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Стохастический анализ механической системы на предмет ее надежности с различными услугами по ремонту

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Аннотация

Надежность увеличивает свою ценность в развитии механического и промышленного мира за счет включения механизма ремонта, доступности и возможности изготовления машин с различной рабочей мощностью в любых условиях. Настоящая статья представляет собой инициативу, предпринятую с механической системой, работающей с единым сервером ремонта для различного характера отказов и услуг. Стратегия пассивной резервной машины используется для поддержания надежности системы на удовлетворительном уровне. Процесс проверки включен для фильтрации машин в зависимости от их неисправности или уровня ремонтных услуг. Вычисленные числовые и графические данные оказались полезными для выяснения поведения прибыли и надежности при увеличении / уменьшении скорости механизма ремонта и интенсивности отказов. Политика предпочтений была инициирована для регулярных сбоев или сбоев, требующих обычных затрат на обслуживание и периода времени, чем основные, чтобы избежать времени ожидания для обычного клиента.

Ключевые слова: Моделирование надежности, геометрическое распределение, доступность системы, отказ, проверка, стоимость обслуживания и функция прибыли.

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Stochastic analysis to mechanical system to its reliability with varrying repairing services

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Abstract

Reliability is enhancing its value in the advancement of mechanical and industrial world by incorporating the repair mechanism, availability and manufacturing possibility of machines with varying working capacity in all conditions. The present paper is an initiative taken with a mechanical system operating with single repair server facility for varying nature of failures and services. Passive standby machine strategy is adopted for maintaining reliability at a gratified level in the system. The inspection process is included for filtering the machines according to its failure or to the level of repair services. The computed numerical and graphical data is proved to be beneficial for clarifying the profit and reliability behaviour with increasing/decreasing rate of repair mechanism and failure rate. The preference policy has been initiated for regular failure or to the failure requiring normal servicing charges and time period than major ones to avoid the waiting time for normal customer.

Keywords: Reliability modelling, geometric distribution, system availability, failure, inspection, maintenance cost and profit function.

Bibliography: 30 titles.

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1. Introduction

In the real world full of industrial advancement and variety of machines, reliability is adding its major importance for their evaluation and analysis such as manufacturing and availability of machines and system, their repairing mechanism and working capacity in all environmental situations and many more. For keeping the technology more reliable there is always a new initiative or substitution policy be kept ready for balancing the possibilities of damage to technology. Along with this keeping standby units in active or passive form is also an alternative method that usually been adopted by many industries for maintaining reliability of system in satisfied level. It has been observed in several systems that rather than placing direct repair server to the failed unit, the inspection process is included for filtering the machines according to its failure or to the level of repair services. The present paper is initially contributed to analysis of the system based on above strategies.

From past many years there has been lots of initiative been taken in reliability evaluation of industrial models for its improvement. In 2008, Bhardwaj et al. [1, 2] had stochastically examined distinct repair and failure mechanism under discrete distribution for the redundant system. In 2009 evaluation of industrial system with linear first order differential equations was initiated by Haggag et al. [3, 4]. Rizwan et al. [5] also investigated hot standby PLC system for enhancing its reliability. An computer based working system with replacement preference to S/W over H/W replacement subject to MOT and MRT was examined by Kumar, A. [6]. In 2014, Singh et al. [7] had stochastically studied a gas turbine plant processing with one gas and steam turbine to an industrial system i.e. power generating system. Malhotra. R et. al. [8, 9], had also initiated with examining system with varying repair demands. Bhatti and Kakkar et al [10, 11, 12, 13, 14] had also initiated together in evaluating different real life models following correlation relation concept and using geometric distributions.

In 2016, Hua et al. [15, 16] had spatially distributed units in his research with major challenge of assessing systems with involving unit degradation paths. Pervaiz et al [17] used Boolean function for assessment of paper plant industry and S.Z. Taj, et al [18] assessed the cable plant subsystem by framing probabilistic modelling. In 2017 N. Adlakha [19] had investigated mechanical system having assembling and activation time for cold standby unit before being into an operative state. Cui et al [20, 21] and Endharta et al. [22] in 2018 had applied F and G balanced systems under Markov processes for k-out-of-n systems reliability. Chen W-L. et al. [23] enhanced his study for retrial machine repair systems with operating units in 'M' numbers out of which 'W' are to be in warm standby mode and a single recovery policy for server breakdown. In 2019, S. Bhardwaj [24] studied neural network prediction model and Dong Q.L. et al. [25] used Bivariate Wiener processes by emerging stochastic degradation system for two-stage failure process. Recently, new balanced mechanisms for examining balanced systems and common cause failures had been initiated by Wu H. et al. [26], Jia H.P. [27] and Fang et al. [28]. Bhatti and Kakkar et al. [29, 30] also enhance his study under reliability with active or passive standby systems with common failure.

