Journal of Applied Mathematics and Physics, 2023, 11, 1795-1805
https://www.scirp.org/journal/jamp
ISSN Online: 2327-4379
ISSN Print: 2327-4352

Study of Optimal Frequency to the Repairable System Due to Failure Finding Interval to Maximize Availability System

Emmanuel Hagenimana[1*], Charline Uwilingiyimana[2], Umuraza Clarisse[3]

[1]Department of Civil Engineering, Institut d'Enseignement Supérieur de Ruhengeri, Musanze, Rwanda
[2]Department of Statistics Applied to Economy, Institut d'Enseignement Supérieur de Ruhengeri, Musanze, Rwanda
[3]School of Economics, Shandong University, Qingdao, China
Email: *ehagenimana@ines.ac.rw

How to cite this paper: Hagenimana, E., Uwilingiyimana, C. and Clarisse, U. (2023) Study of Optimal Frequency to the Repairable System Due to Failure Finding Interval to Maximize Availability System. *Journal of Applied Mathematics and Physics*, **11**, 1795-1805.
https://doi.org/10.4236/jamp.2023.116115

Received: May 23, 2023
Accepted: June 27, 2023
Published: June 30, 2023

Abstract

This research article is based on a study of optimal frequency to the repairable system due to the failure finding interval to maximize as well as minimize the availability of some components devices. We studied together maintenance and corrective actions that carried out item of failure and periodic failure finding designed to check whether a system is still working. The model is proved as well as useful application in detecting the problem related to finding failure tasks of different scheme devices by maximization. The model formulated and the numerical application to the relevant mathematical model have been discussed to demonstrate the article quality. Therefore based on probability analytic development, the optimal maintenance policy is then obtained as solution of an optimization problem in which the maintenance cost rate is the objective function and the risk of corrective maintenance is the constraint function. Finally, the solution to the optimal device in the considered development model has been well adjusted due to derivation to the experimental observation rather than theory which will be taken into consideration in the next applied practical design research related and the system device provided that, the proactive device agreed with using the exponential distribution to the survive distribution function which can not be considered as valid.

Keywords

Maximization, Failure Interval, Repairable System, Inspection Interval, Availability System, Optimal Inspection

1. Introduction

It is known that a secure of system machine is spoiled due to different changes or modifications made to it like an extreme substitute done on that machine system which implies the consequence of the component being declined. The loss of ability to function for some parts normally is unpredicted or not notified before, but it is almost a hidden failure system which is only discovered by inspection, the more details can be seen in [1]-[6]. The risk of such an issue is noticed in time the system device is taken into operation and then fails to operate. To determine the failure of the network device, the notification of customary inspection is advised to execute the well-functioning of the system to bring it as good as new as it was before, see [7] [8]. As the failure part of the system is founded the component is automatically taken to be repaired where the failed part will be repaired or replaced respectively as can be seen in [9] [10]. It is understandable that, the system availability of this state device is always determined by the one who is concerned with the maintenance system. And the quality of not being available in the time needed to be used which is known as unavailability has been discussed in [11]-[16], which gives the corrective impact of maintenance action to improve the system device.

In a time of inspection failure part, a failure of system device can be caused by different factors such as determination the occurrence of the failure point followed by the control point, downtime to failure running out. Also, downtime to failure resulting from the reviews time, a system device is taken to the maintenance to replace the damaged part. Otherwise, it will be repaired or replaced. Some of these factors have been discussed here [17]-[22], where the restoration of specification hidden condition is needed to be considered.

It is observed that the downtime of the system is closely related to the inspection conducted in the interval of time. Therefore as checkup time increases, the relative control frequencies are also increased and the entire downtime of inspection while the downtime of failure is decreased too. Hence the optimal point to the inspection interval is needed for minimizing the complete downtime and maximizing the system availability to the state device at the same time [23] [24] [25] [26] [27] which has been discussed in detail.

Different models have been discussed for the given problem above such as [28]-[32]. These models present also enclose limiting assumptions or has some inconveniences.

The purpose of this model is to make a comparison between our presented model with the one presented by Moubray. To define the optimal of finding failure in the given interval to the system device, to maximize as well as minimize the entire downtime of inspection to the state devices, have been investigated in [33] [34] [35].

The rest of this article is organized as the following: In section 2, we consider the model formulation due to the classical one formulated by Moubray. In part 3, we develop some assumptions which will help us in model structure. By section 4, we present the key proof to our model produced. In section 5, the numerical examples have been discussed to compare the classical and new one model considered in this article. Hence, in section 6, we present the conclusion and acknowledgment.

