MATHEMATICAL MODELING AND COMPUTING, Vol. 8, No. 3, pp. 465–473 (2021)

Mathematical modelling to industrial repair and maintenance policy system for its reliability

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(Received 4 February 2021; Revised 28 May 2021; Accepted 19 June 2021)

The present paper is an initiative taken by emerging reliability model to a automobile repair industries for its products by dividing repair policy into two categories as (a) regular/normal service and (b) strategy for accidental or additional failure. The concept of inspection process has been introduced for proper verification of failure and also to its repairing strategy with time and cost. The maintenance cost for regular services are fixed but for the case of additional failures the additional cost will be decided upon the level of damage. The stochastic analysis for system been numerically and graphically analyzed by calculating reliability variables like MTSF, availability, inspection and maintenance analysis of the system with the concept of geometric distribution, Markov process and regenerative technique. The results been proved beneficial for fulfilling the objective of calculating profit function that increases with increasing repair and decreasing failure rate.

Keywords: *stochastic processes, Markov renewal processes, reliability, availability, maintenance and inspection period.*

2010 MSC: 60K10, 60K20, 62N05, 90B25 **DOI:** 10.23939/mmc2021.03.465

1. Introduction

In the industrial world, the working process are changing every year due to the enhancement in new technologies for manufacturing and maintenance strategies. For the growth of any industry, two important factors to be required are regular incorporation of new designs and providing excellent and advanced maintenance strategies to its customer. So, the present paper is taken to be an initiative in the study of maintenance strategy of an automobile companies for their consumers. The maintenance strategy had been designed for providing service to customer having vehicle as an unit $'X'$ for normal service or high cost failure. On an arrival of unit for its service, first it had to be inspected by an inspection team possessing probability value p_1 for estimating the level of failure. After first inspection state X_I, the failed unit has to be passed out for an repair department following two different mechanisms (a) repair mechanism for the normal or regular service with probability value p_2' and (b) repairing strategy for an accidental or additional failure with probability value p_2'' such that $p_2 = p_2' + p_2''$. Due to complexity of process containing additional failure, its maintenance and handling cost along with repair time and rate r_2 is more as compared to the normal or regular service r_1. So, the repair preference is always maintained for the normal service. Over the past years, many researchers had studied the reliability problems concerning to the different technical or non-technical world . In 2014, Singh et al. [1] applied stochastic technique for examining a turbine plant. Also, Bhatti et al. [2, 3] initiated by introducing the preferable repairing strategy through the geometric distributions for the industrial models.

In 2016, Hua et al. [4, 5] had inculcated the strategy of unit degradation paths in reliability analysis. In case of assessing cable plant subsystem Taj S. Z. et al. [6] framed probabilistic modeling for betterment of its reliability. Mechanical systems having assembling, activation time are considered by Adlakha N. [7], Cui et al. [8,9]. The application of F and G balanced systems under Markov processes are analyzed through Endharta et al. [10]. Chen W.-L. et al. [11] examined retrial machine repair systems with single recovery policy for server breakdown. The concept of industrial modeling was proposed by Saini [12,13] and Barak [14], neural network prediction model by Bhardwaj S. et al. [15] and use of bivariate wiener processes through Dong Q. L. et al. [16] had added new definition to reliability analysis of industrial and non-industrial models in the past year. In addition to above, the balanced mechanisms for examining balanced systems and common cause failures had also been studied by [17–20], Garg R. et al. [21] and Bhatti et al. [22–25] also added their contribution to reliability study of an industrial system using redundancy policy.

