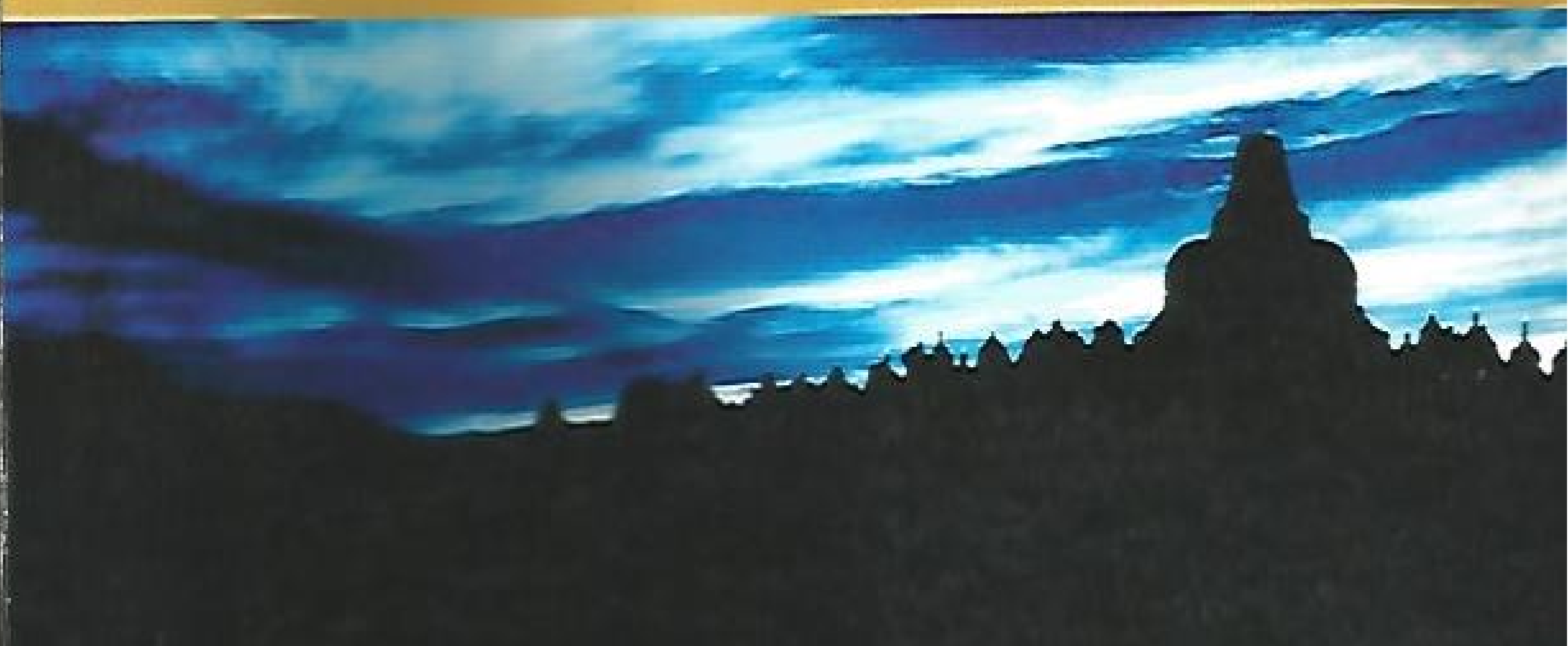

# APCOMS 2009

## The 2nd Asia-Pacific Conference on Manufacturing System

Reconfigurable Manufacturing System for Facing Turbulent Manufacturing Environment

# PROCEEDING BOOK

NOVEMBER 4th-5th, 2009
YOGYAKARTA, INDONESIA

# FOREWORD FROM ORGANIZING COMMITTEE

Distinguished Rector of Universitas Islam Yogyakarta, Dean of Faculty of Industrial Technology, ITB, keynote speakers, participants of Asia Pacific Conference on Manufacturing Systems and National Seminar on Production Systems, Ladies and Gentleman,

Welcome !

This is the second conference for Asia Pacific Conference on Manufacturing Systems, known as APCOMS 2009 and the ninth conference for the National Seminar on Production Systems, known as SNSP. These joint conference is held biannually. At the beginning we start the conference for the national scope and strated from two years ago we extend this national seminar regionally to Asia and Pacific regions.

The conference main objectives are firstly to make a forum for exchanging research results on manufacturing systems; secondly to facilitate discussions among researchers and academicians for better understanding of current challenging issues on manufacturing system research as well as manufacturing practices; and lastly to strengthen the research network around Asia-Pacific.