2. Statement of the Problem

Using the same procedures with the one founded in [36], model, which can be derived respectively in the following manner. We assume that $S(\tau)$ and $\overline{S}(\tau)$ are availability and unavailability system respectively at given time τ. The mean time between failure to the inspection component is α, and failure finding interval is denoted as θ, where downtime to failure is noticed as $\frac{\theta}{2}$ in such that downtime and inspection of system device is assumed to be neglected. Let us take $(0,I)$ as the total interval in such that the total number of the average of failures system is given by

$$N_g = \frac{I}{\alpha}.$$

In the same way the entire downtime to failure is also expressed as

$$\delta_\tau = N_g \frac{\theta}{2}$$

The given availability of system is characterised by the following relation

$$S(\tau) = \frac{I-\delta_\tau}{I} = 1 - \frac{\delta_\tau}{I} = 1 - \frac{\theta}{2\alpha}$$

And the given interval of failure to the system is expressed as

$$\theta = 2\alpha(1-S) = 2\alpha\overline{S}(\tau) \tag{1}$$

Such that, $\overline{S}(\tau)$ is taken as unavailability of the system device.

3. Model Assumptions

The model is based on following assumptions which play a significant role in our model formulation.

A_0: An expression $\frac{I}{\alpha}$ is not taken as the entire number of average while I doesn't consider as stopover in regularly working conditions of the system devices.

A_1: An expression $\frac{\theta}{2}$ can't be seen as perfect while the density function of failure condition is taken as exact under the inspected interval time with respected to the symmetric distribution.

A_2: An unavailability to the system devices caused by the inspection time together with repair time have been taken into consideration. We have seen that, in the above statement, the downtime affected by the inspected with repair time is closed related to the relation $\frac{\theta}{2}$ which is tested as not exact as the entire number of the checked time which is too big.

A_3: It is acknowledged that the finding failure interval of system device is characterized by the unavailability of the system device to be minimized instead of limiting to the supplied availability of the system apparatus. It can help us to get the qualified significance availability of the system which can even not be readily determined as such.

4. Main Proof for the Model

From the above assumptions, it is observed that, for downtime to failure case, the inspection time showed the damaged part of the system devices. Where some areas of the component are tested for working slowly or not compared to the ordinary conditions which imply the maintenance to be taken into consideration such as repair or replacement of component material. Therefore let us use exponential distribution to represent Weibull distribution in the case of time failure to the system device which has a similar mean. In the same way, it better to consider some assumptions to the exponential where the symmetric condition to the density function is less measured in the situation.

Then, let us suppose that the failure to the density function has the following expression,

$$g(\tau) = \frac{1}{\alpha}\exp\left(\frac{\tau}{\alpha}\right)$$

The conditional to the density function given in the interval time is (τ_j, τ_{j+1}), such that $\tau_j = j\theta, j = 0, 1, \cdots$, which is provided by the following equation

$$g_\varsigma(\tau) = \frac{g(\tau)}{G(\tau_{j+1}) - G(\tau_j)} = \frac{g(\chi)}{1 - \exp\left(-\frac{\theta}{\alpha}\right)}$$

then $\chi = \tau - \tau_j$. We conclude that, the expression to the expectation of downtime to failure τ_j, τ_{j+1} is expressed by the following relation

$$I_g = \frac{1}{1 - \exp\left(-\frac{\theta}{\alpha}\right)}\int_0^\theta (\theta - \chi) g(\chi)\,\mathrm{d}\chi = \frac{\theta}{1 - \exp\left(\frac{\theta}{\alpha}\right)} - \alpha \tag{2}$$

It is understandable that, I_j is taken as a function of θ with α which is independent of the inspected time. Assume that I_i with I_r are considered as average to the inspection time with repair time severally. Suppose that the adequate interval time $(0, I)$, such that I is considered as the entire regular time taken for the failure of system device, where inspection time with repair time are not included. Therefore, the failure to the whole number of average is expressed by,

$$N_g = \frac{I}{\alpha + I_g}$$

in the same way, the complete number of average to the inspection time is represented by the following,

$$N_i = \frac{I}{\theta}$$

where, the entire downtime is determined by

$$\delta_g = N_g\left(I_g + I_r\right) + N_i I_i$$

the entire time, inspection with repair time are respectively expressed by the following relation

$$I_\tau = I + N_g I_r + N_i I_i.$$

Hence, the expression of system availability is taken as

$$S(\tau) = 1 - \frac{\delta_\tau}{I_\tau} = \frac{1 - \dfrac{I_g + I_r}{\alpha + I_g} + \dfrac{I_i}{\theta}}{1 + \dfrac{I_r}{\alpha + I_g} + \dfrac{I_i}{\theta}} = \frac{1}{\dfrac{I_r}{\alpha} + \gamma(\theta)} \tag{3}$$

as such that

$$\gamma(\theta) = \left(1 + \frac{I_i}{\theta}\right)\left(1 + \frac{I_g}{\alpha}\right) \tag{4}$$