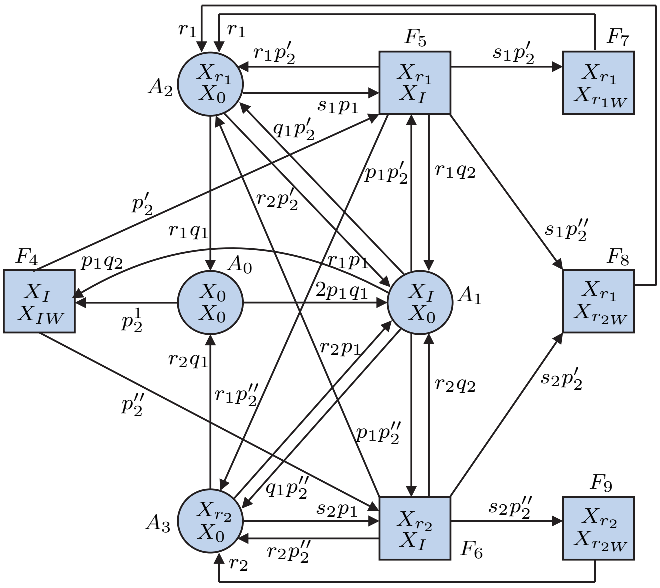

Fig. 1. Transition Model. **Failure States**: $F_4 = (X_I, X_{IW})$, $F_5 = (X_{r_1}, X_I)$, $F_6 = (X_{r_2}, X_I)$, $F_7 = (X_{r_1}, X_{r_{1W}})$, $F_8 = (X_{r_1}, X_{r_{2W}})$, $F_9 = (X_{r_2}, X_{r_{2W}})$. **Availability States**: $A_0 = (X_0, X_0)$, $A_1 = (X_I, X_0)$, $A_2 = (X_{r_1}, X_0)$, $A_3 = (X_0, X_{r_2})$.

In the present paper, an reliability model for vehicle repair service system been designed for the automobiles regular service and accidental failures. In case of failure due to accidents or due to any other reason the inspection process inspect the kind of damage and its repairing strategy with additional time and cost. But for the case of regular service, the maintenance service process and cost were already fixed without any additional cost. This paper provides the results/findings for analyzing the profit analysis by evaluating availability, inspection and distinct repair period for the different failures using geometric distribution, Markov renewal processes. Possible states of the system under operative and failed states are reflected through the transition model Fig. 1.

2. Transition probabilities

Using the transition diagram shown in Fig. 1, the steady state transition probabilities from state S_i to S_j can be calculated by applying

$$P_{ij} = \lim_{t \to \infty} Q_{ij}$$

where Q_{ij} depicts the cumulative density function from the first regenerative state $'i'$ to the second state $'j'$. The evaluated transition probabilities are as follows:

$$P_{01} = \frac{2p_1q_1}{1-q_1^2}, \quad P_{04} = \frac{p_1^2}{1-q_1^2}, \quad P_{12} = \frac{q_1p_2'}{1-q_1q_2}, \quad P_{13} = \frac{q_1p_2''}{1-q_1q_2}, \quad P_{14} = \frac{p_1q_2}{1-q_1q_2},$$

$$P_{15} = \frac{p_1p_2'}{1-q_1q_2}, \quad P_{16} = \frac{p_1p_2''}{1-q_1q_2}, \quad P_{20} = \frac{r_1q_1}{1-s_1q_1}, \quad P_{21} = \frac{r_1p_1}{1-s_1q_1}, \quad P_{25} = \frac{s_1p_1}{1-s_1q_1},$$

$$P_{30} = \frac{r_2q_1}{1-s_2q_1}, \quad P_{31} = \frac{r_2p_1}{1-s_2q_1}, \quad P_{36} = \frac{s_2p_1}{1-s_2q_1}, \quad P_{45} = \frac{p_2'}{1-q_2}, \quad P_{46} = \frac{p_2''}{1-q_2},$$

$$P_{51} = \frac{r_1q_2}{1-s_1q_2}, \quad P_{52} = \frac{r_1p_2'}{1-s_1q_2}, \quad P_{53} = \frac{r_1p_2''}{1-s_1q_2}, \quad P_{57} = \frac{s_1p_2'}{1-s_1q_2}, \quad P_{58} = \frac{s_1p_2''}{1-s_1q_2},$$

$$P_{61}=\frac{r_2q_2}{1-s_2q_2},\quad P_{62}=\frac{r_2p_2'}{1-s_2q_2},\quad P_{63}=\frac{r_2p_2''}{1-s_2q_2},\quad P_{68}=\frac{s_2p_2'}{1-s_2q_2},\quad P_{69}=\frac{s_2p_2''}{1-s_2q_2},$$
$$P_{72}=P_{82}=\frac{r_1}{1-s_1},\quad P_{93}=\frac{r_2}{1-s_2}.$$