In all, all researchers had contributed to their best for enhancing the reliability of mechanical system and machines. The present paper is also one step forward been taken with initiative as an inspection process for filtering the machines according to its failure or to the level of repair service but with some preferences. The preference is been given to regular or to the failure required normal servicing charges and time period to avoid the waiting time for normal customer. The two machines or customer $'X'$ and $'Y'$ having their individual mechanical problems. But due to the possibility of only normal/regular failure to machine $'Y'$ it has been given preference to machine $'X'$ for being repaired and free from inspection procedure. Possible states of the system under operative and failed states are reflected through transition model Figure 1 and Table 1.

Up States

$$S_0 = (X_0, Y_0), \quad S_1 = (X_I, Y_0), \quad S_2 = (X_{r_1}, Y_0), \quad S_3 = (X_{r_2}, Y_0), \quad S_7 = (X_0, Y_{r_2}).$$

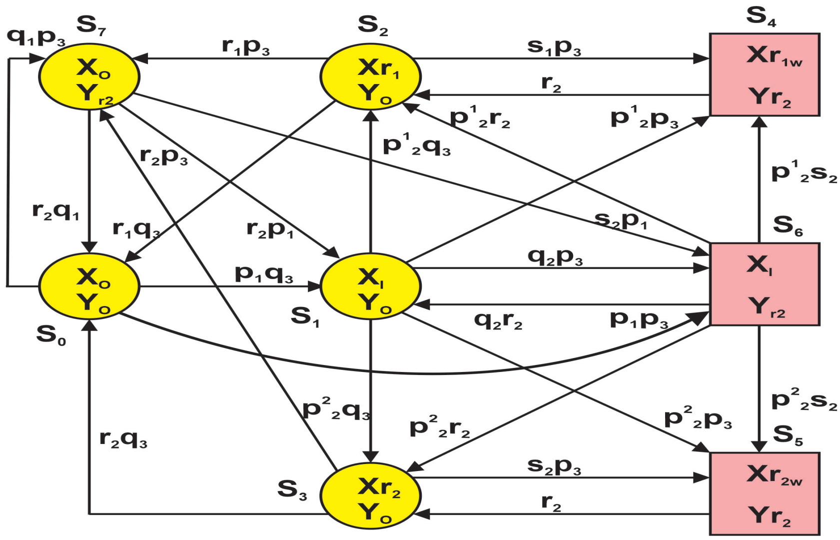

Рис. 1: Transition Model

Таблица 1: Nomenclature

X_0, Y_0	:	Operative behaviour of unit $'X'$ and $'Y'$.
X_I	:	Inspection behaviour of failed unit $'X'$.
$X_{r_1}/X_{r_{1W}}$	:	Special failure repaired service or waiting rate to unit $'X'$.
$X_{r_2}/X_{r_{2W}}/Y_{r_2}$	:	Regular services or waiting rate to unit $'X'$ and $'Y'$.
p_1	:	Probability value for $'X'$ to fall in failure mode
p_2^1/p_2^2	:	Probabilityc value for $'X'$ to get inspected.
p_3	:	Probability value to $'Y'$ for falling in failure mode with regular repair
r_1/r_2	:	Probability repair value to '$'X'$ and $'Y'$ for being repaired (special/regular) successfully.

Down States

$$S_4 = (X_{r_{1w}}, Y_{r_2}), \qquad S_5 = (X_{r_{2w}}, Y_{r_2}), \qquad S_6 = (X_I, Y_{r_2}).$$