By the above expression (3) with (4), the unavailability system is closed related to the minimum of $\gamma(\theta)$. Such that the optimal finding failure interval can not be influenced by repair time of the system which is I_r, while it can perform the unavailability system.

Applying the relation (2) to the given relation (4) we get,

$$\gamma(\theta) = \frac{\dfrac{\theta}{\alpha} + \dfrac{I_i}{\alpha}}{1 - \exp\left(-\dfrac{\theta}{\alpha}\right)}$$

We are interested to see the behaviour of the function $\gamma(\theta)$ where the relation $\dfrac{\mathrm{d}\gamma(\theta)}{\mathrm{d}\theta} = 0$ with

$$\exp(\nu) - 1 = \nu + \rho$$

represents a figure which having minimum at the point $\theta = \theta_\varepsilon$, that is unique where

$$\rho = \frac{I_i}{\alpha}, \nu = \frac{I_i}{\theta}$$

It is understandable that, θ_ε is considered as function to the given variable ρ.

Consider

$$\gamma_\alpha = \gamma(\theta_\varepsilon),$$

We have the maximum to the availability of system which is expressed by the following

$$S_{\max}(\tau) = \frac{1}{\dfrac{I_r}{\alpha} + \gamma_\alpha}$$

which is indicated by $S_{0,\max}(\tau)$.

Therefore, the following expression is retained

$$S_{0,\max}(\tau) = S_{\max}(\tau)(I_r = 0) = \frac{1}{\gamma_\alpha}.$$

Hence, $S_{\max}(\tau)$ is expressed by the following

$$S_{\max}(\tau) = \frac{S_{0,\max}(\tau)}{1 + S_{0,\max}(\tau)\frac{I_r}{\alpha}}.$$

It is clear that, $\frac{I_i}{\alpha} \to 0, \frac{\theta_\varepsilon}{\alpha} \to 0$ together with $S_{0,\max} \to 1$

Therefore, $\frac{\theta_\varepsilon}{\alpha}$ is increasing so fast, since $S_{0,\max}(\tau)$ is decreasing in $\frac{I_i}{\alpha}$.

However $\frac{I_i}{\alpha}$ is absolutely smallest one.

To simplify our model solution, we adjust the following important expressions below.

$$\frac{\theta_\varepsilon}{\alpha} = 1.2725\left(\frac{I_i}{\alpha}\right)^{0.5748}, S_{0,\max} = 1 - 0.9806\left(\frac{I_i}{\alpha}\right)^{0.4570}. \tag{5}$$

By considering the relation (5), we get

$$\frac{\theta_\varepsilon}{\alpha} = 1.3259\left(1 - S_{0,\max}\right)^{1.0968}$$

5. Numerical Example for Model Application

Using the related data discussed by [37] [38] in his model, we illustrate the formula developed above where the entire time services in a period of one year is considered as $I = 30$. And the total failure number of the system device is taken as $N_g = 3$, such that the interval time of sampling have been taking a year. Therefore mean time between failure interval, in this case, is 10 years maximum. By using the assumption to the exponential distribution, mean time between to failure is expressed as the following,

$$\alpha = \frac{I - N_g I_g}{N_g} = 9.4924$$

The error observed in this case is relatively around 5.1%. Using the assumption of $\frac{\theta}{2}$, $I_g = 0.51$; together with assumption on exponential distribution

$$I_g = 0.5076,$$

We get

$$\frac{\theta}{\alpha} = \frac{1}{9.4924} = 0.1053474358 \simeq 0.1053$$

In general, due to these assumptions, the downtime to the failure of the system produce an error in the following derived relation.

$$\frac{I_g - \frac{\theta}{2}}{I_g} = \left(0.1038 + 15.2849\frac{\theta}{\alpha}\right)\%$$

Therefore the error generated is closed related to the large interval of the inspection made on the system device. Thus, let us use $\frac{I_g}{\alpha} = 0.0004$, we get the following relative value

$$\frac{\theta_\varepsilon}{\alpha} = 0.0252, S_{0,\max} = 98.58\%$$

Which is impossible to get the availability of the system having a significant value of 98.58%.

