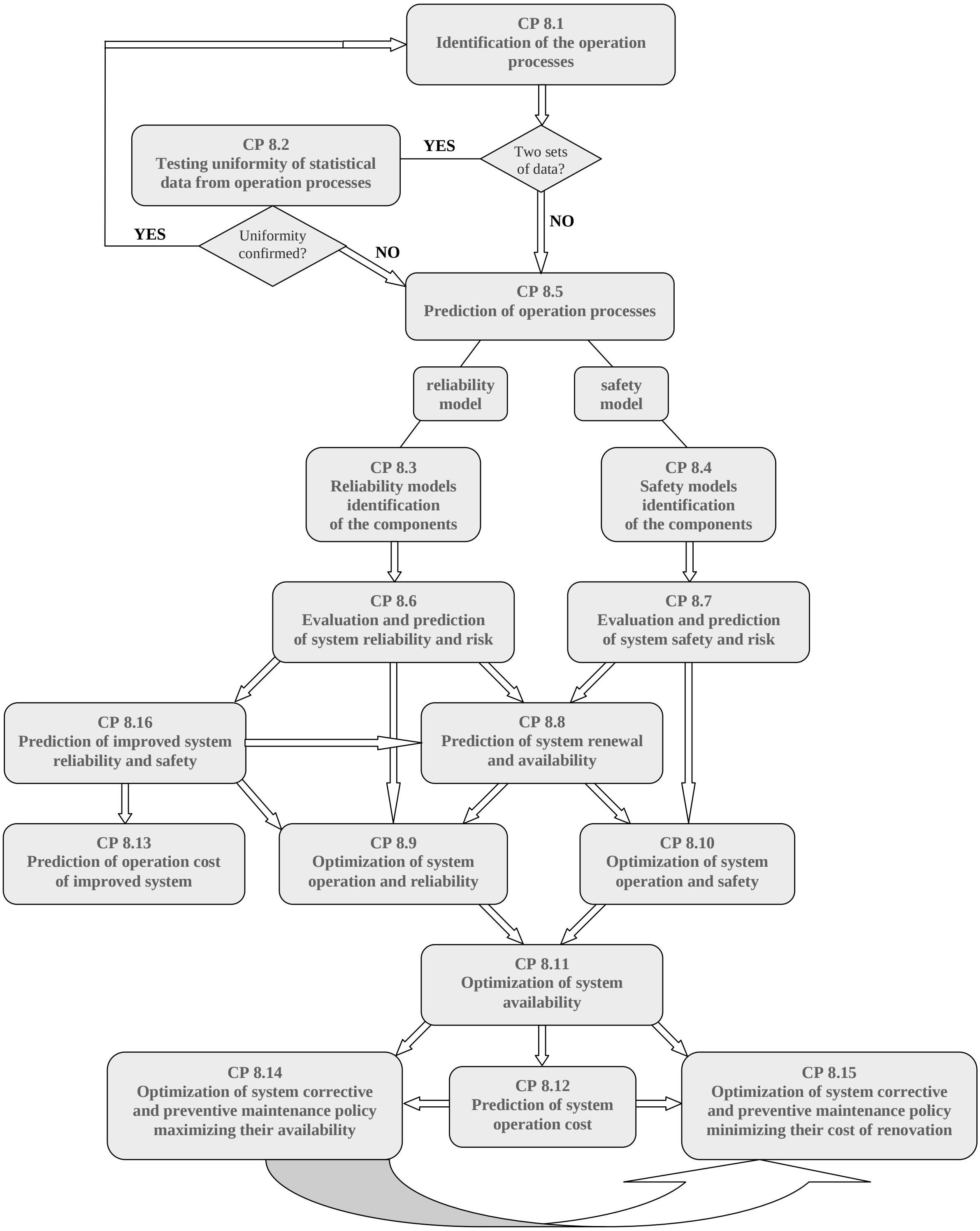

Figure 1. The scheme of the integrated package of software tools.

operation states as the suitable for these variables uniform, triangular, double trapezium, quasi-trapezium, exponential, Weibull, normal and chimney distributions;

- testifying the hypotheses about the fitting empirical distributions with the distinguished distributions;
- in the case of the hypotheses acceptance, the computer program allows to determine the theoretical mean values of the sojourn times of the system operation process in the particular operation states, if the hypotheses are rejected, the program allows to find the empirical values of the mean values of these variables.