2. Transition Probabilities

Using the transition diagram shown in Figure 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 first regenerative state $'i'$ to second state $'j'$. The evaluated transition probabilities are as follows:

$$P_{01} = \frac{p_1 q_3}{1 - q_1 q_3} \quad P_{20} = \frac{r_1 q_3}{1 - s_1 q_3} \quad P_{62} = \frac{p_2^1 r_2}{1 - q_2 s_2}$$

$$P_{06} = \frac{p_1 p_3}{1 - q_1 q_3} \quad P_{24} = \frac{s_1 p_3}{1 - s_1 q_3} \quad P_{63} = \frac{p_2^2 r_2}{1 - q_2 s_2}$$

$$P_{07} = \frac{q_1 p_3}{1 - q_1 q_3} \quad P_{27} = \frac{r_1 p_3}{1 - s_1 q_3} \quad P_{64} = \frac{p_2^1 s_2}{1 - q_2 s_2}$$

$$P_{12} = \frac{p_2^1 q_3}{1 - q_2 q_3} \quad P_{30} = \frac{r_2 q_3}{1 - s_2 q_3} \quad P_{65} = \frac{p_2^2 s_2}{1 - q_2 s_2}$$

$$P_{13} = \frac{p_2^2 q_3}{1 - q_2 q_3} \quad P_{35} = \frac{s_2 p_3}{1 - s_2 q_3} \quad P_{70} = \frac{r_2 q_1}{1 - s_2 q_1}$$

$$P_{14} = \frac{p_2^1 p_3}{1 - q_2 q_3} \quad P_{37} = \frac{r_2 p_3}{1 - s_2 q_3} \quad P_{71} = \frac{r_2 p_1}{1 - s_2 q_1}$$

$$P_{15} = \frac{p_2^2 p_3}{1 - q_2 q_3} \quad P_{42} = P_{53}(t) = \frac{r_2}{1 - s_2} \quad P_{76} = \frac{s_2 p_1}{1 - s_2 q_1}$$

$$P_{16} = \frac{q_2 p_3}{1 - q_2 q_3} \quad P_{61} = \frac{q_2 r_2}{1 - q_2 s_2}$$

2.1. Mean Sojourn Times

By 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:

$$\mu_0 = \frac{1}{1 - q_1 q_3}, \quad \mu_1 = \frac{1}{1 - q_2 q_3}, \quad \mu_2 = \frac{1}{1 - s_1 q_3}, \quad \mu_3 = \frac{1}{1 - s_2 q_3}$$

$$\mu_4 = \mu_5 = \frac{1}{1 - s_2}, \quad \mu_6 = \frac{1}{1 - q_2 s_2}, \quad \mu_7 = \frac{1}{1 - s_2 q_1}.$$

3. Mean Time to System Failure (MTSF)

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

$$R_0 = Z_0 + q_{01} \copyright R_1 + q_{07} \copyright R_7$$

$$R_1 = Z_1 + q_{12} \copyright R_2 + q_{13} \copyright R_3$$

$$R_2 = Z_2 + q_{20} \copyright R_0 + q_{27} \copyright R_1$$

$$R_3 = Z_3 + q_{30} \copyright R_0 + q_{37} \copyright R_1$$

$$R_7 = Z_7 + q_{70} \copyright R_0 + q_{71} \copyright R_1$$

By solving above equations, we obtain

$$MTSF = \lim_{h \to 1} \frac{N_1(h)}{D_1(h)} - 1 = \frac{N_1}{D_1}$$

where

$$N_1 = \mu_0[1 - P_{71}(P_{12} + P_{13})] + \mu_1[P_{01} + P_{07}P_{71}] + \mu_2(P_{12} + P_{13})[P_{01} + P_{07}P_{71}]$$
$$+\mu_7(P_{12} + P_{13})[P_{07} + P_{02}P_{27}]$$
$$D_1 = 1 - (P_{12} + P_{13})P_{20}(P_{01} + P_{07}P_{71}) + P_{27}((P_{71} + P_{70}P_{01}) - P_{07}P_{70}.$$

4. Availability and Maintenance Analysis of the System

Using probabilistic argument and through reliability models design as figure 1, the relations related to availability and maintenance analysis of the system are obtained as:

$$X_0 = Z_0 + q_{01}©X_1 + +q_{06}©X_6 + +q_{07}©X_7.$$
$$X_1 = Z_1 + q_{12}©X_2 + q_{13}©X_3 + q_{14}©X_4 + q_{15}©X_5 + q_{16}©X_6.$$
$$X_2 = Z_2 + q_{20}©X_0 + q_{24}©X_4 + q_{27}©X_7.$$
$$X_3 = Z_3 + q_{30}©X_0 + q_{35}©X_5 + q_{37}©X_7.$$
$$X_4 = Z_4 + q_{42}©X_2.$$
$$X_5 = Z_5 + q_{53}©X_3.$$
$$X_6 = Z_6 + q_{61}©X_1 + q_{62}©X_2 + q_{63}©X_3 + q_{64}©X_4 + q_{65}©X_5.$$
$$X_7 = Z_7 + q_{70}©X_0 + q_{71}©X_1 + q_{76}©X_6.$$

