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Research on Maintenance Method and Upgrade Strategy of Engine Block Production Line Equipment

Yanfang ZHAO[a], Yanhua MA[a], Fansen KONG[a], Dianlong HOU[a], Ying JIANG[a]

[a] *School of Mechanical Science and Engineering, Jilin University, Changchun 130022, PR China*

Abstract. With the internationalization of manufacturing industry in our country today, how to ensure the high reliability of production equipment and minimize the cost of equipment maintenance has become an important issue for the survival and development of enterprises. Flexible formulation of the corresponding equipment update strategy is of great significance for reducing the operating costs of enterprises, improving the labor productivity of enterprises and even enhancing the competitiveness of the industry. This article research on maintenance method and replacement policy of engine cylinder automatic production line equipment of a car factory uses failure statistics and analysis method to process related equipment maintenance data and obtain the failure model. On this basis, the equivalent cycle model for series system of multiple devices is established. The equivalent cycle model is established on the finite interval [0,T]. In the model, reliability and maintenance costs are respectively as the objective function, and the other one as the constraints. Then a variable cycle preventive maintenance model is established, in which the average cost rate is as the objective function, and reliability of each preventive interval as the constraints. These preventive maintenance decision models can provide a quantitative basis for decision making in maintenance activities. And , according to the failure frequency and maintenance costs of each engine cylinder production line equipment, this article identify the key equipments for maintenance. Using these key equipments as study object, make an empirical study for these preventive maintenance decision models. Finally, based on game theory, replacement policy for the engine cylinder production line equipment is researched. This replacement model provides a more systematic decision-making way for equipment replacement analysis. Providing a new thinking method, it can be a reference available for maintenance staff.

1. The reliability model of the engine block production line equipment

The process of setting up the field data statistical model is expressed in reference [1].There are 5 steps about the process: (1) Define problems, plan collection methods and collect failure data, (2) Preliminary analysis of data, (3) Distribution type hypothesis, (4) Estimation of parameters of distribution function, (5) Goodness of fit test of distribution.

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Corresponding author: Yanhua MA
Email address: `yhma@jlu.edu.cn` (Yanhua MA)

1.1. *The hypothesis of equipment time between failures distribution*

In this paper, the reliability model was set up using the time between failures of the No. 201608 equipment. Equipment 201608 is a preliminary cleaning machine. According to the inherent characteristic of engine cylinder block production line equipment from certain enterprise, we assumed time between failures obeys the Weibull distribution.

Weibull distribution of probability density function $f(t)$, Weibull distribution function $F(t)$, Failure rate function $\lambda(t)$, can be expressed in reference [1].

1.2. *The parameter estimation of distribution function*

Parameter estimation is a process that the population parameter value is estimated using collected sample observation value [2]. Characteristic parameters were calculated using the maximum likelihood estimation proposed by Gaussian.

According to the Weibull distribution of the probability density function $f(t)$, the data capacity for n, t_1, t_2, ..., t_n, parameters of the likelihood function ,the density function for time between failures , the distribution function for time between failures, the function for reliability, the function for failure rate are expressed in reference [2].

1.3. *K-S inspection of distribution*

K-S test is an effective practical distribution goodness-of-fit test method. We used it to test the distribution model of engine cylinder block production line equipment.

When the time between failures of the No. 201608 equipment obeys the Weibull distribution, the degree of difference between the theoretical distribution and empirical distribution is D_n=0.064543. Taking α= 0.05 from schedule 11 of reference[3], the test statistic λ= 1.36 was obtained as:

$$\lambda = 1.36 > \sqrt{n}D_n = \sqrt{174} \times 0.064543 = 0.8514 \tag{1}$$

In conclusion, at the same significant level, the hypothesis that the time between failures of equipment obeys the Weibull distribution is acceptable.

1.4. *Reliability index and life index*

We take the equipment 201608 as an example to calculate digital features of its reliability.