The computer program CP 8.2 is used for testing uniformity of statistical data from operation processes of complex technical systems. The aims of the program CP 8.2 are:

- testing the uniformity of the two sets of statistical data containing the realizations of the conditional sojourn times of the same complex technical system operation process in the fixed operation state coming from two independent experiments;
- if the uniformity of the data is confirmed, the computer program enables joining these two data sets into one set of statistical data that can be used to carry out the identification of the system operation process.

The computer program CP 8.3 is used for reliability models identification of the components of complex technical systems. The aims of the program CP 8.3 are:

- estimation unknown parameters of the exponential distributions of the component conditional lifetimes of the complex technical system in the subsets of reliability states, especially the unknown intensities of component departure from the reliability state subset;
- verification the hypotheses, that system components have exponential multistate reliability functions with intensities of departure from the reliability state subsets estimated by application of the first part of the program.

The computer program CP 8.4 is used for safety models identification of the components of complex technical systems. The aims of the program CP 8.4 are:

- estimation unknown parameters of the exponential distributions of the component conditional lifetimes of the complex technical system in the subsets of safety states, especially the unknown intensities of component departure from the safety state subset;
- verification the hypotheses, that system components have exponential multistate safety functions with intensities of departure from the safety state subsets estimated by application of the first part of the program.

The computer program CP 8.5 is used for prediction of operation processes of complex technical systems. The aim of the program CP 8.5 is:

- determining the mean values of the unconditional sojourn times of the system operation process at the operation states, the limit values of the transient probabilities of the system operation process at the particular operation states and the system operation process total sojourn times at the particular operation states for the fixed sufficiently large system operation time.

The computer program CP 8.6 is used for evaluation and prediction of the complex technical system reliability and risk. The aims of the program CP 8.6 are:

- evaluation and prediction complex technical system reliability and risk characteristics: the conditional reliability functions in particular operation states, the unconditional reliability function, the mean values and standard deviations of the unconditional lifetimes in the reliability state subsets and in particular reliability states of the considered systems, the system risk function and the moment when the system risk exceeds a permitted level;

The computer program CP 8.7 is used for evaluation and prediction of the complex technical system safety and risk. The aims of the program CP 8.7 are:

- evaluation and prediction complex technical system safety and risk characteristics: the conditional safety functions in particular operation states, the unconditional safety function, the mean values and standard deviations of the unconditional lifetimes in the safety state subsets and in particular safety states, the system risk function and the moment when the system risk exceeds a permitted level;

The computer program CP 8.8 is used for prediction of complex technical systems renewal and availability. The aims of the program CP 8.8 are:

- prediction the characteristics of the renewal and availability of the repairable complex technical system;
- determining the following characteristics for ignored time renovation: the distribution, the expected value and the variance of the time until the *Nth* exceeding of reliability critical state of this system, the distribution, the expected value and the variance of the number of exceeding the reliability critical state of this system up to the particular moment;
- determining the following characteristics in the case when the system renovation time is non-ignored: the distribution function, the expected

value and the variance of the time until the exceeding the reliability critical state of this system, the distribution, the expected value and the variance of the number of exceeding the reliability critical state of this system up to the particular moment, the distribution function, the expected value and the variance of the time until the system's renovation, the distribution, the expected value and the variance of the number of system's renovations up to the particular moment, the availability coefficient of the system at the particular moment and in the time interval.

The computer program CP 8.9 is used for optimization of complex technical systems operation and reliability. The aim of the program CP 8.9 is:

- determining the optimal characteristics of the complex technical system reliability and risk: the optimal unconditional reliability function of complex technical multistate system, the optimal mean values of unconditional lifetimes of complex technical multistate systems in the reliability state subsets, the optimal risk function of complex technical multistate system and the optimal moment when the system risk exceeds a permitted level.

The computer program CP 8.10 is used for optimization of complex technical systems operation and safety. The aims of the program CP 8.10 are:

- determining the optimal characteristics of the complex technical system safety and risk: the optimal unconditional safety function of complex technical multistate system, the optimal mean values of unconditional lifetimes of complex technical multistate systems in the safety state subsets, the optimal risk function of complex technical multistate system and the optimal moment when the system risk exceeds a permitted level.