By solving above equations, we get the value of reliability parameters as: Availability:

$$A_0 = -\frac{N_2(1)}{D_2'(1)}, \qquad Z_i = 0 \qquad fori = 4, 5, 6.$$

Busy schedule of Inspection:

$$B_0 = -\frac{N_3(1)}{D_2'(1)}, \qquad Z_i = 0 \qquad fori = 0, 2, 3, 4, 5, 7.$$

Busy schedule of Repairman r_1:

$$B_0' = -\frac{N_4(1)}{D_2'(1)}, \qquad Z_i = 0 \qquad fori = 0, 1, 3, 4, 5, 6, 7.$$

Busy schedule of Repairman r_2:

$$B_0'' = -\frac{N_5(1)}{D_2'(1)}, \qquad Z_i = 0 \qquad fori = 0, 1, 2.$$

where

$$N_2(1) = \mu_0(1 - P_{16}P_{61})[P_{20} + P_{27}P_{70}] + \mu_1[(1 - P_{24})[P_{01} + P_{06}P_{61} + P_{07}(P_{71} + P_{76}P_{61})]$$
$$+P_{27}(P_{06}P_{71} - P_{01}P_{76})(1 - P_{61})] + (1 - P_{16}P_{61})[(\mu_2 + \mu_3 + \mu_7)(1 - P_{07}P_{70} + P_{27} + P_{20}P_{07})]$$

$$N_3(1) = (1 - P_{24})[\mu_1([P_{01} + P_{06}P_{61} + P_{07}(P_{71} + P_{76}P_{61})] + P_{27}(P_{06}P_{71} - P_{01}P_{76})$$
$$(1 - P_{61})) + \mu_6([P_{06} + P_{01}P_{16} + P_{07}(P_{76} + P_{71}P_{16})] + P_{27}(P_{01}P_{76} - P_{06}P_{71})(1 - P_{61}))]$$

$$N_4(1) = (1 - P_{16}P_{61})\mu_2(1 - P_{07}P_{70})$$

$$N_5(1) = (1 - P_{16}P_{61})\mu_3(1 - P_{07}P_{70}) + \mu_4[(P_{01} + P_{07}P_{71})[P_{14} + P_{15} + P_{16}(P_{64} + P_{65}) \\ +P_{24}(P_{12} + P_{13} + P_{16}(P_{62} + P_{63}))] + P_{06} + P_{07}P_{76}[P_{64} + P_{65} + P_{61}(P_{14} + P_{15}) \\ +P_{24}(P_{62} + P_{63} + P_{61}(P_{12} + P_{13}))] + P_{27}(P_{06}P_{71} - P_{01}P_{76})[(P_{64} + P_{65})(1 - P_{16}) \\ (P_{14} + P_{15})(1 - P_{61})]] + \mu_6([P_{06} + P_{01}P_{16} + P_{07}(P_{76} + P_{71}P_{16})] \\ +P_{27}(P_{01}P_{76} - P_{06}P_{71})(1 - P_{61})) + \mu_7(1 - P_{07}P_{70} + P_{27} + P_{20}P_{07})$$

$$D_2'(1) = -\mu_0(1 - P_{16}P_{61})[P_{20} + P_{27}P_{70}] - \mu_1[(1 - P_{24})[P_{01} + P_{06}P_{61} + P_{07}(P_{71} + P_{76}P_{61})] \\ +P_{27}(P_{06}P_{71} - P_{01}P_{76})(1 - P_{61})] - (1 - P_{16}P_{61})[(\mu_2 + \mu_3 + \mu_7)(1 - P_{07}P_{70} + P_{27} + P_{20}P_{07})] \\ -\mu_4[(P_{01} + P_{07}P_{71})[P_{14} + P_{15} + P_{16}(P_{64} + P_{65}) + P_{24}(P_{12} + P_{13} + P_{16}(P_{62} + P_{63}))] \\ +P_{06} + P_{07}P_{76}[P_{64} + P_{65} + P_{61}(P_{14} + P_{15}) + P_{24}(P_{62} + P_{63} + P_{61}(P_{12} + P_{13}))] \\ +P_{27}(P_{06}P_{71} - P_{01}P_{76})[(P_{64} + P_{65})(1 - P_{16})(P_{14} + P_{15})(1 - P_{61})]] \\ -\mu_6([P_{06} + P_{01}P_{16} + P_{07}(P_{76} + P_{71}P_{16})] + P_{27}(P_{01}P_{76} - P_{06}P_{71})(1 - P_{61}))]$$

5. Conclusion

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

$$P = C_1A_0 - C_2B_0 - C_3[B_0' + B_0'']$$

where C_1: be the per unit up time revenue by the system. C_2,C_3: be the per unit down time expenditure on the system. As per the data analysis, the performance of profit function was analyzed through having some fixed parameters C_1, C_2 and C_3 as $C_0 = 1500$, $C_1 = 300$, $C_2 = 350$ and $p_2 = 0.6$.

