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The Application of Preventive Replacement Strategy on Machine Component in Deteriorating Condition – A Case Study in the Processing Industries

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Abstract

The operation of a particular component in deteriorating condition will lead to a high machine downtime. This is due to the failure of component at unexpected time. As a result it will increase cost of maintenance and production lost. One of the solutions to this matter is to use Preventive Replacement (PR). PR is one of the maintenance optimisation strategies that can balance the failure cost in unexpected time (maintenance and production lost) and maintenance benefits (minimise downtime) for a deteriorating component. Therefore, the objective of this paper is to introduce the PR strategy for determining an optimal replacement time for component that deteriorates over time. The constant-interval replacement model developed by [1] is applied in a case study in this paper. The results from the case study analysis showed that failure time followed the weibull distribution and hence, the optimum replacement time can be determined.

Keywords

Deteriorating component, Weibull distribution, Maintenance optimisation, Replacement strategy and Economic decision.

1. Introduction

Normally, all equipment or component lifetime will go through three conditions, namely decreasing failure rate (DFR), constant failure rate (CFR) and increasing failure rate (IFR) [4]. The critical condition of the component lifetime usually in IFR conditions (deteriorate condition) that will increase the frequency of failures. The application of traditional maintenance or corrective maintenance (CM), will cause increasing maintenance cost (failure cost) and production losses (downtime). Therefore, one of the practical strategies for reducing the maintenance cost and production losses is by applying the preventive maintenance (PM). The Preventive replacement (PR) is one of the popular PM strategies. PR refers to periodically replacing of non-repairable component in deteriorating condition. The main objective of PR is to reduce the frequency of failures resulting in a balance of failure cost (failure replacement) and maintenance benefits such as downtime, reliability, availability etc.

The earliest PR strategy model was developed by [3] and it becomes a fundamental criteria for various replacement problems. The PR strategy is widely applied in industrial areas and mostly applied on machine components problems. For example, [5] developed models base on PR strategy and applied it for cutting tool problem of a CNC milling process. The main objective of the model is to determine the optimal replacement intervals couple with the forecasting of tool replacement to minimise the production cost. [1] modified the PR model by [6] and applied it to machine tool problem in crankshaft line process. They simplified the model to determine the optimum replacement time to minimise the downtime.

In this paper, the application of PR strategy for the cutting tool problem in processing industries is presented. The constant-interval replacement model developed by [1] is applied on the case study. The main objective of this model is to determine the optimum replacement time of cutting tool for minimise the expected cost per cycle time of replacement. The paper is structure as follows; firstly, the characteristic of component lifetime is illustrated to show the different failure frequency (failure rate) of component between DFR, CFR and IFR conditions. The next section described the constant-interval replacement model in term of it characteristics and assumptions. Finally, a numerical example of the application of the model in a processing industry on the base of cutting tool problem is presented.

2. Characteristic of Component Lifetime

From maintenance point of view, normal lifetime of the component / system will go through in three stages; decreasing failure rate (DFR), constant failure rate (CFR) and increasing failure rate (IFR) [4]. The trend of component lifetime can be shown as a shape of bathtub curve shown in figure 1. The life characteristics of a new component will start at early life (DFR) followed by useful life (CFR) and ended by wear-out life (CFR). At the stage of wear-out life (CFR), the number of failure (failure rate) will increase and it's refers to deteriorate condition. This stage also known as a critical condition that contributes to the most of production losses and high maintenance cost through increasing maintenance and production downtime.