The computer program CP 8.11 is used for optimization of complex technical systems availability. The aims of the program CP 8.11 are:

- predicting the optimal characteristics of the complex technical system renewal and availability;
- determining the distribution of the optimal time until the successive exceeding of reliability critical state, the expected value and the variance of the optimal time until the successive exceeding the reliability critical state, the distribution of the optimal number of exceeding the reliability critical state up to a fixed moment of time and the expected value and the variance of the optimal number of exceeding the reliability critical state at a fixed moment of time the case when the system is repairable and the time of their renovation is ignored;
- determining the distribution function of the optimal time until the successive exceeding the reliability critical state, the expected value and the variance of the optimal time until the successive exceeding the reliability critical state, the distribution of the optimal number of exceeding the reliability critical state up to a fixed moment of time, the expected value and variance of the optimal number of exceeding the reliability critical state up to a fixed moment of time, the distribution function of the optimal time until the successive renovation, the expected value and the variance of the optimal time until the successive renovation, the distributions of the optimal number of renovations up to a fixed moment of time, the expected value and variance of the optimal number of renovations up to a fixed moment of time, the optimal steady availability coefficient and the optimal availability coefficient in a fixed time interval for the considered system in the case when the system is repairable and the time of their renovation is non-ignored.

The computer program CP 8.12 is used for prediction of operation cost of complex technical systems. The aims of the program CP 8.12 are:

- determining the costs of the non-repairable and repairable complex technical systems before and after these systems operation processes optimization.

The computer program CP 8.13 is used for prediction of operation cost of improved complex technical systems. The aims of the program CP 8.13 are:

- determining the costs of the non-repairable and repairable improved complex technical systems with reserve and improved components before and after these systems operation processes optimization.

The computer program CP 8.14 is used for optimization of complex technical systems corrective and preventive maintenance policy maximizing their availability. The aims of the program CP 8.14 are:

- maximizing the availability of complex technical systems by optimization the corrective and preventive maintenance policy;
- determining the optimal value of the system preventive maintenance period of time that maximizes the availability coefficient of this system using the method of secants, in the case when such optimal value exists;
- determining the values of the system availability coefficient for the fixed values of the preventive maintenance period of time, in the case when there is no optimal value of the preventive

maintenance period of time that maximizes the system availability coefficient.

The computer program CP 8.15 is used for optimization of complex technical systems corrective and preventive maintenance policy minimizing their cost of renovation. The aims of the program CP 8.15 are:

- minimizing the cost of renovation of complex technical systems by optimization of the corrective and preventive maintenance policy;
- determining the optimal value of the system age at which the system successive preventive renovation is performed that minimizes the cost of the system renovation per unit of time using the method of secants, in the case when such optimal value exists;
- determining the values of the system operation cost for the selected fixed values of the system age at which the system successive preventive renovation is performed, in the case when there is no optimal value of the system age at which the system successive preventive renovation is performed that minimizes the cost of the system renovation per unit of time.

The computer program CP 8.16 is used for prediction of improved complex technical systems reliability and safety. The aims of the program CP 8.16 are:

- prediction of improved complex technical systems reliability: determining the reliability characteristics of the improved complex technical systems with hot and cold single reservation of their components and of the improved complex technical systems with reduced intensities of departure from the reliability state subsets of their components;
- determining the unconditional reliability function, the mean values and standard deviations of the unconditional lifetimes in the reliability state subsets and in particular reliability states, the system risk function and the moment when the system risk exceeds a permitted level of the complex technical systems before and after their improvement;
- using the presented computer program, it is also possible to perform the prediction the safety of the improved complex technical systems.

In the next parts of the paper, the software tools i.e. these programs are applied and tested in the maritime and coastal transportation industry to provide practically validated individual safety and reliability decision support systems for individual maritime transport sectors. The computer programs may be applied not only in maritime industry sectors but in other industry sectors as well.

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References: Project Reports

[1] Kołowrocki, K. & Soszyńska J. (2009). Methods of complex technical systems operation processes modeling. Task 7.1 in WP7: Integrated package of solutions for complex industrial systems and processes safety and reliability optimization. Poland-Singapore Joint Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[2] Blokus-Roszkowska, A., Guze, S., Kołowrocki, K., Kwiatuszewska-Sarnecka, B., Milczek, B. & Soszyńska, J. (2009). Methods of complex technical systems reliability, availability and safety evaluation and prediction. Task 7.2 in WP7: Integrated package of solutions for complex industrial systems and processes safety and reliability optimization. Poland-Singapore Joint Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[3] Blokus-Roszkowska, A., Guze, S., Kołowrocki, K., Jurdziński, M., Kwiatuszewska-Sarnecka, B., Milczek, B., Soszyńska, J., Salahuddin Habibullah, M. & Fu, X. (2009). Methods of unknown parameters of complex technical systems operation, reliability, availability, safety models evaluation. Task 7.3 in WP7: Integrated package of solutions for complex industrial systems and processes safety and reliability optimization. Poland-Singapore Joint Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[4] Blokus-Roszkowska, A., Guze, S., Kołowrocki, K., Kwiatuszewska-Sarnecka, B., Milczek, B. & Soszyńska, J. (2009). Methods of complex technical systems reliability, availability and safety improvement. Task 7.4 in WP7: Integrated package of solutions for complex industrial systems and processes safety and reliability optimization. Poland-Singapore Joint Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[5] Blokus-Roszkowska, A., Kołowrocki, K. & Soszyńska, J. (2009). Methods of complex technical systems operation, reliability, availability, safety and cost optimization. Task

