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Based on Preventive Maintenance Strategy Analysis cold standby system reliability optimization design

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ABSTRACT: *In order to make the system meeting the two requirements: (1) the designed system have maximize reliability;(2) the designed system have a lowest cost. In this paper, we use the methods of linear programming and Lagrange multiplier method, in view of the above two requirements, we discuss the optimization scheme which is reliability of the system.*

KEYWORDS: *Preventive maintenance, cold standby systems, reliability, optimal design*

I. INTRODUCTION

We considered the cold redundant system, which was composited by two same type components and a repair equipment. the distribution of parts is general distributed distribution whose averages is $1/\lambda$ .After malfunction, the time obeys the general distributed, which is from average μ_1 .

We considered the cold redundant system, which was composited by two same type components and a repair equipment. the distribution of parts is general distributed distribution whose averages is $1/\lambda$ .After malfunction, the time obeys the general distributed, which is from average μ_1 .

Assumption：(1) moment t_0 , the parts is working. The other part is cold redundant. When working parts happen malfunction, we repair it immediately, at the same time, supply parts begin to work.
(2) When the working time whose the working parts, reach the specified time, the parts have not yet been failure. The working parts are maintained preventive. Stocking parts switch to the working state. Parts of preventive maintenance time obey the general distribution $G_2(t)$, whose average is μ_2 .
Because there is only one repairing equipment. When the age of working part reach the specified time, the part have not been failure. If the other part is malfunction repairing or preventive repairing, the working parts are not preventive maintenanced and repaired. It continue to work. If the parts which is repairing or preventive repair, have been repaired. Then it begin to work immediately. While the working part switch to prevent repair.
Until a component repair or preventive maintenance have completed. If the other is still working, and the working time is less than T , then the repair parts are reserved.
(3)Assume <1>All of the component can been repaired,<2> The switch is completely reliable, <3> instantaneous is completed instantaneously, <4> The life of two components, the time of repair, the time of preventive repair are independent of each other.
The definition of system state are as follows:
0: One of component is working, the other component is cold standby, component new.

1: One of component is working, the other component is repaired.
2: One of component is working, the other component is preventive repaired,
3: One of component is repaired or preventive repaired, working, the other component is waiting for repaired.

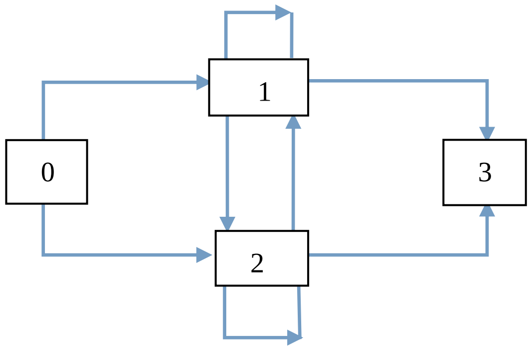

Fig. Because we consider the time before the fault only, so the fault state 3 is the absorbing state, the state transition diagram of figure 1:

Moment $X(t) = j$, if the time is t, the system status is j, $j = 0, 1, 2, 3. \{X(t), t \geq 0\}$ is a half Markov process, whose absorbing state is 3 state.

The Y_1 is repair time, the Y_2 is preventive maintenance time, and the specify time T is regarded as fixed-length random variables X_T. The distributed is $U(t) = P\{X(t) \leq t\} = \begin{cases} 0, t < T \\ 1, t \geq T \end{cases}$.