Mean sojourn times. By denoting mentioning sojourn time in state $S_i(i=0-9)$ by symbol $'\mu_i'$, the value of mean sojourn time for state S_i is calculated as:

$$\mu_0=\frac{1}{1-q_1^2},\quad \mu_1=\frac{1}{1-q_1q_2},\quad \mu_2=\frac{1}{1-s_1q_1},\quad \mu_3=\frac{1}{1-s_2q_1},\quad \mu_4=\frac{1}{1-q_2},$$
$$\mu_5=\frac{1}{1-s_1q_2},\quad \mu_6=\frac{1}{1-s_2q_2},\quad \mu_7=\mu_8=\frac{1}{1-s_1},\quad \mu_9=\frac{1}{1-s_2}.$$

3. Mean time to system failure (MTSF)

To calculate MTSF of the proposed system, the absorbing states are taken to be the failure ones. Then, MTSF analysis at time $'t'$ is obtained by solving the following equations:

$$X_0=Z_0+q_{01}©X_1, \tag{1}$$
$$X_1=Z_1+q_{12}©X_2+q_{13}©X_3, \tag{2}$$
$$X_2=Z_2+q_{20}©X_0+q_{21}©X_1, \tag{3}$$
$$X_3=Z_3+q_{30}©X_0+q_{31}©X_1. \tag{4}$$

Solving above equations, one can obtain

$$\text{MTSF}=\frac{N_1}{D_1}$$

where

$$N_1=\mu_0(1-P_{12}P_{21}-P_{13}P_{21})+\mu_1P_{01}+\mu_2P_{01}(P_{12}+P_{13}), \tag{5}$$
$$D_1=1-P_{21}P_{12}-P_{21}P_{13}+P_{20}P_{01}(P_{12}+P_{13}). \tag{6}$$

4. Availability Analysis of the System

Using reliability models design as Fig. 1, the relationships on availability period of the system are obtained as:

$$X_0=Z_0+q_{01}©X_1++q_{04}©X_4, \tag{7}$$
$$X_1=Z_1+q_{12}©X_2+q_{13}©X_3+q_{14}©X_4+q_{15}©X_5+q_{16}©X_6, \tag{8}$$
$$X_2=Z_2+q_{20}©X_0+q_{21}©X_1+q_{25}©X_5, \tag{9}$$
$$X_3=Z_3+q_{30}©X_0+q_{31}©X_1+q_{36}©X_6, \tag{10}$$
$$X_4=q_{45}©X_5+q_{46}©X_6, \tag{11}$$
$$X_5=q_{51}©X_1+q_{52}©X_2+q_{53}©X_3+q_{57}©X_7+q_{58}©X_8, \tag{12}$$
$$X_6=q_{61}©X_1+q_{62}©X_2+q_{63}©X_3+q_{68}©X_8+q_{69}©X_9, \tag{13}$$
$$X_7=q_{72}©X_2, \tag{14}$$
$$X_8=q_{82}©X_2, \tag{15}$$
$$X_9=q_{93}©X_3. \tag{16}$$