7.5 in WP7: Integrated Package of Solutions for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[6] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for identification of the operation processes of complex technical systems. Task 8.1 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[7] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for testing uniformity of statistical data from operation processes of complex technical systems. Task 8.2 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[8] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K., & Soszyńska, J. (2010). The computer program for reliability models identification of the components of complex technical systems. Task 8.3 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[9] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for safety models identification of the components of complex technical systems. Task 8.4 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[10] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for prediction of operation processes of complex technical systems. Task 8.5 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[11] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for evaluation and prediction of the complex technical system reliability and risk. Task 8.6 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[12] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for evaluation and prediction of the complex technical system safety and risk. Task 8.7 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[13] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for prediction of complex technical systems renewal and availability. Task 8.8 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[14] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for optimization of complex technical systems operation and reliabilityTask 8.9 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[15] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for optimization of complex technical systems operation and safety. Task 8.10 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[16] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for optimization of complex technical systems availability. Task 8.11 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University, 2010.

[17] Kołowrocki, K., Mazurek, J. & Soszyńska J. (2010). The computer program for prediction of operation cost of complex technical systems. Task 8.12 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and

Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[18] Kołowrocki, K., Mazurek, J. & Soszyńska, J. (2010). The computer program for prediction of operation cost of complex technical systems with reserve and improved components. Task 8.13 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[19] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for optimization of complex technical systems corrective and preventive maintenance policy maximizing their availability. Task 8.14 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[20] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for optimization of complex technical systems corrective and preventive maintenance policy minimizing their cost of renovation. Task 8.15 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[21] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). The computer program for prediction of improved complex technical systems reliability and safety. Task 8.16 in WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[22] Kołowrocki, K. & Soszyńska, J. (2010). The port oil piping transportation system operation, reliability, risk, availability and cost identification, prediction and optimization - Testing IS&RSS. Task 9.1 in WP9: Applications and Testing of Packages of Tools in Complex Maritime Transportation Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[23] Blokus-Roszkowka, A. & Kołowrocki, K. (2010). The shipyard ship-rope elevator operation, reliability, risk, availability and cost identification, prediction and optimization - Testing IS&RSS. Task 9.2 in WP9: Applications and Testing of Packages of Tools in Complex Maritime Transportation Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[24] Blokus-Roszkowka, A. & Kołowrocki, K. (2010). The shipyard ground ship-rope transportation system operation, reliability, risk, availability and cost identification, prediction and optimization - Testing IS&RSS. Task 9.3 in WP9: Applications and Testing of Packages of Tools in Complex Maritime Transportation Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University, 2010.

[25] Kołowrocki, K. & Soszyńska, J. (2010). The Stena Baltica ferry technical system operation, reliability, risk, availability and cost identification, prediction and optimization - Testing IS&RSS. Task 9.4 in WP9: Applications and Testing of Packages of Tools in Complex Maritime Transportation Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[26] Kołowrocki, K. & Soszyńska, J. (2010). The container gantry crane operation, reliability, risk, availability and cost identification, prediction and optimization - Testing IS&RSS. Task 9.5 in WP9: Applications and Testing of Packages of Tools in Complex Maritime Transportation Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[27] Kołowrocki K. & Soszyńska, J. (2010). The exemplary system operation, reliability, risk, availability and cost identification, prediction and optimization - Testing IS&RSS. Task 9.6 in WP9: Applications and Testing of Packages of Tools in Complex Maritime Transportation Systems and Processes Safety and Reliability Optimization. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0.Gdynia Maritime University.