The semi Markov nuclear system is:

$$Q_{01}(t) = P\{X \leq t, X < X_T\} = \int_0^t \overline{U}(u) dF(u)$$

$$Q_{02}(t) = P\{X_T \leq t, X > X_T\} = \int_0^t \overline{F}(u) dU(u)$$

$$Q_{i1}(t) = P\{X \leq t, Y_i < X \leq X_T\} = \int_0^t G_i(u) \overline{U}(u) dF(u)$$

$$Q_{i2}(t) = P\{Y_i \leq t, X > Y_i > X_T\} + P\{X_T \leq t, Y_i \leq X_T < X\}$$

$$= \int_0^t \overline{F}(u) U(u) dG_i(u) + \int_0^t F(u) G_i(u) dU(u), i = 1, 2$$

$$Q_{i3}(t) = P\{X \leq t, Y_i > X\} = \int_0^t \overline{G}_i(u) dF(u), i = 1, 2$$

transform the above equations do Laplace-Stieltjes

$$\hat{Q}_{01}(s) = \int_0^T e^{-st} dF(t)$$

$$\hat{Q}_{02}(s) = e^{-st} \overline{F}(t)$$

$$\hat{Q}_{i1}(s) = \int_0^T e^{-st} G_i(t) dF(t) \qquad i = 1, 2$$

$$\hat{Q}_{i2}(s) = \int_T^\infty e^{-st} \overline{F}(t) dG_i(t) + e^{-st} \overline{F}(T) G_i(T) \qquad i = 1, 2$$

$$\hat{Q}_{i3}(s) = \int_0^\infty e^{-st} \overline{G}_i(t) dF(t) \qquad i = 1, 2$$

Let $\Phi_i(t)$ is 0 time, The system starts into the state distribution system MTTFF, r_j Is the mean,

$j = 0, 1, 2$. Markov updates the equation

$$\begin{cases} \Phi_0(t) = Q_{01}(t) * \Phi_1(t) + Q_{02}(t) * \Phi_2(t) \\ \Phi_i(t) = Q_{i3}(t) + Q_{i1}(t) * \Phi_1(t) + Q_{i2}(t) * \Phi_2(t), i = 1, 2 \end{cases} \quad (1)$$

transform the above equations do Laplace-Stieltjes

$$\begin{cases} \hat{Q}_0(s) = \hat{Q}_{01}(s) * \hat{\Phi}_1(s) + \hat{Q}_{02}(s) * \hat{\Phi}_2(s) \\ \hat{\Phi}_i(s) = \hat{Q}_{i3}(s) + \hat{Q}_{i1}(s) * \hat{\Phi}_{i1}(s) + \hat{Q}_{i2}(s) * \hat{\Phi}_2(s) \quad i = 1, 2 \end{cases} \quad (2)$$

slove $\Phi_0(s)$,

MTTFF is $r_i = -\frac{d}{ds}\hat{\Phi}_i(s)\Big|_{s=0}$

above（2）, About s derivation，and let $s = 0$

$$\begin{cases} r_0 = \hat{Q}_{01}(0) * r_1 + \hat{Q}_{02}(0) * r_2 + \varepsilon_0 \quad i = 1, 2 \\ r_i = \hat{Q}_{i1}(0) * r_1 + \hat{Q}_{i2}(0) * r_2 + \varepsilon_i \quad i = 1, 2 \end{cases} \quad (3)$$

$$\begin{cases} \varepsilon_0 = -[\hat{Q}_{01}'(0) + \hat{Q}_{02}'(0)] \quad i = 1, 2 \\ \varepsilon_i = -[\hat{Q}_{i1}'(0) + \hat{Q}_{i2}'(0) + \hat{Q}_{i3}'(0)] \quad i = 1, 2 \end{cases}$$

Model assumptions:

(1) assumes a life of two parts, repair and preventive maintenance time independent of time, followed a normal distribution.

(2) $C(\overline{X})$ represents the stress in the mean cost function of $\overline{X}$, $C(D_X)$ represents the stress variances D of the cost function of $\overline{Y}$.

(3) Let $C(\overline{Y})$ represents the mean intensity, $C(D_Y)$ represents the intensity of D_Y the variance of the cost function.

Due to the high intensity of the mean must rely on the use of fine materials, and in the process strictly control various processes and take appropriate measures to achieve, which is bound to increase the cost. So, $C(\overline{Y})$ is a monotonically increasing function of $\overline{Y}$.