Today and tomorrow, we will have 58 papers to be presented at APCOMS and 22 papers to be presented at SNSP. I' m expecting that all papers will stimulates critical discussion and provides interesting time for all of you during your stay in this joint conference.

Moreover, Yogyakarta is also an interesting historical city. As one of the main tourist destination in Indonesia, I do hope that besides of spending your time for discussion, you can spend your time to enjoy the Javanese food, traditional, and culture in Yogyakarta.

I would like to thanks to all of conference participants for your paper contribution. To both keynote speakers, I would also like to convey my gratitude for your interesting speech. Lastly, I think, we would not be able to make this conference happened without all hard works and extra efforts contribute by the reviewers and others member of organizing committee. May I take this opportunity to thanks you all for the efforts you shown.

Thank you and please do enjoy the conference.

Dr. Ir. [illegible] Ari Samadhi
Prof. Dr. Ir. [illegible]
Organizing Committee Chairs
2nd Asia Pacific Conference on Manufacturing Systems
9th National Seminar for Production Systems

## [illegible] Product Development, Product Warranty

# [illegible]NTENTS:

2nd Asia Pacific Conference on Manufacturing System
4-5 November 2009, Yogyakarta, Indonesia

# An Integrated Approach Involving Reliability Improvement and Servicing Strategy For Warranted Products

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*[illegible] additional cost caused by the product sold with warranty is significant and the cost is reported [illegible] of sales price. Reducing the warranty cost is of important to the manufacturer. There are [illegible] that can be considered to reduce the warranty cost i.e. reliability improvement, preventive [illegible] and warranty servicing strategy. Most models developed in the literature (called partial models) [illegible] improvement, preventive maintenance and warranty servicing strategy separately. As [illegible] interact each other to influence the warranty cost, we need to consider them as an [illegible]. In this paper we develop an integrated model considering two approaches i.e. reliability [illegible] and servicing strategy which minimizes the expected warranty cost. A numerical example is [illegible] the optimal solution of the model developed and compares it with that of partial models .*

[illegible] *cost, integrated model, reliability improvement and servicing strategy.*

## [illegible]

[illegible] the manufacturer provides a [illegible] but it causes an additional cost as [illegible] all failures under warranty. [illegible] the manufacturer is significant [illegible] 2% to 10% of sales price [illegible]. To find an effective way [illegible] cost is of important to the [illegible]

[illegible] which can be considered to [illegible] warranty cost i.e. reliability [illegible] maintenance (PM) and [illegible] 2008). The costs depend [illegible] and the warranty policy. The [illegible] of failures and hence RI [illegible] and this in turn decreases [illegible] (2006) studied RI for [illegible]. The number of failures can be [illegible] PM over the warranty [illegible] warranted products has been [illegible] (1986), Chun and Lee [illegible] (1994). For repairable items, [illegible] and this topic has been studied by Nguyen and Murthy (1986,1989), Jack and Schouten (2000) and Jack and Murthy (2001).

The studies of reducing the warranty cost in the literature consider approaches of RI, PM and SS independently. In fact, the approaches of RI, PM and SS interact each other in reducing the warranty cost. Reliability of a product influences PM required for the product and an optimal SS that minimizes the warranty cost. PM carried out also affects reliability of the product and this in turn determining a type of SS. SS which involves replacement and imperfect repair can also improve reliability of the product. As a result, one needs an integrated approach to reduce the warranty cost.

In this paper we develop an integrated [illegible] considers RI and SS. The outline of this paper [illegible] as follows. Section 2 provides the [illegible] model. Section 3 explains the [illegible] model. Section 4 analyzes the [illegible] solution. Section 5 gives a [illegible] the performance of the model [illegible] that of partial models. [illegible] conclusion and [illegible]

## 2. NOTATIONS

The following notations are used to formulate the mathematical models:

$\tau$ : parameter of SS as a decision variable $(0 < \tau \le W)$

$\bar{\theta}$ : target of RI as decision variable where $(\theta_l < \bar{\theta} < \theta_0)$ or $(\theta_0 < \bar{\theta} < \theta_l)$

$\theta$ : reliability parameter as the indicator of item reliability

$\theta_0$ : initial value of reliability parameter

$\theta_l$ : parameter value of the highest reliability can be achieved by improving the parameter

$W$ : warranty period (year)

$C_m$ : average cost of each minimal repair ($)

$C_r$ : average cost of each replacement ($, $C_r > C_m$)

$\rho$ : cost ratio of replacement cost to minimal repair cost $[= C_r / C_m]$

$F(t;\theta)$ : distribution function for time to first item failure as a function of time $t$ with parameter $\theta$

