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Full Length Research Article

Structural Dependence Replacement Model for Parallel System of Two Units

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ABSTRACT: In this paper, two units' Parallel system was considered in which both units operate simultaneously. The system is subjected to two types of failures. Type I failure is minor and occur with the failure of a single component and is checked by minimal repairs, while type II failure is catastrophic in which both components failed and the system is replaced. It is assumed that when one component is receiving minimal repair treatment other non failed component will receive some preventive maintenance action like oiling, greasing, etc. The system is also replaced preventively at the age t_P . The aim is to modify an existing model that addressed the problem of replacing the system preventively before failure or at failure .The paper discusses and subsequently obtained the optimum replacement times t_P that minimize the expected cost numerically.

Keywords: Structural dependence, replacement, minimal repair, preventive maintenance

INTRODUCTION

The lifespan of industrial equipment is prolonged through maintenance. Thus, maintenance has impact on component and system reliability. Inadequate maintenance results in system failure which is costly and also brings about poor system performance and low production. For most industrial equipment, maintenance policies are provided to reduce the incidence of system frowning to failure. Literature about equipment replacement can be obtained in Nakagawa (1989), Sheu (1997), Assaf and Levikson (1982), and Wang and Handschin (2000).

Maintenance planning is important to industrial equipment. It can either be corrective or preventive. Corrective maintenance is performed at the equipment failure while preventive maintenance is done before the equipment fails. Typical example of preventive maintenance is periodically changing the engine oil so that the engine stays lubricated to avoid failure, periodic replacement of equipment, etc.

According to McCall (1965), Pierskalla and Volka (1976), maintenance improve system availability. The earliest preventive maintenance (replacement) model was developed by Barlow and Proschan (1965). This model is widely applied to industrial equipment and mostly on machine components. Jainqiang and Keow (1997) developed preventive replacement strategy and applied it for cutting tool problem of a CNC milling process. The model has the objective of determining optimal replacement interval. Bahrami et al. (2000) modified the replacement model by Jardine (1973) and applied it to machine tool problem in Crankshaft line process.

Components interaction can be classified as economic, stochastic or structurally dependent according to their maintenance action (Thomas, 1986). Economic dependence implies that group replacement cost less than the individual component replacement. Stochastic dependence implies that the working condition of components influences the lifetime distribution of the other components while the structural dependence implies that maintenance of failed component implies the maintenance of working component.

Most of the literature emphasizes on the replacement of the entire equipment without considering the fact that not all the components that constitute the equipment failure. Some may still be functional. For such equipment, it may not be feasible to replace the entire system on the failure of one component. The equipment may come back into operation after the repair or replacement of the failed component.

According to Cho and Parlar (1991), multi component maintenance models deal with optimal maintenance policies for such systems comprising of several components that may depend or may not depend on each other.

In this paper, we modified the model developed by Yasui *et al.* (1988). It is assumed replacements of the entire equipment at predetermine age or at failure of all the components that constitute the equipment or whichever come first. It is also assumed that when one component is receiving minimal repair treatment other non-failed components will receive some preventive maintenance action like oiling, greasing, etc. The objective of this paper is to determine the optimal replacement time so as minimize the expected cost per cycle of time of replacement.

METHODOLOGY

Assumptions and Notations

1. The system is replaced preventively at time t_P or at the first instance of type II failure whichever occur first.
2. Failure of one component is repairable.
3. At type I failure, the failed component is repaired minimally while the non-failed component received preventive maintenance action.

c_0 is the cost of replacement when no component fails (age replacement)

c_2 is replacement cost when both components fed simultaneously (type II failure)

c_m is the cost of minimal repair of the failed component (type I failure)

c_P is the cost of preventive maintenance of the non-failed component

$F(t)$ is independent and identical distribution (CDF) of failed system.

$\overline{F}(t) = 1 - F(t)$ is the reliability or survival function.