Solving of the last equations gives the value of availability period of system as:

$$A_0 = -\frac{N_2(1)}{D_2(1)},$$

$$\begin{aligned} N_2(1) &= \mu_0 P_{20}[1 - P_{51} + P_{51}(P_{12} + P13)] + \mu_1[(P_{21} + P_{25}P_{51}) + P_{20}(P_{01} + P_{04}P_{51})] \\ &\quad + \mu_2 P_{01}[P_{12} + P_{52}(1 - P_{12} - P13)] + \mu_3[P_{01}(P_{13} + P_{53}(1 - P_{12} - P13)) \\ &\quad + 1 - P_{51}], \end{aligned} \tag{17}$$

$$\begin{aligned} D_2(1) &= -[\mu_0 P_{20}[1 - P_{51} + P_{51}(P_{12} + P13)] + \mu_1[(P_{21} + P_{25}P_{51}) + P_{20}(P_{01} + P_{04}P_{51})] \\ &\quad + \mu_2 P_{01}[P_{12} + P_{52}(1 - P_{12} - P13)] + \mu_3[P_{01}(P_{13} + P_{53}(1 - P_{12} - P13)) \\ &\quad + 1 - P_{51}] + \mu_4[P_{20}P_{04}(1 - P_{51}(P_{15} + P_{16})) + P_{14}(P_{21} + P_{20}P_{01}) \\ &\quad + P_{14}P_{25}P_{51}] + (\mu_5 + \mu_6)[1 - (P_{21} + P_{20}P_{01})(P_{12} + P_{13})] + (\mu_7 + \mu_8 + \mu_9) \\ &\quad \times [1 - (P_{12} + P_{13})(P_{21} + P_{20}P_{01})](P_{57} + P_{58})] \end{aligned} \tag{18}$$

5. Inspection analysis of the system

Using reliability models design as Fig. 1, the relations consisting of inspecting the failure of system are obtained as:

$$X_0 = q_{01}ⓒX_1 + +q_{04}ⓒX_4, \tag{19}$$
$$X_1 = Z_1 + q_{12}ⓒX_2 + q_{13}ⓒX_3 + q_{14}ⓒX_4 + q_{15}ⓒX_5 + q_{16}ⓒX_6, \tag{20}$$
$$X_2 = q_{20}ⓒX_0 + q_{21}ⓒX_1 + q_{25}ⓒX_5, \tag{21}$$
$$X_3 = q_{30}ⓒX_0 + q_{31}ⓒX_1 + q_{36}ⓒX_6, \tag{22}$$
$$X_4 = Z_4 + q_{45}ⓒX_5 + q_{46}ⓒX_6, \tag{23}$$
$$X_5 = Z_5 + q_{51}ⓒX_1 + q_{52}ⓒX_2 + q_{53}ⓒX_3 + q_{57}ⓒX_7 + q_{58}ⓒX_8, \tag{24}$$
$$X_6 = Z_6 + q_{61}ⓒX_1 + q_{62}ⓒX_2 + q_{63}ⓒX_3 + q_{68}ⓒX_8 + q_{69}ⓒX_9, \tag{25}$$
$$X_7 = q_{72}ⓒX_2, \tag{26}$$
$$X_8 = q_{82}ⓒX_2, \tag{27}$$
$$X_9 = q_{93}ⓒX_3. \tag{28}$$

Whence, the value of reliability parameters is the next:

$$B_0 = -\frac{N_3(1)}{D_2(1)},$$

where

$$\begin{aligned} N_3(1) &= \mu_1[(P_{21} + P_{25}P_{51}) + P_{20}(P_{01} + P_{04}P_{51})] + \mu_4[P_{20}P_{04}(1 - P_{51}(P_{15} + P_{16})) \\ &\quad + P_{14}(P_{21} + P_{20}P_{01}) + P_{14}P_{25}P_{51}] + (\mu_5 + \mu_6)[1 - (P_{21} + P_{20}P_{01})(P_{12} + P_{13})]. \end{aligned} \tag{29}$$