[28] Kołowrocki, K. & Soszyńska, J. (2010). Integrated Safety and Reliability Decision Support System – IS&RDSS. Tasks 10.0-10.15 in WP10: Safety and Reliability Decision Support Systems for Various Maritime and Coastal Transport Sectors. Poland-Singapore Joint

Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[29] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010) Identification of complex technical systems operation processes - Training course addressed to industry. Task 11.1 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[30] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Testing uniformity of statistical data from the complex technical systems operation processes - Training course addressed to industry. Task 11.2 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[31] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska J. (2010). Identification of complex technical system components reliability models - Training course addressed to industry. Task 11.3 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[32] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J.(2010). Identification of complex technical system components safety models - Training course addressed to industry. Task 11.4 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[33] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Prediction of complex technical systems operation processes - Training course addressed to industry. Task 11.5 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[34] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Prediction of complex technical systems reliability and risk - Training course addressed to industry. Task 11.6 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[35] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Prediction of complex technical systems safety and risk - Training course addressed to industry. Task 11.7 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[36] Blokus-Roszkowka A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Prediction of complex technical systems renewal and availability - Training course addressed to industry. Task 11.8 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[37] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Optimization of complex technical systems operation and reliability - Training course addressed to industry. Task 11.9 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[38] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Optimization of complex technical systems operation and safety - Training course addressed to industry. Task 11.10 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[39] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Optimization of complex technical systems availability - Training course addressed to industry. Task 11.11 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[40] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Operation cost analysis of complex technical systems - Training course addressed to industry. Task 11.12 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[41] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Operation cost analysis of complex technical systems with reserve and improved components - Training course addressed to industry. Task 11.13 in WP11: Education, Training, Results Dissemination and

Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[42] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Optimization of complex technical systems corrective and preventive maintenance policy maximizing their availability - Training course addressed to industry. Task 11.14 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[43] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Optimization of complex technical systems corrective and preventive maintenance policy minimizing their cost of renovation - Training course addressed to industry. Task 11.15 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

[44] Blokus-Roszkowka, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Prediction of improved complex technical systems reliability and safety - Training course addressed to industry. Task 11.16 in WP11: Education, Training, Results Dissemination and Implementation. Poland-Singapore Joint Research Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University.

References: Supporting Bibliography

[45] Amari, S.V. & Misra R.B. (1997). Comment on: Dynamic reliability analysis of coherent multistate systems. *IEEE Transactions on Reliability* 46, 460-461.

[46] Aven, T. (1985). Reliability evaluation of multistate systems with multistate components. *IEEE Transactions on Reliability* 34, 473-479.

[47] Aven, T. (1993). On performance measures for multistate monotone systems. *Reliability Engineering and System Safety* 41, 259-266.

[48] Aven, T. & Jensen, U. (1999). *Stochastic Models in Reliability*. Springer-Verlag, New York

[49] Barbu, V. & Limnios, N. (2006). Empirical estimation for discrete-time semi-Markov processes with applications in reliability. *Journal of Nonparametric Statistics*, Vol. 18, No. 7-8, 483-498.

[50] Barlow, R.E. & Wu, A.S. (1978). Coherent systems with multi-state components. *Mathematics of Operations Research* 4, 275-281.

[51] Brunelle, R.D. & Kapur, K.C. (1999). Review and classification of reliability measures for multistate and continuum models. *IEEE Transactions* 31, 1117-1180.

[52] Collet, J. (1996). Some remarks on rare-event approximation. *IEEE Transactions on Reliability* 45, 106-108.

[53] Ferreira, F. & Pacheco, A. (2007). Comparison of level-crossing times for Markov and semi-Markov processes. *Statistics & Probability Letters*, Vol. 77, No. 2, 151-157.

[54] Gamiz, M.L. & Roman, Y. (2008). Non-parametric estimation of the availability in a general repairable. *Reliability Engineering & System Safety*, Vol. 93, No. 8, 1188-1196.

[55] Giudici, P. & Figini, S. (2009). *Applied data mining for business and industry*. John Wiley & Sons Ltd.

[56] Glynn, P.W. & Haas, P.J. (2006). Laws of large numbers and functional central limit theorems for generalized semi-Markov processes. *Stochastic Models*, Vol. 22, No. 2, 201-231.

[57] Grabski, F. (2002). *Semi-Markov Models of Systems Reliability and Operations Analysis*. Monograph. System Research Institute, Polish Academy of Science, (*in Polish*).

[58] Guze, S. & Kołowrocki, K. (2008). Reliability analysis of multi-state ageing consecutive „k out of n: F" systems. *International Journal of Materials & Structural Reliability*. Vol. 6. No. 1, 47-60.

[59] Guze, S., Kołowrocki, K. & Soszyńska, J. (2008). Modeling environment and infrastructure influence on reliability and operation processes of port transportation systems. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 2, Vol. 1, 179-188.

[60] Habibullah, M.S., Lumanpauw, E., Kolowrocki, K., Soszynska, J. & Ming, N.G. (2009). A computational tool for general model of operation processes in industrial systems. operation processes. *Electronic Journal Reliability & Risk Analysis: Theory & Applications*, Vol. 2, No 4, 181-191.