Since $\frac{I_r}{\alpha}$ varies from 0.0004 up to 0.004, $\frac{S_{0,\max}(\tau) - S_{\max}(\tau)}{S_{0,\max}(\tau)}$ also varies from 0.0284% up to 0.2910%, which express that the repair time of the system can not cause the change to the availability of system device.

By considering of availability to the system which is $S(\tau) < S_{0,\max}(\tau)$, the relation given above in (12) provides two solutions of variable θ. Where those solutions are considered to be less compared to the θ_ε, otherwise has a value which is bigger than θ_ε respectively. Therefore, the biggest or greater one is selected to be economic system as an efficiency solution of θ.

Under the two models proposed here is to compare between the old one and new one, which is constructed through to the value of availability system where $I_g = 0$ together with $\frac{I_i}{\alpha} = 0.0004$. The estimate solution of finding failure interval time from the relation (12) together with (4) have been illustrated in Table 1 below. It implies the largest deviation value due to the biggest value to

Table 1. Different failures interval founded due to parameter value of θ attributed.

$S(\tau)$	θ in Equation (3) (Months)	θ M. model $\alpha = 9.4924$	error %	θ M.model $\alpha = 10$	error%
0.9858	2.7498	5.4786	97.68	5.7786	108.28
0.98	5.5562	6.8226	22.67	7.1600	29.26
0.97	8.4184	9.0845	8.07	9.5000	13.78
0.96	11.0682	11.3786	2.79	11.8200	8.26
0.95	13.6517	13.6562	0.03	14.3800	5.38
0.94	16.2345	15.9351	1.78	16.7400	3.39
0.93	18.8326	18.2180	3.19	19.1800	1.79
0.92	21.4452	20.4982	4.37	21.5800	0.58
0.91	24.1018	22.7578	5.38	23.8700	0.37
Expected value			16.21		19.01

the availability of the system. Therefore, from the above observation the given above relation in (4) is closed related to the unavailability of the scheme which is smaller than 5.1%.

Hence, the given system device provided that, the protective device agrees with using the exponential distribution to the survive distribution function which can not be considered as a valid, accurate statement to maintain in this new model derived

6. Conclusions

In this article, we have used different models to develop an effective one to find out the optimal finding failure interval for the system device. And the solutions to the optimal device in the considered developed model has well adjusted due to derivation to the experimental observation rather than theory, which may be taken into consideration in the next applied practical design research related. In the theory of mathematical application in this model, we have theoretically and mathematically demonstrated a big gap between the two considered models, the classic one and the new one developed in this article. Hence our suggestion to our reader is to use the new one developed model more than the classic one in their practical application for next research.

Our future related research will be focussed on an extension of our model by using more than one of the new assumptions. Our major challenge is to formulate a research model where the system degradation will be explained by conditional parameters such as those related to climate change. The above new idea will help us to achieve maximum efficiency in the next failure finding task by optimization.

Acknowledgements

Sincere thanks to the members of JAMP for their professional performance, and special thanks to managing editor *Hellen XU* for a rare attitude of high quality.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Babishin, V. and Taghipour, S. (2016) Joint Optimal Maintenance and Inspection for a k-Out-of-n System. *The International Journal of Advanced Manufacturing Technology*, **87**, 1739-1749. https://doi.org/10.1007/s00170-016-8570-z

[2] Taghipour, S. and Banjevic, D. (2011) Periodic Inspection Optimization Models for a Repairable System Subject to Hidden Failures. *IEEE Transactions on Reliability*, **60**, 275-285. https://doi.org/10.1109/TR.2010.2103596

[3] Hagenimana, E., Song, L.X. and Kandege, P. (2016) Computation of Instant System Availability and Its Applications. *SpringerPlus*, **5**, Article No. 954. https://doi.org/10.1186/s40064-016-2590-x

[4] Hauge, B.S. (2002) Optimizing Intervals for Inspection and Failure-Finding Tasks. *Proceedings of Annual Reliability and Maintainability Symposium*, Seattle, WA, USA, 28-31 January 2002. https://doi.org/10.1109/RAMS.2002.981613

[5] Babishin, V. and Taghipour, S. (2016) Optimal Maintenance Policy for Multicomponent Systems with Periodic and Opportunistic Inspections and Preventive Replacements. *Applied Mathematical Modelling*, **40**, 10480-10505. https://doi.org/10.1016/j.apm.2016.07.019