6. Maintenance analysis of the system

Using reliability models design as Fig. 1, the relations related to maintenance analysis consisting of repairing the failure of system are obtained as:

$$X_0 = Z_0 + q_{01}ⓒX_1 + +q_{04}ⓒX_4, \tag{30}$$
$$X_1 = Z_1 + q_{12}ⓒX_2 + q_{13}ⓒX_3 + q_{14}ⓒX_4 + q_{15}ⓒX_5 + q_{16}ⓒX_6, \tag{31}$$

$$X_2 = Z_2 + q_{20}©X_0 + q_{21}©X_1 + q_{25}©X_5, \quad (32)$$
$$X_3 = Z_3 + q_{30}©X_0 + q_{31}©X_1 + q_{36}©X_6, \quad (33)$$
$$X_4 = Z_4 + q_{45}©X_5 + q_{46}©X_6, \quad (34)$$
$$X_5 = Z_5 + q_{51}©X_1 + q_{52}©X_2 + q_{53}©X_3 + q_{57}©X_7 + q_{58}©X_8, \quad (35)$$
$$X_6 = Z_6 + q_{61}©X_1 + q_{62}©X_2 + q_{63}©X_3 + q_{68}©X_8 + q_{69}©X_9, \quad (36)$$
$$X_7 = Z_7 + q_{72}©X_2, \quad (37)$$
$$X_8 = Z_8 + q_{82}©X_2, \quad (38)$$
$$X_9 = Z_9 + q_{93}©X_3. \quad (39)$$

Whereof, the values of maintenance/repair parameters are:

Busy schedule of Repairman r_1:

$$B_0' = -\frac{N_4(1)}{D_2(1)}, \quad Z_i = 0 \quad \text{for} \quad i = 0,1,3,4,6,9.$$

Busy schedule of Repairman r_2:

$$B_0'' = -\frac{N_5(1)}{D_2(1)}, \quad Z_i = 0 \quad \text{for} \quad i = 0,1,2,4,5,7,8.$$

where

$$N_4(1) = \mu_2 P_{01}[P_{12} + P_{52}(1 - P_{12} - P13)] + \mu_5[1 - (P_{21} + P_{20}P_{01})(P_{12} + P_{13})] + (\mu_7 + \mu_8)[1 - (P_{12} + P_{13})(P_{21} + P_{20}P_{01})](P_{57} + P_{58}), \quad (40)$$
$$N_5(1) = \mu_3[P_{01}(P_{13} + P_{53}(1 - P_{12} - P13)) + 1 - P_{51}] + \mu_6[1 - (P_{21} + P_{20}P_{01}) \times (P_{12} + P_{13})] + \mu_9[1 - (P_{12} + P_{13})(P_{21} + P_{20}P_{01})](P_{57} + P_{58}). \quad (41)$$

7. Results and conclusions

The total profit of the system to its steady state will be calculated by using:

$$P = C_1A_0 - C_2B_0 - C_3B_0' - C_4B_0'', \quad (42)$$

where C_1: be the per unit up time revenue by the system. C_2, C_3 and C_4: be the per unit down time expenditure on the system. As per the data analysis, the performance of profit function was analyzed through some fixed parameters C_1,C_2, C_3 and C_4 as $C_1 = 10000$, $C_2 = 1000$, $C_3 = 1500$, $C_4 = 800$, $p_2' = 0.36$ and $p_2'' = 0.24$.

Tables 1 and 2 reflect that the behavior of the profit function and reliability parameters like MTSF, availability analysis, inspection and maintenance cost for the system corresponding to failure rate p_1 and repair rate r_1, r_2 values. Fig. 2 shows that the profit function will decrease with respect to failure rate p_1 for certain r_1, r_2 values. Whereas Fig. 3 reflects its increasing behavior for the certain p_1 with increasing r_1.

Hence in the present paper, the designing of reliability model and its analysis through stochastic and Markov renewal processes has been concluded to be an efficient and beneficial process for analyzing profit function to the vehicle repair mechanism followed in industries. The emphasis or inclusion of division process in repair policy into two categories as (a) regular/normal service and (b) strategy for accidental or additional failure, has added an improvement to the reliability of repair mechanism by avoiding the confusion of characterizing the level of failure and its repair cost. In all, the concept of inspection process in observing and filtering the failed vehicle into two different categories, mathematical modeling, results for reliability parameters had proved to be an effective source for the repairmen, users and service provider for easy handling of failed units.