[61] Helvacioglu, S. & Insel, M. (2008). Expert system applications in marine technologies. *Ocean Engineering*, Vol. 35, No. 11-12, 1067-1074.

[62] Hryniewicz, O. (1995). *Lifetime tests for imprecise data and fuzzy reliability requirements. Reliability and Safety Analyses under Fuzziness.* Onisawa T. and Kacprzyk J., Eds., Physica Verlag, Heidelberg, 169-182.

[63] Huang, J., Zuo, M.J. & Wu, Y, (2000). Generalized multi-state k-out-of-n:G systems. *IEEE Transactions on Reliability* 49, 105-111.

[64] Hudson, J.C. & Kapur, K.C. (1982). Reliability theory for multistate systems with multistate

components. *Microelectronics and Reliability* 22, 1-7.
[65] Hudson, J.C. & Kapur, K.C. (1983). Reliability analysis of multistate systems with multistate components. *Transactions of Institute of Industrial Engineers* 15, 127-135.
[66] Hudson, J. & Kapur, K. (1985). Reliability bounds for multistate systems with multistate components. *Operations Research* 33, 1985, 735-744.
[67] Klabjan, D. & Adelman, D. (2006). Existence of optimal policies for semi-Markov decision processes using duality for infinite linear programming. *Siam Journal on Control and Optimization*, Vol. 44, No. 6, 2104-2122.
[68] Kołowrocki, K. (1998). On applications of asymptotic reliability functions to the reliability and risk evaluation of pipelines. *International Journal of Pressure Vessels and Piping* 75, 545-558
[69] Kołowrocki, K. (2003). An asymptotic approach to reliability evaluation of large multi-state systems with applications to piping transportation systems. *International Journal of Pressure Vessels and Piping*, 80, 59-73.
[70] Kołowrocki, K. (2004). *Reliability of Large Systems*. Amsterdam - Boston - Heidelberg - London - New York - Oxford - Paris - San Diego - San Francisco - Singapore - Sydney - Tokyo, Elsevier, ISBN: 0080444296.
[71] Kołowrocki, K, (2006). Reliability and risk evaluation of complex systems in their operation processes. *International Journal of Materials & Structural Reliability*, Vol. 4, No 2, 129-147.
[72] Kołowrocki, K. (2007). Reliability modelling of complex systems – Part 1. *International Journal of Gnedenko e-Forum "Reliability: Theory & Application"*, Vol. 2, No 3-4, 116-127.
[73] Kołowrocki, K. (2007). Reliability modelling of complex systems – Part 2. *International Journal of Gnedenko e-Forum "Reliability: Theory & Application"*, Vol. 2, No 3-4, 128-139.
[74] Kołowrocki, K. (2008). Reliability and risk analysis of multi-state systems with degrading components. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 2, Vol. 2, 205-216.
[75] Kołowrocki, K. (2008). *Reliability of large systems*. Section in Encyclopedia of Quantitative Risk Analysis and Assessment, John Wiley & Sons, Vol. 4, 1466-1471.
[76] Kołowrocki, K. & Soszyńska, J. (2006). Reliability and availability of complex systems. *Quality and Reliability Engineering International* Vol. 22, Issue 1, J. Wiley & Sons Ltd., 79-99.
[77] Kołowrocki, K. & Soszyńska, J. (2008). A general model of industrial systems operation processes related to their environment and infrastructure. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 2, Vol. 2, 223-226.
[78] Kolowrocki, K. & Soszynska, J. (2009). Modeling environment and infrastructure influence on reliability and operation *process of port oil transportation system. Electronic Journal Reliability & Risk Analysis: Theory & Applications*, Vol. 2, No 3, 131-142.
[79] Kolowrocki, K. & Soszynska, J. (2009). Safety and risk evaluation of Stena Baltica ferry in variable operation conditions. *Electronic Journal Reliability & Risk Analysis: Theory & Applications*, Vol. 2, No 4, 168-180.
[80] Kołowrocki, K. & Soszyńska, J.(2009). Statistical identification and prediction of the port oil pipeline system's operation process and its reliability and risk evaluation. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 3, Vol. 2, 241-250.
[81] Kołowrocki, K. & Soszyńska, J. (2009). Methods and algorithms for evaluating unknown parameters of operation processes of complex technical systems. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 3, Vol. 1, 2, 211-222.
[82] Kołowrocki, K. & Soszyńska, J. (2009). Methods and algorithms for evaluating unknown parameters of components reliability of complex technical systems. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 4, Vol. 2, 223-230.
[83] Kołowrocki, K. & Soszyńska, J. (2009). Statistical identification and prediction of the port oil pipeline system's operation process and its reliability and risk evaluation. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 4, Vol. 2, 241-250.
[84] Kołowrocki, K. & Soszyńska, J. (2009). Methods and algorithms for evaluating unknown parameters of components reliability of complex technical systems. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 4, Vol. 2, 223-230.
[85] Kolowrocki, K. & Soszynska, J. (2009). Reliability, risk and availability based optimization of complex technical systems operation processes. Part 1. Theoretical backgrounds. *Electronic Journal Reliability & Risk Analysis: Theory & Applications*, Vol. 2, No 4, 141-152.