Table 2 and Figure 2 reflects that the profit function will decrease as the failure rate p_1 increases from 0.1 to 0.9 for certain r_1, r_2, p_3 values. Whereas Table 3 and Figure 3 reflects its opposite behaviour for certain p_1, p_3 with increasing r_1, r_2. Hence, with the help of numerical and graphical analysis it has been proved that the profit function increases with increasing repair and decreasing failure rate. In other words, the research paper will verify its objectives of benefiting the industries by developing new techniques using prescribed repairng techniques for different failure.

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Таблица 2: Reliability parameters w.r.t repair r_1,r_2, Failure Rate p_3

Repair, Failure Rate	MTSF	A_0	B_0	$B_0' + B_0''$	Profit
	13.34816	0.439386	0.071212	0.88796	326.9289262
	8.26087	0.382619	0.076136	0.915303	230.7321359
	6.718898	0.363914	0.076619	0.926769	198.5157803
$r_1 = 0.06$,	6.024452	0.355656	0.076143	0.93332	183.9797496
$r_2 = 0.04$,	5.650493	0.351492	0.075428	0.937648	176.4327009
$p_3 = 0.2$	5.426997	0.349245	0.074682	0.940759	172.1972711
	5.283912	0.347999	0.073974	0.943121	169.7147604
	5.187718	0.347315	0.073322	0.944984	168.231833
	11.95662	0.730824	0.130052	0.710412	808.5761745
	6.44206	0.628585	0.179353	0.769325	619.8084424
	4.611465	0.57487	0.205185	0.800348	520.627402
$r_1 = 0.3$	3.701681	0.541837	0.221014	0.819481	459.6323401
$r_2 = 0.1$,	3.160083	0.519522	0.231661	0.832451	418.4274372
$p_3 = 0.5$	2.802469	0.503476	0.239279	0.841815	388.7952611
	2.549898	0.491411	0.244974	0.84889	366.5126824
	2.362903	0.48203	0.249373	0.854418	349.1869919
	11.17526	0.867294	0.131712	0.594928	1053.202165
	5.860592	0.795704	0.206111	0.647095	905.2398548
	4.068428	0.752177	0.254561	0.679733	813.9911542
$r_1 = 0.65$	3.154762	0.724026	0.289165	0.701777	753.6677721
$r_2 = 0.15$,	2.590463	0.70537	0.315597	0.717387	712.2912115
$p_3 = 0.8$	2.198814	0.693146	0.336889	0.728752	683.589792
	1.903705	0.685638	0.35483	0.737123	664.0154099
	1.666667	0.681853	0.370562	0.743258	651.4703642

Таблица 3: Reliability parameters w.r.t Failure rate p_1, p_3

Failure Rate p_1,p_3	MTSF	A_0	B_0	$B_0' + B_0''$	Profit
	5.187718	0.347315	0.073322	0.944984	168.231833
	5.346386	0.525387	0.147298	0.854984	444.6463936
	5.527778	0.631806	0.207931	0.768851	616.2317649
$p_1 = 0.8$	5.728331	0.703059	0.256255	0.693314	735.0530471
$p_3 = 0.2$	5.946468	0.754788	0.295017	0.628232	823.7964199
	6.181694	0.794554	0.326554	0.57213	893.6185798
	6.434177	0.826391	0.352603	0.523485	950.586493
	6.704545	0.852641	0.374421	0.481001	998.2854495
	2.509642	0.170905	0.09413	0.984894	-116.5943514
	2.604938	0.303493	0.156777	0.947438	76.602372
	2.702541	0.412269	0.203008	0.897451	243.3935662
$p_1 = 0.6$	2.802469	0.503476	0.239279	0.841815	388.7952611
$p_3 = 0.5$	2.904762	0.580645	0.268817	0.784946	515.5913978
	3.009473	0.646232	0.293449	0.729478	625.9958088
	3.116667	0.702148	0.314321	0.67686	722.0244016
	3.226415	0.749953	0.332213	0.627792	805.5379368
	2.691851	0.120397	0.11433	0.994673	-201.8382064
	2.765625	0.234297	0.177468	0.975075	-43.07078764
	2.835925	0.341	0.215672	0.941976	117.1070403
$p_1 = 0.4$	2.903458	0.438468	0.240567	0.899243	270.7977208
$p_3 = 0.8$	2.96875	0.525427	0.257924	0.850976	412.9208633
	3.032202	0.601609	0.270802	0.800524	540.990066
	3.094124	0.667504	0.280893	0.750277	654.3913683
	3.154762	0.724026	0.289165	0.701777	753.6677721