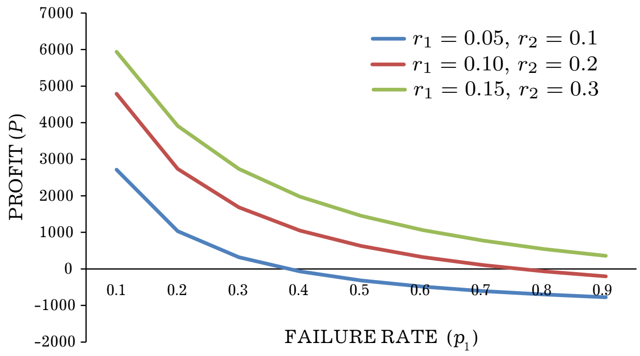

Fig. 2. Profit Function w.r.t Failure rate p_1.

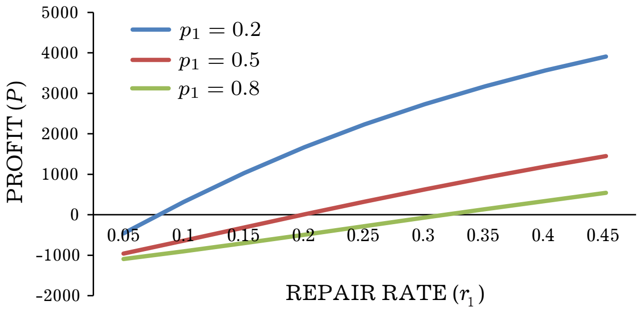

Fig. 3. Profit Function w.r.t Repair Rate r_1.

Table 1. Reliability parameters coresponding to repair r_1, r_2.

Repair, Failure Rate	MTSF	A_0	B_0	B_0'	B_0''	Profit
$r_1 = 0.05$, $r_2 = 0.1$	20.25153	0.380629	0.120876	0.462907	0.346199	2714.089884
	8.391813	0.228019	0.14289	0.541161	0.368779	1030.527018
	5.136245	0.162396	0.151527	0.570916	0.371503	318.8608734
	3.631317	0.126153	0.156087	0.586365	0.371134	-71.0072537
	2.761341	0.103235	0.158904	0.595802	0.370187	-316.4102685
	2.189542	0.087465	0.160822	0.602177	0.369206	-484.8045143
	1.779877	0.075973	0.16221	0.60679	0.368317	-607.3308571
	1.466689	0.067246	0.163286	0.610305	0.367542	-700.3166739
	1.214021	0.060415	0.164136	0.613094	0.366874	-773.1275698
$r_1 = 0.1$, $r_2 = 0.2$	24.53095	0.569349	0.17741	0.333188	0.282714	4790.124792
	9.338624	0.389394	0.236272	0.433009	0.340759	2735.550675
	5.498282	0.295282	0.264469	0.478392	0.360453	1682.404641
	3.800143	0.238045	0.280895	0.503976	0.369078	1048.332413
	2.846442	0.199755	0.291663	0.520372	0.373479	626.5443742
	2.232704	0.172443	0.299307	0.531821	0.375971	326.6120563
	1.800382	0.152058	0.305059	0.540333	0.377499	103.0208718
	1.474781	0.136333	0.309592	0.54698	0.378503	-69.53162112
	1.215894	0.123909	0.313306	0.552391	0.37921	-206.1746362
$r_1 = 0.15$, $r_2 = 0.3$	27.94835	0.671694	0.207058	0.256152	0.2318	5940.214328
	10.12077	0.497987	0.296048	0.353567	0.303256	3910.86254
	5.807068	0.395208	0.344364	0.402908	0.334166	2736.024639
	3.94852	0.328136	0.374602	0.432405	0.350437	1977.799591
	2.923351	0.281236	0.395384	0.452027	0.360175	1450.798626
	2.272727	0.246792	0.410661	0.466107	0.366568	1064.840408
	1.819845	0.220578	0.422496	0.476817	0.371082	771.1928774
	1.482621	0.200106	0.432071	0.485364	0.37447	541.3650528
	1.217741	0.183825	0.440126	0.49248	0.377157	357.6795491

Table 2. Reliability parameters coresponding to Failure rate p_1.