[86] Kolowrocki, K. & Soszynska, J. (2009). Reliability, risk and availability based optimization of complex technical systems operation processes. Part 2. Application in Port Transportation. *Electronic Journal Reliability & Risk Analysis: Theory & Applications*, Vol. 2, No 4, 153-167.

[87] Kolowrocki, K. & Soszynska, J. (2010). Testing uniformity of statistical data sets coming from complex systems operation processes. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 4, Vol. 1,123-132.

[88] Kolowrocki, K., Soszynska, J. (2010). Reliability modeling of a port oil transportation system's operation processes. *International Journal of Performability Engineering*, Vol. 6, No. 1, 77-87.

[89] Kolowrocki, K. & Soszynska, J. (2010). Reliability, availability and safety of complex technical systems: modelling – identification – prediction – optimization. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability* Association, Issue 4, Vol. 1,133-158.

[90] Kołowrocki, K. & Soszyńska, J. (2010). Safety and risk evaluation of a ferry technical system. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 4, Vol. 1, 159-172.

[91] Kolowrocki, K. & Soszynska, J. (2010). Preliminary statistical identification and prediction of the container gantry crane operation process. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 4, Vol. 1,173-181.

[92] Kołowrocki, K., Soszyńska, J., Judziński, M. & Dziula, P. (2007). On multi-state safety analysis in shipping. *International Journal of Reliability, Quality and Safety Engineering. System Reliability and Safety*, Vol. 14, No 6, 547-567.

[93] Kołowrocki, K., Soszyńska, J., Xie, M., Kien, M. & Salahudin, M. (2008). Safety and reliability of complex industrial systems and process. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association*, Issue 4, Vol. 2, 227-234.

[94] Kołowrocki, K. & Soszyńska, J. (2011). On safety analysis of complex technical maritime transportation system. Journal of Risk and Reliability, (to appear).

[95] Kossow, A. & Preuss, W. (1995). Reliability of linear consecutively-connected systems with multistate components. *IEEE Transactions on Reliability* 44, 518-522.

[96] Kuo, W. & Prasad, V.R. (2000). An annotated overview of system-reliability optimization. *IEEE Transactions on Reliability*, 49(2), 176-187.

[97] Kuo, W. & Zuo M.J. (2003). *Optimal Reliability Modeling: Principles and Applications*. Hoboken: John Wiley & Sons, Inc.

[98] Levitin, G. & Lisnianski, A. (2000). Optimisation of imperfect preventive maintenance for multistate systems. *Reliability Engineering and System Safety* 67, 193-203.

[99] Levitin, G. & Lisnianski, A. (2000). Optimal replacement scheduling in multi-state series-parallel systems. *Quality and Reliability Engineering International* 16, 157-162.

[100] Limnios, N. & Oprisan, G. (2005) *Semi-Markov Processes and Reliability*. Birkhauser, Boston.

[101] Limnios, N., Ouhbi, B. & Sadek, A. (2005). Empirical estimator of stationary distribution for semi-Markov processes. *Communications in Statistics-Theory and Methods*, Vol. 34, No. 4, 987-995 12.

[102] Lisnianski, A. & Levitin, G. (2003). *Multi-State System Reliability. Assessment, Optimisation and Applications.* World Scientific Publishing Co. Pte. Ltd., New Jersey, London, Singapore, Hong Kong.

[103] Macci, C. (2008). Large deviations for empirical estimators of the stationary distribution of a semi-Markov process with finite state space. *Communications in Statistics-Theory and Methods*, Vol. 37, No. 19,3077-3089.

[104] Malinowski, J. (2005). *Algorithms for reliability evaluation of various kind of network systems*. Monograph. WIT, Warsaw, (*in Polish*)

[105] Meng, F. (1993). Component-relevancy and characterisation in multi-state systems. *IEEE Transactions on Reliability* 42, 478-483.