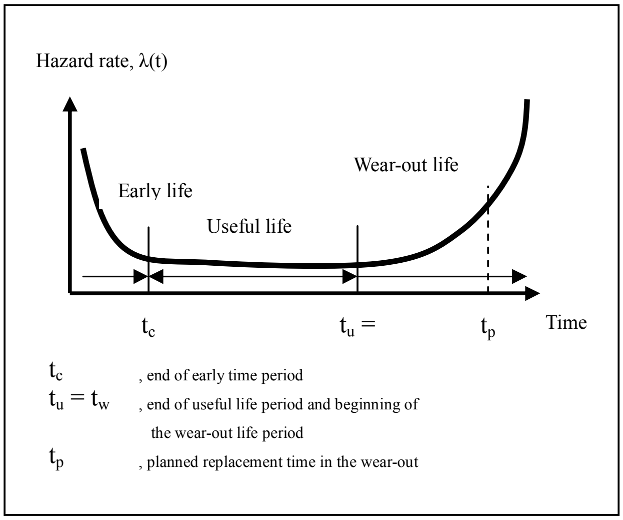

Figure 1: Bathtub curve of life characteristic of the component – hazard rate versus time

The preventive replacement is one of the effective strategies to reduce the probability of failure (reduce failure cost) and downtime (reduce production losses) in the deteriorate condition. [6] stated that preventive replacement is the most appropriate maintenance strategy for component which operates in the stage of wear-out life (CFR). However, the best time to carry out the PR must be considered. If preventive replacement is applied too frequently, the cost of maintenance and production downtime will increase. While, if preventive replacement is applied occasionally, it will increase the downtime of sudden failure (breakdown) plus downtime of maintenance and production lost. Hence, with compromise between these two replacement conditions (too frequently and occasionally) will result the optimum time of replacement (t_p), which minimise the total component cost of downtime due to maintenance downtime and sudden failure downtime.

3. The Constant-Interval Replacement Model

In development of Constant-Interval Replacement Model (CIRM), the decision criterion is defined by $C(t_p)$, " the total expected cost/cycle time" of replacing a piece of component in cycle period $(0, t_p)$. [1] assumed that the expected number of failure occurring the cycle period $(0, t_p)$, is equal to the probability of occurrence a failure before time t_p, $F(t_p)$. Therefore, the final form of decision function, $C(t_p)$ can be expressed as below;

$$C(t_p) = \frac{c_p + c_f * F(t_p)}{t_p} \qquad (1)$$

Where,

$C(t_p)$ = The total expected cost/cycle time
$F(t_p)$ = Probability that the equipment would break in period $(0, t_p)$
c_p = Cost of preventive replacement
c_f = Cost of failure replacement
t_p = The optimum time which satisfies the $C(t_p)$

The best value, t_p can be obtained by standard differential calculus. Setting $d//dt\ C(t_p) = 0$, knowing that, $c_f > 0$, which gives;

$$t_p = \frac{F(t_p) + \frac{c_p}{c_f}}{f(t_p)} \qquad (2)$$

The advantage of this model that it is simpler compares to the classical model [1]. [1] proved that the results using this model essentially similar with the classical model with assumption the lifetime of the equipment follows the normal distribution.

4. Numerical Example

In this section, a numerical example of a cutting tool in a processing industry is presented. The cutting process will start when the product from previous process move by conveyer to sawing machine (cutting process) and the output of this line is final product. The main problem with this line is when sudden failures of cutting tool occurred. The tool is classified as failed when the cutting process have an affect to the quality of product. Usually, this is due to excessive wear of the cutting tool. Once the cutting tool fails, it will cause bottleneck and will increase the production lost and downtime (failure) lost.

Therefore, the study will concentrates on developing an optimal maintenance policy to reduce the numbers of sudden failure of the cutting tool. The main objective of the policy is to find the optimum time interval of preventive replacement to balance the failure cost and productivity.