Failure Rate p_1	MTSF	A_0	B_0	B_0'	B_0''	Profit
$p_1 = 0.2$	7.641509	0.082177	0.053364	0.62632	0.35945	-458.6347274
	8.030303	0.158934	0.101175	0.583263	0.369189	317.9212417
	8.391813	0.228019	0.142895	0.541161	0.368779	1030.527018
	8.728814	0.289071	0.178864	0.501739	0.362324	1669.379718
	9.043716	0.342591	0.209748	0.465655	0.352438	2235.724965
	9.338624	0.389394	0.236272	0.433009	0.340759	2735.550675
	9.615385	0.430361	0.259118	0.403637	0.3283	3176.396088
	9.875622	0.466315	0.278877	0.37726	0.315677	3565.841702
	10.12077	0.497987	0.296048	0.353567	0.303256	3910.86254
$p_1 = 0.5$	2.699387	0.034045	0.055027	0.644842	0.350708	-962.4060944
	2.730924	0.06876	0.108263	0.620891	0.362695	-642.155432
	2.761341	0.103235	0.158904	0.595802	0.370187	-316.4102685
	2.790698	0.13682	0.206473	0.570338	0.374011	7.013494318
	2.819048	0.169083	0.250743	0.545062	0.374899	322.5713514
	2.846442	0.199755	0.291663	0.520372	0.373479	626.5443742
	2.872928	0.228695	0.329304	0.496536	0.370278	916.6216037
	2.898551	0.255852	0.363813	0.473723	0.365726	1191.541164
	2.923351	0.281236	0.395384	0.452027	0.360175	1450.798626
$p_1 = 0.8$	1.461149	0.021534	0.055441	0.649416	0.347844	-1092.501846
	1.463934	0.04411	0.1101	0.630453	0.359148	-901.9961643
	1.466689	0.067246	0.163286	0.610305	0.367542	-700.3166739
	1.469415	0.090536	0.214484	0.589431	0.373351	-491.9488854
	1.472112	0.113651	0.263329	0.568217	0.376899	-280.6626106
	1.474781	0.136333	0.309592	0.54698	0.378503	-69.53162112
	1.477421	0.158389	0.353151	0.525972	0.378458	139.0118347
	1.480035	0.179678	0.393969	0.505385	0.377033	343.1033202
	1.482621	0.200106	0.432071	0.485364	0.37447	541.3650528

Acknowledgement

The author is grateful to the Journal Editor and Reviewer for providing valuable comments which led to an improvement in the present manuscript.

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Математичне моделювання системи політики промислового ремонту та технічного обслуговування для її надійності

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Ця стаття є ініціативою, яка вироблена новою моделлю надійності для автомобільних галузей ремонту своєї продукції, розділивши політику ремонту на дві категорії: (a) регулярний/звичайний сервіс та (b) стратегія для випадкових або додаткових відмов. Поняття процесу перевірки було введено для належної перевірки несправності, а також для її стратегії ремонту за часом та витратами. Витрати на обслуговування регулярних послуг фіксовані, але у випадку додаткових збоїв додаткові витрати визначатимуться залежно від рівня збитків. Стохастичний аналіз для системи чисельно та графічно проаналізовано шляхом обчислення змінних надійності, таких як середній час до відмови системи, доступність, перевірка та технічне обслуговування системи з концепцією геометричного розподілу, марковського процесу та регенеративної техніки. Результати виявились корисними для досягнення мети розрахунку функції прибутку, яка зростає зі збільшенням ремонту та зменшенням рівня відмов.

Ключові слова: *стохастичні процеси, процеси відновлення Маркова, надійність, доступність, період технічного обслуговування та перевірки.*