1) maximum time between failures $t_{0.95}$

$$0.95 = 1 - \exp\left[-\left(\frac{t_{0.95}}{96.49}\right)^{0.79}\right], \quad t_{0.95} = 229.57 \tag{2}$$

2) mean time between failures $MTBF$

$$\begin{aligned} MTBF = E(t) &= \int_0^\infty t f(t) dt = \int_0^\infty t d(1 - R(t)) \\ &= \int_0^\infty R(t) dt = 110.326(\text{hour}) \end{aligned} \tag{3}$$

2. Setting up the preventive maintenance model of the engine block production line equipment

2.1. *Theoretic analysis*

2.1.1. *The model of mixed failure rate*

In the study, the model of mixed failure rate based on the recursive decline factor and failure rate increasing factor was adopted. Using this model, before and after equipment preventive maintenance, failure rate function is:

$$\lambda_{i+1}(t) = b\lambda_i(t + aT_i) \quad t \in (0, T_{i+1}) \tag{4}$$

where values of a and b can be obtained according to the specific situation of each equipment.
The failure rate of the system in $[T_k, T]$ is:

$$\begin{aligned} \lambda_{i,ki+1}(t) = b\lambda_{i,ki}(t + aT_{pi}) &= b^{ki}\lambda_i(t + k_i aT_{pi}) \\ &0 < t < T - k_i T_{pi} \end{aligned} \tag{5}$$

2.1.2. The reliability model

Reliability is an important index for measuring the safety, applicability and durability of equipment. The reliability of the series system at T moment can be expressed in reference [4].

2.1.3. The total maintenance cost

In the finite time interval $[0, T]$, the total maintenance cost of the system is consisted of three parts: preventive maintenance cost, minimum maintenance cost and production cost. It is expressed in reference [4].

2.1.4. The optimization model of equivalent periodic preventive maintenance

At T moment, taking the total maintenance cost as optimized object and the reliability as constraint conditions, we obtained the optimization model in reference [5] : where R is the reliability constraint value, and C is the cost constraint value.

2.2. Setting up the Variable periodic preventive maintenance model of the engine block production line equipment

Taking the average cost rate of the complete maintenance time-domain as the objective function, and the time domain reliability as the constraint condition, the optimization model of variable cycle preventive maintenance is in reference [6].
where R is the reliability constraint value; in order to facilitate the calculation, N is given by the experience.

3. The empirical research on the preventive maintenance strategy of the engine block production line equipment

Based on history maintenance data of block production line equipment from a certain enterprise, we analyzed failure rate, time between failures, fault maintenance time, downtime and maintenance cost of the production line equipment, and determined the key equipment. Then, considering the key equipment as the research object, we carried on the real diagnosis analysis and research to the model of peer periodic preventive maintenance and the model of variable periodic preventive maintenance model.

3.1. The analysis of history data of the engine block production line equipment

The research object of this paper is an engine cylinder block production line equipment. When we make decision on maintenance of the production line equipment, we should first determine the equipment that plays an important role in the normal production. Using all maintenance data of the cylinder body from September 2012 to July 2014, the key equipment of the production line was analyzed from different angles. The failure rate of production line equipment is shown in Figure1. The maintenance time of production line equipment is shown in Figure 2. The downtime of production line equipment is shown in Figure 3. The downtime accounts for the proportion of the maintain time of main production line equipment during the data collection is shown in Figure 4. The maintenance cost of each production line equipment is shown in Figure 5. As shown in Figures 1-5, No. 200714 and No. 201609 are the key maintenance objects.