[6] Berdai, M., Tahan, A. and Gagnon, M. (2017) Imprecise Probabilities in Fatigue Reliability Assessment of Hydraulic Turbines. *Journal of Risk and Uncertainty in Engineering Systems*, *Part B*: *Mechanical Engineering*, **3**, 011006. https://doi.org/10.1115/1.4034690

[7] Hagenimana, E., Song, L.X. and Kandege, P. (2016) Technical Application for Inspection Sampling for Repairable Systems in an Economic System. *SpringerPlus*, **5**, Article No. 1955. https://doi.org/10.1186/s40064-016-3605-3

[8] Rausand, M. and Vatn, J. (2017) Reliability Centred Maintenance. In: *Complex System Maintenance Handbook*, Springer, London, 79-108. https://doi.org/10.1007/978-1-84800-011-7_4

[9] Qiu, Q.G., Cui, L.R. and Gao, H.D. (2017) Availability and Maintenance Modelling for Systems Subject to Multiple Failure Modes. *Computers & Industrial Engineering*, **108**, 192-198. https://doi.org/10.1016/j.cie.2017.04.028

[10] McPherson, J.W. (2013) Reliability Physics and Engineering: Time-to-Failure Modeling. Springer, New York.

[11] Ahmadi1, A., Kumar, U. and Söderholm, P. (2010) Operational Risk of Aircraft System Failure. *International Journal of Performability Engineering*, **6**, 149-158.

[12] Ben-Daya, M. and Rahim, M.A. (2001) Integrated Production, Quality & Maintenance Models. In: Rahim, M.A. and Ben-Daya, M., eds., *Integrated Models in Production Planning*, *Inventory*, *Quality*, *and Maintenance*, Springer, Boston, MA, 3-28. https://doi.org/10.1007/978-1-4615-1635-4_1

[13] Hopkinson, J., Perera, N. and Kiazim, E. (2016) Investigating Reliability Centered Maintenance (RCM) for Public Road Mass Transportation Vehicles. *MATEC Web of Conferences*, **81**, 08006. https://doi.org/10.1051/matecconf/20168108006

[14] Bris, R. (2003) New Method to Minimize the Preventive Maintenance Cost of Series-Parallel Systems. *Reliability Engineering & System Safety*, **82**, 247-255. https://doi.org/10.1016/S0951-8320(03)00166-2

[15] Emovon, I., Norman, R.A. and Murphy, A.J. (2016) Elements of Maintenance System and Tools for Implementation within Framework of Reliability Centred Maintenance—A Review. *Journal of Mechanical Engineering and Technology*, **8**, 1-34.

[16] Ahmadi, A. and Kumar, U. (2011) Cost Based Risk Analysis to Identify Inspection and Restoration Intervals of Hidden Failures Subject to Aging. *IEEE Transactions on Reliability*, **60**, 197-209. https://doi.org/10.1109/TR.2011.2104530

[17] Nabati, E.G. and Thoben, K.D. (2017) Big Data Analytics in the Maintenance of Off-Shore Wind Turbines: A Study on Data Characteristics. In: Freitag, M., Kotzab, H. and Pannek, J., eds., *Dynamics in Logistics. Lecture Notes in Logistics*, Springer, Cham, 131-140. https://doi.org/10.1007/978-3-319-45117-6_12

[18] da Motta, S.B. and Colosimo, E.A. (2002) Determination of Preventive Maintenance Periodicities of Standby Devices. *Reliability Engineering & System Safety*, **76**, 149-154. https://doi.org/10.1016/S0951-8320(01)00134-X

[19] Percy, D. and Kobbacy, K.A.H. (2000) Determining Economical Maintenance Intervals. *International Journal of Production Economics*, 67, 87-94. https://doi.org/10.1016/S0925-5273(00)00013-X

[20] Rausand, M. (2004) System Reliability Theory: Models, Statistical Methods, and Applications. John Wiley & Sons, Hoboken, 397 p.