[106] Mercier, S. (2008). Numerical bounds for semi-Markovian quantities and application to reliability. *Methodology and Computing in Applied Probability*, Vol. 10, No. 2, 179-198.

[107] Merrick, J.R.W. & van Dorp, R. (2006). Speaking the truth in maritime risk assessment. *Risk Analysis*, Vol. 26, No. 1, 223-237.

[108] Natvig, B. (1982). Two suggestions of how to define a multi-state coherent system. *Adv. Applied Probability* 14, 434-455.

[109] Natvig, B. (1984). *Multi-state coherent systems.* In: Encyclopaedia of Statistical Sciences, Wiley and Sons, New York.

[110] Natvig, B. & Streller, A. (1984). The steady-state behaviour of multistate monotone systems. *J. Applied Probability* 21, 826-835.

[111] Ohio, F. & Nishida, T. (1984). On multistate coherent systems. *IEEE Transactions on Reliability* 33, 284-287.
[112] Rice, J.A. (2007). *Mathematical statistics and data analysis.* Duxbury. Thomson Brooks/Cole. University of California. Berkeley.
[113] Soszyńska, J. (2004). Reliability of large series system in variable operation conditions. *Joint Proceedings 17,* Gdynia Maritime University Press, Gdynia, 36-43.
[114] Soszyńska, J. (2004). Reliability of large parallel systems in variable operation conditions. *Faculty of Navigation Research Works* 16, Gdynia, 168-180.
[115] Soszyńska, J. (2006). Reliability of large series-parallel system in variable operation conditions. International *Journal of Automation and Computing*, Vol. 3, No 2, 199-206.
[116] Soszyńska, J. (2006). Reliability evaluation of a port oil transportation system in variable operation conditions. *International Journal of Pressure Vessels and Piping,* Vol. 83, Issue 4, 304-310.
[117] Soszyńska, J. (2006). Safety analysis of multistate systems in variable operations conditions (in Polish). *Diagnostyka* 3(39), 25-34.
[118] Soszyńska, J. (2007). *Systems reliability analysis in variable operation conditions*. PhD Thesis, Gdynia Maritime University-System Research Institute Warsaw, (in Polish).
[119] Soszyńska, J. (2008). Asymptotic approach to reliability evaluation of large "*m* out of *l*" – series system in variable operation conditions. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association,* Issue 2, Vol. 2, 323-346.
[120] Soszyńska, J. (2010). Reliability and risk evaluation of a port oil pipeline transportation system in variable operation conditions. *International Journal of Pressure Vessels and Piping,* Vol. 87 No 2-3, 81-87.
[121] Soszyńska, J., Kołowrocki, K., Blokus-Roszkowska, A., Guze, S. (2010). Identification of complex technical system components safety models. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association,* Issue 4, Vol.2, 399-496.
[122] Soszyńska, J., Kołowrocki, K., Blokus-Roszkowska, A. & Guze, S. (2010) Prediction of complex technical systems operation processes. *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association,* Issue 4, Vol. 2, 379-510.
[123] Suich, R.C., Patterson, R.L. (1991). k-out-of-n:G system: Some cost considerations. *IEEE Transactions on Reliability*, 40(3), 259-264.
[124] Tang, H., Yin, B.Q. & Xi, H.S. (2007). Error bounds of optimization algorithms for semi-Markov decision processes. *International Journal of Systems Science,* Vol. 38, No. 9,725-736.
[125] Vercellis, S. (2009). *Data mining and optimization for decision making.* John Wiley & Sons Ltd.
[126] Wilson, A.G., Graves, T.L., Hamada, M.S. et al (2006). Advances in data combination, analysis and collection for system reliability assessment. *Statistical Science*, Vol. 21, No. 4, 514-531.
[127] Xue, J. (1985). On multi-state system analysis. *IEEE Transactions on Reliability* 34, 329-337.
[128] Xue, J. & Yang, K. (1995). Dynamic reliability analysis of coherent multi-state systems. *IEEE Transactions on Reliability* 4, Vol. 44, 683-688.
[129] Xue, J., Yang, K. (1995). Symmetric relations in multi-state systems. *IEEE Transactions on Reliability 4*, Vol. 44, 689-693.
[130] Yu, K., Koren, I. & Guo, Y. (1994). Generalised multistate monotone coherent systems. *IEEE Transactions on Reliability* 43, 242-250.
[131] Zio, E. (2006). *An introduction to the basics of reliability and risk analysis*. World Scientific Publishing Co. Pte. Ltd.