$U(t_P)$ total expected maintenance / replacement cost

$\mu_2(t_P) = \int_0^{t_P} \left\{1 - \left[F(t)\right]^2\right\} dt$ is the finite mean

$r(t)$ is the failure rate

Thus, the replacement time can be obtained by minimizing the cost per unit time

$$C(t_P) = \frac{U(t_P)}{\mu_2(t_P)} \qquad (1)$$

$$C(t_P) = \frac{c_0\left[\overline{F}(t_P)\right]^2 + 2c_m\int_0^{t_P} r(t)dt + 2c_P + c_2\left[F(t_P)\right]^2}{\int_0^{t_P}\left\{1-\left[F(t)\right]^2\right\}dt} \qquad (2)$$

The optimal replacement time t_P could be obtained by minimizing equation (1) and solving for t_P such that

$$C'(t_P) = 0 \qquad (3)$$

RESULTS AND DISCUSSION

Assume the failure time followed the Weibull distribution with CDF

$$F(t) = 1 - e^{-[\frac{t}{\lambda}]^\beta} \qquad (4)$$

and

$$r(t) = \frac{\beta}{\lambda}\left(\frac{t}{\lambda}\right)^{\beta-1}, \qquad (5)$$

where β is the shape parameter and λ is the scale parameter, then from (1)

$$C(t_P) = \frac{c_o\left[e^{-\left[\frac{t_P}{\lambda}\right]^\beta}\right]^2 + 2c_m\int_0^{t_P}\frac{\beta}{\lambda}\left(\frac{t}{\lambda}\right)dt + c_P + c_2\left[\left(1-e^{-\left[\frac{t}{\lambda}\right]^\beta}\right)\right]^2}{\int_0^{t_P}\left[1-\left(1-e^{-\left[\frac{t}{\lambda}\right]\beta}\right)^2\right]dt} \qquad (6)$$

Let $C = \frac{c_2}{c_0}$ and $C_m = \frac{c_m}{c_p}$ then the costs $C(t_p)$ are obtained for $C = 10, 20, 30, 40, 50, 60, 70, 80, 90, 100$ and $C_m = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10$ as summarized in Table 1.

From table 1 above, it is clear that, as the time t_p increases from 0.1 to 0.5, the expected cost decreases. Similarly, the cost increases with increase in t_p from 0.6 to 1.

Table 1: Optimum policy for the cost ratios for values of $0.1 \leq t_p \leq 1$, β=4, λ=0.7

t_p \ C	10	20	30	40	50	60	70	80	90	100
0.1	39.98	39.98	39.98	39.98	39.98	39.98	39.98	39.98	39.98	39.98
0.2	19.87	19.88	19.89	19.89	19.9	19.91	19.91	19.92	19.93	19.93
0.3	13.02	13.13	13.24	13.35	13.46	13.57	13.68	13.79	13.9	14.01
0.4	9.87	10.64	11.41	12.18	12.94	13.71	14.48	15.25	16.02	16.78
0.5	9.82	12.99	16.16	19.33	22.51	25.68	28.85	32.02	35.19	38.36
0.6	14.19	23.09	31.99	40.89	49.79	58.69	67.6	76.5	85.4	94.3
0.7	23.38	41.58	59.79	77.99	96.2	114.4	132.61	150.81	169.02	187.22
0.8	34.9	63.41	91.92	120.42	148.93	177.43	205.94	234.44	262.95	291.46
0.9	44.99	81.08	117.16	153.24	189.32	225.4	261.48	297.57	333.65	369.73
1	52.34	91.96	131.58	171.2	210.83	250.45	290.07	329.69	369.31	408.94

CONCLUSION

From the table 1 above, planned replacement policy for industrial equipment is the best criteria for minimizing total cost. The analysis indicates that the optimum time t_P is 0.3. The modified model in this paper will assist in maintenance decision making and guide maintenance engineers and managers in better prediction of planned replacement time at minimum cost.

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