From a reliability point of view, under symmetrical conditions require a lower variance, and therefore, $C(D_Y)$ is a monotone decreasing function of D_Y.

Here are two cases to discuss the reliability of the optimization problem:

1. at the level of reliability required, so that the total cost TC (Total Cost) minimum.

In this case, the constraint conditions $\frac{\overline{Y} - \overline{X}}{\sqrt{D_Y + D_X}} \geq z$: here set $z \geq 0$.

The objective function is: $\min \ TC = C(\overline{X}) + C(D_X) + C(\overline{Y}) + C(D_Y)$

Application of Lagrange function

$$L(\overline{X}, D_X, \overline{Y}, D_Y, \lambda) = C(\overline{X}) + C(D_X) + C(\overline{Y}) + C(D_Y) + \lambda[\overline{Y} - \overline{X} - z(D_X + D_Y)^{1/2}]$$

For each variable were partial derivative, and make it equal to zero,

$$\left.\begin{aligned}
\frac{\partial L}{\partial X} &= \frac{\partial C(\overline{X})}{\partial \overline{X}} - \lambda = 0 \\
\frac{\partial L}{\partial Y} &= \frac{\partial C(\overline{Y})}{\partial \overline{Y}} + \lambda = 0 \\
\frac{\partial L}{\partial D_X} &= \frac{\partial C(D_X)}{\partial D_X} - \frac{\lambda z}{2}(D_X + D_Y)^{1/2} = 0 \\
\frac{\partial L}{\partial D_Y} &= \frac{\partial C(D_Y)}{\partial D_Y} - \frac{\lambda z}{2}(D_X + D_Y)^{1/2} = 0 \\
\frac{\partial L}{\partial \lambda} &= \overline{Y} - \overline{X} - z(D_X + D_Y)^{1/2} = 0
\end{aligned}\right\}$$

If all cost functions are convex, that there is a positive second derivative, the above optimization problem locally optimal solution that is global solution.

This can be used to solve the optimization problem of Mathematical software.

1. under the condition of constant total cost, reliability maximized.

Time constraints for: $C(\overline{X}) + C(D_X) + C(\overline{Y}) + C(D_Y) \le r$ (the total cost limit)

The objective function: $\max \quad z = (\overline{Y} - \overline{X})(D_Y + D_X)^{-1/2}$

Application of Lagrange function:

$$L(\overline{X}, D_X, \overline{Y}, D_Y, \lambda) = (\overline{Y} - \overline{X})(D_X + D_Y)^{-1/2} + \lambda[C(\overline{X}) + C(D_X) + C(\overline{Y}) + C(D_Y) - r]$$

For each variable were partial derivative, and make it equal to zero

$$\left.\begin{aligned}
\frac{\partial L}{\partial X} &= -(D_X + D_Y)^{-1/2} + \lambda\frac{\partial C(\overline{X})}{\partial \overline{X}} = 0 \\
\frac{\partial L}{\partial Y} &= -(D_X + D_Y)^{-1/2} + \lambda\frac{\partial C(\overline{Y})}{\partial \overline{Y}} = 0 \\
\frac{\partial L}{\partial D_X} &= -\frac{1}{2}(\overline{Y} - \overline{X})(D_X + D_Y)^{-3/2} + \lambda\frac{\partial C(D_X)}{\partial D_X} = 0 \\
\frac{\partial L}{\partial D_Y} &= -\frac{1}{2}(\overline{Y} - \overline{X})(D_X + D_Y)^{-3/2} + \lambda\frac{\partial C(D_Y)}{\partial D_Y} = 0 \\
\frac{\partial L}{\partial \lambda} &= C(\overline{X}) + C(D_X) + C(\overline{Y}) + C(D_Y) - r = 0
\end{aligned}\right\}$$

Under the conditions of $D_X / D_Y \ge 1/2$ local solution above optimization problem is a global optimal solution. Again, this can also be adopted to solve the optimization problem of Mathematical software.

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