[21] Kuschel, T. (2017) The Capacitated Planned Maintenance Problem. In: *Capacitated Planned Maintenance*, Springer, Cham, 7-24. https://doi.org/10.1007/978-3-319-40289-5_2

[22] Ylipää, T., Skoogh, A., Bokrantz, J. and Gopalakrishnan, M. (2017) Identification of Maintenance Improvement Potential Using OEE Assessment. *International Journal of Productivity and Performance Management*, **66**, 126-143. https://doi.org/10.1108/IJPPM-01-2016-0028

[23] Duan, C., Deng, C. and Wang, B.R. (2019) Multi-Phase Sequential Preventive Maintenance Scheduling for Deteriorating Repairable Systems. *Journal of Intelligent Manufacturing*, **30**, 1779-1793. https://doi.org/10.1007/s10845-017-1353-z

[24] Mehairjan, R.P.Y. (2017) Risk Linked Reliability-Centred Maintenance Management Model. In: *Risk-Based Maintenance for Electricity Network Organizations*, Springer, Cham, 55-81. https://doi.org/10.1007/978-3-319-49235-3_4

[25] Tekin, I., Durgun, M.Y., Gencel, O., *et al.* (2017) Concretes with Synthetic Aggregates for Sustainability. *Construction and Building Materials*, **133**, 425-432. https://doi.org/10.1016/j.conbuildmat.2016.12.110

[26] Zhang, J.C., Lyu, H. and Hou, J.X. (2003) A Novel General Model for RAP and RRAP Optimization of k-Out-of-n: G Systems with Mixed Redundancy Strategy. *Reliability Engineering & System Safety*, **82**, 247-255.

[27] Samrout, M., Yalaoui, F., Châtelet, E. and Chebbo, N. (2005) New Methods to Minimize the Preventive Maintenance Cost of Series-Parallel Systems Using Ant Colony Optimization. *Reliability Engineering & System Safety*, **76**, 346-354. https://doi.org/10.1016/j.ress.2004.09.005

[28] Cadini, F., Agliardi, G.L. and Zio, E. (2017) Estimation of Rare Event Probabilities in Power Transmission Networks Subject to Cascading Failures. *Reliability Engineering & System Safety*, **158**, 9-20. https://doi.org/10.1016/j.ress.2016.09.009

[29] Jiang, R.Y. and Jardine, A.K.S. (2006) Optimal Failure-Finding Interval through Maximizing Availability Optimal Failure-Finding Interval through Maximizing Availability. *International Journal of Plant Engineering and Management*, **3**, 174-178.

[30] Lienhardt, B., Hugues, E., Bes, C. and Noll, D. (2008) Failure-Finding Frequency for a Repairable System Subject to Hidden Failures. *Journal of Aircraft*, **45**, 1804-1809. https://doi.org/10.2514/1.31149

[31] Leemis, L. (2017) Lower Confidence Bounds for System Reliability from Binary Failure Data Using Bootstrapping. In: Glen, A. and Leemis, L., eds., *Computational Probability Applications*, Springer, Cham, 217-237. https://doi.org/10.1007/978-3-319-43317-2_15

[32] Zhao, H., You, J.-X. and Liu, H.-C. (2016) Failure Mode and Effect Analysis Using MULTIMOORA Method with Continuous Weighted Entropy under Interval-Valued Intuitionistic Fuzzy Environment. *Soft Computing*, **21**, 5355-5367. https://doi.org/10.1007/s00500-016-2118-x

[33] Alaswad, S. (2017) A Review on Condition-Based Maintenance Optimization Models for Stochastically Deteriorating System. *Reliability Engineering & System Safety*, **157**, 54-63. https://doi.org/10.1016/j.ress.2016.08.009

[34] ten Wolde, M. and Ghobbar, A.A. (2013) Optimizing Inspection Intervals Reliability and Availability in Terms of a Cost Model: A Case Study on Railway Carriers. *Reliability Engineering & System Safety*, **114**, 137-147. https://doi.org/10.1016/j.ress.2012.12.013

[35] Dhillon, B.S. (1988) Mechanical Reliability: Theory, Models, and Applications. Amer Inst of Aeronautics &.

[36] Ahmadi, A., Söderholm, P. and Kumar, U. (2010) On Aircraft Scheduled Maintenance Program Development. *Journal of Quality in Maintenance Engineering*, **16**, 229-255. https://doi.org/10.1108/13552511011072899

[37] Bhangu, N.S., Pahuja, G.L. and Singh, R. (2017) Enhancing Reliability of Thermal Power Plant by Implementing RCM Policy and Developing Reliability Prediction Model: A Case Study. *International Journal of System Assurance Engineering and Management*, **8**, 1923-1936. https://doi.org/10.1007/s13198-016-0542-z

[38] Demidenko, E. (2013) Mixed Models: Theory and Applications with R Capacitated Planned Maintenance. John Wiley & Sons, Hoboken.