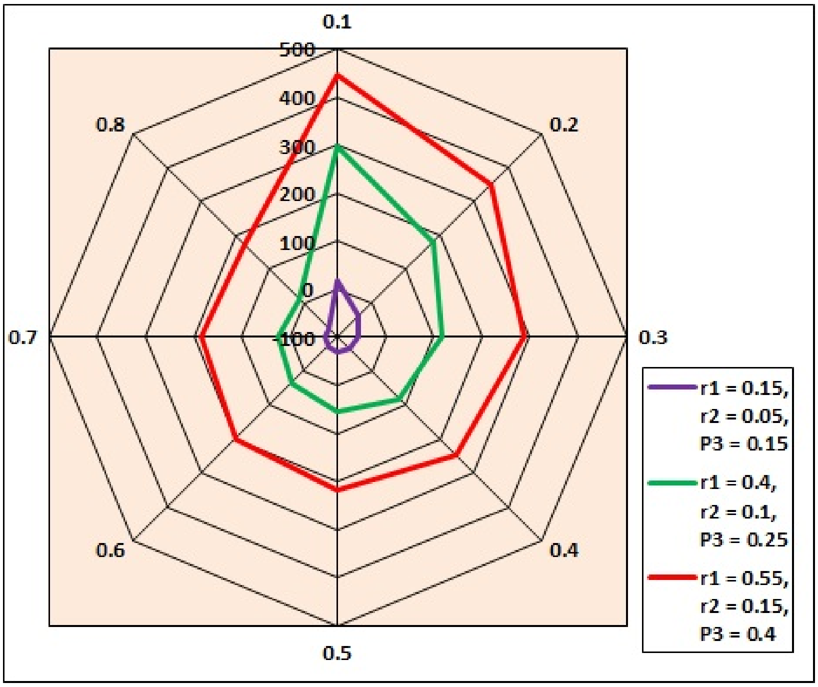

Рис. 2: Profit vs Failure rate

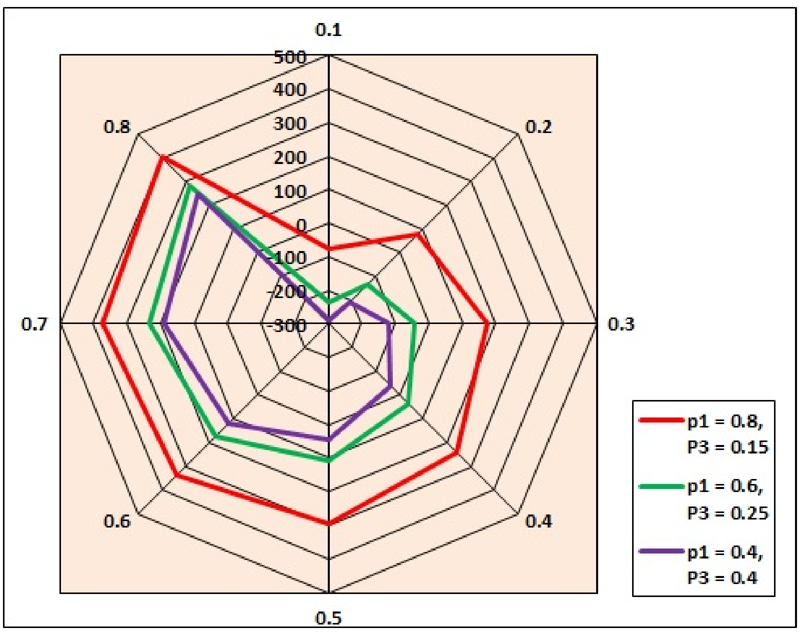

Рис. 3: Profit vs Repair rate

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