4.1 Failure Distribution

In duration of four months, failure time data of the cutting tool is collected. This failure time data is analysed to determine the failure distribution. Referring to the analysis of Least-Squares Curve-Fitting (LSCF) and Maximum Likelihood Estimator (MLE) [4], the lifetime of the cutting tools indicate that it's under a deteriorating phase, which their failures time follows the weibull distribution with the shape parameter of 1.7 and scale parameter of 80. Therefore, the preventive replacement strategy will be a good strategy for reducing the failure cost per operating cycle. It is because the important criteria to apply PR is that the failure time must be at a deteriorating phase (in this case study the failure time followed the weibull distribution with the shape parameter > 1). The Cumulative Distribution Function (CDF) and Probability Density Function (PDF) for weibull distribution are defined as follow.

$$F(t) = 1 - e^{-(\frac{t}{\theta})^{\beta}} \quad (3)$$

$$f(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{-(t/\theta)^{\beta}} \quad (4)$$

4.2 Model Application

In order to apply the constant-interval replacement model, (equation (1) and (2)), the following information is required:

- Failure time distribution: The failure time of cutting tool followed the weibull distribution with shape parameter, β = 1.7 and scale parameter, θ = 80 hours.
- Failure cost, C_f: The failure cost, C_f including failure replacement cost and failure downtime (production losses) is predicted to be RM 1000.
- PR cost, C_p: The preventive maintenance cost, C_p including preventive replacement cost and preventive replacement downtime is predicted to be RM 500.

The main objective of this model is to determine the PR time, t_p. The best value of, t_p (optimum time) that satisfies the equation (1) can be determined by using equation (2) and the analysis of the results are shown in the appendix. Table in the appendix illustrates that the best value of, t_p (optimum time) is 75.9 ≈ 76 hours. The minimum cost per cycle time which corresponds to optimum replacement time, t_p is $C(t_p)$ = 14.4828 cost/cycle time. Therefore, the time to perform the preventive replacements, t_p = 76 hours is used. It means that every 76 hours of operating the new cutting tool will be

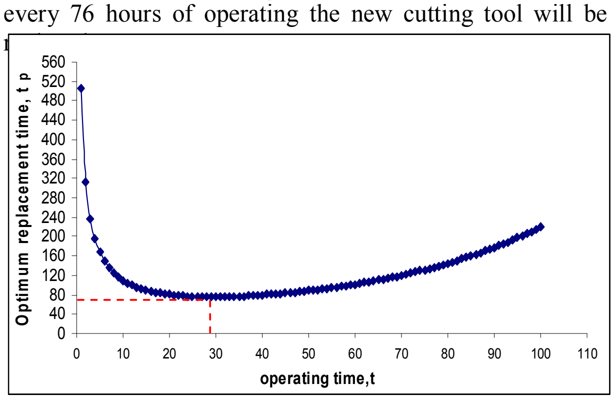

Figure 2- The optimum replacement time, t_p versus operating time, t.

The analysis of the results in the appendix is plotted in figure 2. The figure shows that the best value of, t_p (optimum time) that satisfies the equation (1) is 76 hrs. This represents the optimum replacement time, t_p that yields the minimum total cost/cycle time as $C(t_p)$ = 14.4828 cost/cycle time.

5. Conclusion

This paper has shown that, the application of the preventive maintenance strategy is able to minimise the total cost per cycle time, while the component is in the deteriorating condition. The constant-interval replacement model that developed by [1] has been applied for a cutting tool problem in a processing industry. The lifetime of cutting tools is in deteriorating condition, which follows the weibull distribution with the shape and scale parameters is 1.7 and 80, respectively. According the analysis results, the optimum time, t_p (preventive replacement time) is 76 hrs that yields the minimum total cost/cycle time as $C(t_p)$ = 14.4828 cost/cycle time. The methods and models that have been applied in this paper contribute to the maintenance decision making and can assist the maintenance manager to make better economic decision about component maintenance.