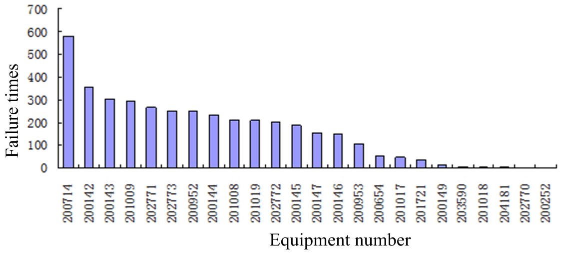

Figure 1: The failure rate of production line equipment

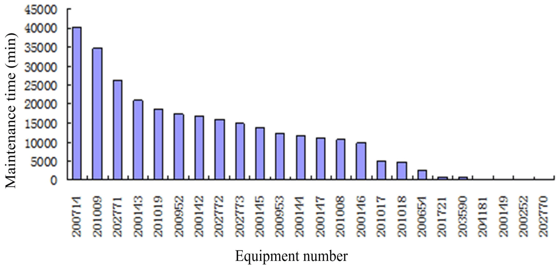

Figure 2: The maintenance time of production line equipment

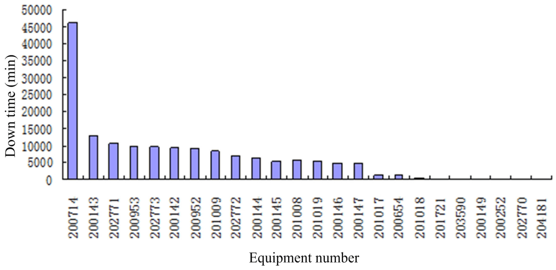

Figure 3: The downtime of production line equipment

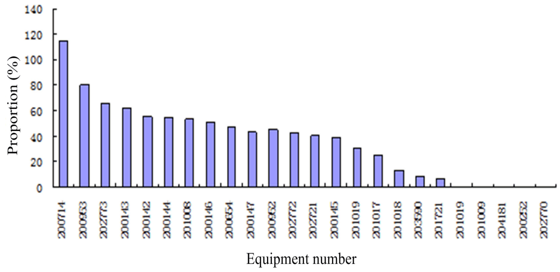

Figure 4: The proportion of the maintain time of main production line equipment

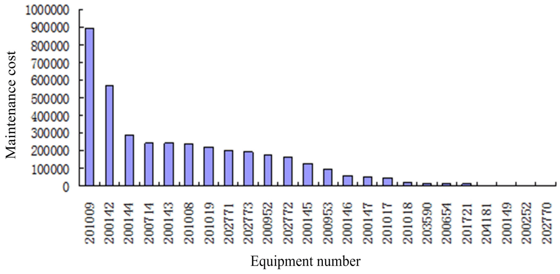

Figure 5: The maintenance cost of each production line equipment

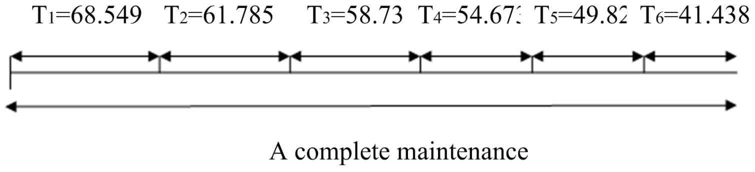

Figure 6: Figure6. the diagram of preventive maintenance process

3.2. Empirical research on the preventive maintenance cycle model of engine block production line equipment

3.2.1. Empirical research on the model of taking total maintenance cost as the objective function with reliability constraint

No. 201609 and No.201514 are the key equipment. We assumed the series system is composed of these two subsystems, and each subsystem is independent.
Using the Matlab, the optimization results of the total maintenance cost with different reliability constraint values were obtained, which is shown in Table 1.

Using the matlab, the optimization results of the cost without reliability constraint are $T_{p1} = 300$, $T_{p2} = 300$, $C_{\min} = 4631.9$. Compared with the situation of reliability constraint, there is the minimum total maintenance cost, the largest preventive maintenance cycle of each subsystem in the situation with reliability constraint, which is consistent with the actual situation of the enterprise.

3.2.2. Empirical research on the model taking the reliability as the objective function with total maintenance cost constraints

Using the matlab for mathematical model, the reliability optimization results of series system can be obtained with different total maintenance cost constraint, which is shown in Table 2. Using the Matlab, the optimized reliability function without maintenance cost constraint was obtained, where $T_{p1} = 24.65$, $T_{p2} = 48.68$, $R_T = 0.8939$. Compared with the situation of reliability constraint, there is the minimum preventive maintenance cycle for the subsystems, and the maximum reliability value with unconstrained condition.

3.3. Empirical research on the variable cycle preventive maintenance model of the engine block production line equipment

Using the Matlab, the average cost rate of the system in a complete maintenance period was optimized with different reliability constraint values. Finally, we obtained the optimization results T_1, T_2, T_3, T_4, T_5, T_6, which is shown in Table 3. According to the result shown in the Table 3, taking the reliability constraint value $R = 0.782$ as an example, the diagram of preventive maintenance process is shown in Figure 6.
when $T_1 = T_2 = T_3 = T_4 = T_5 = T_6$, the maintenance model will change into an equal cycle model. We solved this model and obtained the optimization results, which are shown in Table 4.

4. Empirical research on the upgrade strategy of engine cylinder block production line equipment based on the game theory

4.1. The upgrade strategy of engine block production line equipment

We researched the upgrade strategy using the matrix model in reference [7]. First, Combined with the statistical data of engine cylinder block production line equipment No. 200142, the countermeasure of the upgrade problem was set as $G = \{S_1, S_2; A\}$, where $S_1 = \{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5\}$={continue to use the existing equipment, overhaul to the existing equipment, The modern modification to existing equipment, Use prototype equipment upgrade existing equipment, With high efficiency new performance equipment upgrade existing equipment} ; $S_2 = \{\beta_1, \beta_2, \beta_3\}$={Existing equipment dominate the market, in the market the upgrading of equipment appear and gradually popular, in the market the high efficiency new performance equipment appear and gradually popular}.

4.1.1. Setting up the model of payoff matrix for player I

We set up the model of payoff matrix for player I.
In this paper, the total cost calculation method was used for the model of upgrade strategy. We calculated the total cost for different strategies during the same time as earned values of payoff matrix. When player II was under strategy β_1, which means that the existing product still dominate the market, we calculated the corresponding various data of five kinds of strategies for α. It is shown in Table 5.

Table 1: The optimization results of the total maintenance cost with different reliability constraint values

Subsystem 1	Subsystem 2	Maintenance cost	Reliability
300	200	6384	0.5423
270	150	8479	0.6079
225	142	10344	0.6419
200	135	29604	0.6752
150	120	32448	0.6898
100	115	33371	0.7126
86	105	33787	0.7235
54	98	33986	0.8126
38	85	39514	0.8576
28	80	41740	0.9026
25	60	43278	0.9039

Table 2: The reliability optimization results of series system different total maintenance cost constraint

Subsystem 1 preventive	Subsystem 2 preventive	Reliability	Maintenance cost
298.65	203.82	0.5736	4561
286.43	185.76	0.6147	5479
273.48	174.67	0.6306	6417.3
190.62	169.75	0.6689	28725
120.54	140.54	0.6963	31513
100.65	120.68	0.7263	32390
98.76	117.49	0.7564	32568
54.86	81.57	0.8207	32977
35.34	75.53	0.8634	38090
28.76	66.54	0.8974	40049
26.47	49.65	0.9273	41513

Table 3: The optimization results

T1/h	T2/h	T3/h	T4/h	T5/h	T6/h	Average cost rate C	Reliability constraint value R
120.355	100.643	96.764	91.428	84.676	73.399	462.78	0.452
109.685	93.674	87.687	85.674	75.684	69.743	579.43	0.534
95.684	92.673	86.537	80.845	74.759	67.854	649.69	0.568
92.687	89.764	82.645	76.537	70.565	63.785	729.31	0.594
85.576	83.241	79.752	73.365	68.542	64.942	816.58	0.647
79.537	75.476	70.842	67.842	63.694	56.285	890.04	0.656
72.694	68.547	64.845	60.785	51.636	46.879	960.46	0.724
68.549	61.785	58.734	54.673	49.823	41.438	1020.73	0.782
59.643	52.673	47.572	43.745	40.642	32.674	1374.63	0.869
50.742	47.563	45.759	39.685	30.643	21.744	1743.58	0.937

Table 4: The maintenance model will change into an equal cycle model

T/h	Average cost rate	Reliability constraint value
93.6783	628.45	0.452
89.6534	742.63	0.534
83.7875	769.69	0.568
79.8634	795.47	0.594
75.4373	845.78	0.647
74.7648	942.32	0.656
68.0956	1080.46	0.724
65.6947	1521.68	0.782
53.6342	1763.16	0.869
46.8248	1969.82	0.937