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Appendix - *The analysis of optimum replacement time,* t_p

t	F(t)	f(t)	tp	t	F(t)	f(t)	tp	t	F(t)	f(t)	tp	t	F(t)	f(t)	tp
1	0.000582	0.000988	506.44	31	0.180905	0.008964	75.96	61	0.467769	0.009355	103.45	91	0.712016	0.006697	180.97
2	0.001888	0.001604	312.98	32	0.189919	0.009064	76.11	62	0.477095	0.009296	105.11	92	0.718661	0.006593	184.84
3	0.003759	0.002126	236.96	33	0.19903	0.009157	76.34	63	0.48636	0.009234	106.82	93	0.725202	0.006489	188.83
4	0.006122	0.002594	195.11	34	0.208231	0.009243	76.62	64	0.495562	0.009169	108.58	94	0.731638	0.006384	192.92
5	0.008934	0.003024	168.30	35	0.217515	0.009322	76.97	65	0.504697	0.009101	110.39	95	0.73797	0.00628	197.13
6	0.01216	0.003424	149.56	36	0.226874	0.009394	77.38	66	0.513764	0.009031	112.26	96	0.744198	0.006176	201.47
7	0.015775	0.003801	135.71	37	0.236301	0.009459	77.84	67	0.522758	0.008958	114.18	97	0.750322	0.006072	205.92
8	0.019755	0.004156	125.06	38	0.24579	0.009518	78.36	68	0.531678	0.008882	116.16	98	0.756342	0.005968	210.51
9	0.024081	0.004493	116.63	39	0.255334	0.00957	78.93	69	0.540521	0.008804	118.19	99	0.762258	0.005865	215.23
10	0.028736	0.004814	109.83	40	0.264927	0.009615	79.55	70	0.549284	0.008723	120.29	100	0.768071	0.005762	220.09
11	0.033705	0.00512	104.24	41	0.274563	0.009655	80.23	71	0.557966	0.00864	122.44				
12	0.038972	0.005412	99.59	42	0.284235	0.009688	80.95	72	0.566564	0.008556	124.66				
13	0.044524	0.005691	95.68	43	0.293937	0.009716	81.72	73	0.575077	0.008469	126.94				
14	0.050349	0.005957	92.38	44	0.303664	0.009737	82.54	74	0.583502	0.008381	129.29				
15	0.056435	0.006212	89.57	45	0.31341	0.009753	83.40	75	0.591837	0.00829	131.70				
16	0.06277	0.006455	87.18	46	0.323169	0.009764	84.31	76	0.600082	0.008199	134.18				
17	0.069342	0.006688	85.13	47	0.332935	0.009769	85.27	77	0.608234	0.008105	136.73				
18	0.076142	0.00691	83.38	48	0.342704	0.009768	86.27	78	0.616292	0.008011	139.35				
19	0.083159	0.007122	81.88	49	0.35247	0.009763	87.31	79	0.624254	0.007915	142.05				
20	0.090384	0.007324	80.60	50	0.362229	0.009753	88.41	80	0.632121	0.007817	144.82				
21	0.097805	0.007517	79.53	51	0.371975	0.009738	89.54	81	0.639889	0.007719	147.67				
22	0.105415	0.0077	78.62	52	0.381703	0.009718	90.73	82	0.647559	0.00762	150.60				
23	0.113203	0.007875	77.87	53	0.39141	0.009694	91.95	83	0.655129	0.00752	153.61				
24	0.121161	0.00804	77.26	54	0.40109	0.009666	93.23	84	0.662598	0.007419	156.71				
25	0.12928	0.008197	76.77	55	0.41074	0.009633	94.54	85	0.669966	0.007317	159.89				
26	0.137551	0.008345	76.40	56	0.420355	0.009596	95.91	86	0.677232	0.007215	163.17				
27	0.145967	0.008484	76.14	57	0.429931	0.009555	97.32	87	0.684396	0.007112	166.53				
28	0.154517	0.008616	75.96	58	0.439464	0.00951	98.78	88	0.691456	0.007009	169.99				
29	**0.163196**	**0.00874**	**75.88**	59	0.44895	0.009462	100.29	89	0.698414	0.006905	173.55				
30	0.171994	0.008856	75.88	60	0.458387	0.00941	101.85	90	0.705267	0.006801	177.21				

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