Table 5: The data of five decision making strategies

		Strategy 1 Using the original equipment	Strategy 2 Overhaul of existing equipment	Strategy 3 Modernization refit	Strateg 4 Update of prototype new equipment	Strategy 5 High performance equipment update
Productivity coefficient		0.7	0.98	1.25	1	1.3
Basic investment		0	10000	15000	30000	90000
Net value of original equipment		3000	3000	3000	3000	4000
Total operating expenses	(1year)	3500	2000	1000	950	4600
	(2year)	4850	3600	1850	1465	5150
	(3year)	5280	4200	2700	1885	5420
	(4year)	5700	4900	3150	2680	6440
	(5year)	5970	5900	3960	3960	7260
	(6year)	6050	6500	4550	4695	7790
	(7year)	6840	7600	5400	5910	8030
	(8year)	7130	8100	5950	6550	8340
	(9year)	7800	8400	6080	6970	9650
	(10year)	8240	8800	6940	7500	12000

Similarly, when player II was under strategy β_2 and β_3, we calculated the corresponding various data of five kinds of strategies for α.
Setting the total cost of the player II under different strategy as the earned value of player I of payoff matrix, we calculated the payoff matrix of player I as follows,

$$A = \begin{pmatrix} 9.194 & 9.900 & 11.060 \\ 7.449 & 7.398 & 7.551 \\ 4.766 & 4.627 & 4.514 \\ 6.957 & 7.136 & 6.407 \\ 12.360 & 12.842 & 10.581 \end{pmatrix}$$

The earned value is the net present value. Unit: ten thousand yuan.

4.1.2. *Solution of the matrix model*

In this case, $\max_{\mathrm{i}} \min_{\mathrm{j}} a_{ij} \neq \min_{j} \max_{i} a_{ij}$. It means there is no best pure strategy. Therefore, it is necessary to establish the linear programming model to determine the optimal mixed strategy.

$$LPI: \ \min S_X = x_1' + x_2' + x_3' + x_4' + x_5'$$

$$s.t \begin{cases} 9.194x_1' + 7.449x_2' + 4.766x_3' + 6.957x_4' + 12.360x_5' \geq 1 \\ 9.900x_1' + 7.398x_2' + 4.627x_3' + 7.136x_4' + 12.842x_5' \geq 1 \\ 11.060x_1' + 7.551x_2' + 4.514x_3' + 6.407x_4' + 10.581x_5' \geq 1 \\ x_1', x_2', x_3', x_4', x_5' \geq 0 \end{cases}$$

$$LPII: \max S_Y = y_1' + y_2' + y_3'$$

$$s.t\begin{cases} 9.194y_1' + 9.900y_2' + 11.060y_3' \le 1 \\ 7.449y_1' + 7.398y_2' + 7.551y_3' \le 1 \\ 4.766y_1' + 4.627y_2' + 4.514y_3' \le 1 \\ 6.957y_1' + 7.136y_2' + 6.407y_3' \le 1 \\ 12.360y_1' + 12.842y_2' + 10.581y_3' \le 1 \\ y_1',\ y_2',\ y_3' \ge 0 \end{cases}$$

By solving LP1, the most optimal solution is

$$X^* = \{0.488,\ 0,\ 0,\ 0, 0.512\}$$

By solving LP2, the most optimal solution is

$$Y^* = \{0.131,\ 0,\ 0.869\}$$

Theoptimal countermeasure expectations $V_G = 10.816$ ten thousand yuan.
In sum, existing products still dominate the market. The market has appeared the upgrading of products and gradually popular. The market has appeared high efficiency new performance products and gradually popular. Their possibility are 0.131, 00.869, respectively. Renewal of equipment decision makers choose intact use existing equipment, equipment big repair, existing equipment modernization, with the modified prototype equipment upgrade the existing equipment, with high efficiency new performance equipment upgrade the feasibility of existing equipment respectively are 0.488, 0, 0, 0 and 0.512, respectively. The optimal countermeasure expectations is 108160 yuan.

5. Conclusion

In this paper, using equipment maintenance methods and related theory of upgrade strategy, one engine cylinder block production line equipment preventive maintenance methods and equipment upgrade strategy were studied. The game theory in the operational research theory was applied in equipment upgrade strategy formulation. Market analysis was merged into the technical analysis field, and the equipment upgrade strategy was investigated based on the game theory. It provides a new idea for enterprises to develop equipment upgrade strategy.

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