$f(t;\theta)$ : density function related to $F(t;\theta)$ $[= dF(t;\theta)/dt]$

$r(t;\theta)$ : failure rate function related to $F(t;\theta)$ $[= f(t;\theta)/\bar{F}(t;\theta)]$

$R(t;\theta)$ : Cumulative failure rate related to $F(t;\theta)$ $[= \int_0^t r(u;\theta)du]$

$J_P(\theta_0,\bar{\theta})$ : RI cost per unit sold for improving the parameter from $\theta_0$ to $\bar{\theta}$ ($/unit)

$J_S(\tau,\bar{\theta})$ : expected warranty cost per unit sold as a function of $\tau$ and $\bar{\theta}$ ($/unit)

$J_T(\tau,\theta)$ : expected warranty cost per unit sold as a function of $\tau$ and $\theta$ ($/unit)

## 3. MODEL FORMULATION

We consider repairable items sold with the warranty period $W$. Under this policy, the manufacturer has to rectify all claims at no cost to the buyer. We assumed that all failures within the warranty period are valid claims and the time to repair is small and hence can be treated as being zero.

### 3.1 Modeling Failures

The time to the first failure is modeled by a distribution function $F(t;\theta)$. The tim... depends on the type of the rectific... minimally repaired then the process ... non-homogeneous Poisson process ... rate function $r(t;\theta)$.

### 3.2 Servicing Strategy

SS can be defined as a strate... occurred within the warranty peri... considers minimal repair whereas ... involve repair and replacement. The ... replacement in the literature divide... two intervals to three intervals fo... The SS with two intervals is co... (1981) and Nguyen and Murthy (... intervals has been studied by N... Jack and Schouten (2000) and Jack ...

Nguyen and Murthy (1989) ... the first interval. SS where replac... early or close to the warranty period ... and Schouten (2000) considered m... and third interval. In the second in... replaced by a new item depending ... item. Although the SS yields the ... difficult to implement. Then Jack ... simplified it and only the first fail... results in replacement. The resultin... but it is easy to implement (Jack et al. ...

We describe the SS of Jack ... follows:

- The warranty period is divided ... parameter $\tau_1$ and $\tau_2$ where ... $(\tau_1, \tau_2)$ and $[\tau_2, W]$.
- All failures in $[0, \tau_1]$ and $[\tau_2, W]$ are ...
- The first failure occurs in $(\tau_1, \tau_2)$ ... item and subsequent failures ... repaired.

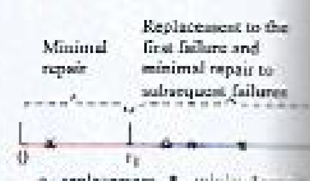


Figure 1: The SS of Jack ...

Suppose that $J_1(\tau_1, \tau_2, \theta)$ is the ... per unit sold. Jack and Murthy ... $J_1(\tau_1, \tau_2; \theta)$ and it is given in Equati...

$$[illegible] = C_m \left\{ R(\tau_1;\theta) + \int_{\tau_1}^{\tau_2} \left(\rho + R(W - x;\theta)\right) \frac{f(x;\theta)}{\bar{F}(\tau_1;\theta)} dx + \left[R(W;\theta) - R(\tau_2;\theta)\right] \frac{\bar{F}(\tau_2;\theta)}{\bar{F}(\tau_1;\theta)} \right\} \quad (1)$$

[illegible] the SS of Jack and Murthy (2001) in [illegible] the integrated model. Furthermore, we set $\tau_1 = \tau$ [illegible]. Hence, the warranty period is divided into two [illegible] $[0,\tau]$ and $(\tau, W]$. Let $\bar{\theta}$ denote the reliability [illegible]. Then, the expected warranty cost is a function of [illegible] and it is given by

$$[illegible] + \int_{\tau}^{W} \left(\rho + R(W - x,\theta)\right) \frac{f(x,\theta)}{\bar{F}(\tau,\theta)} dx \Big] \quad (2)$$

### [illegible]ility Improvement

[illegible] defined as an effort to improve the reliability of [illegible] can minimize the warranty cost. Let $\theta_0$ denote [illegible] reliability parameter. The RI can be performed by [illegible] the reliability parameter from $\theta_0$ to $\bar{\theta}$. The RI [illegible] by either increasing or decreasing of the [illegible] value depending on the characteristic of the [illegible] parameter. If failure distribution is given by [illegible] distribution, $\bar{\theta} > \theta_0$ for the scale parameter and [illegible] shape parameter.

[illegible] requires cost which is called the RI cost. For [illegible] the RI is considered only if the reduction [illegible] cost exceeds the RI cost. Various models of [illegible] of RI have been proposed by Vintr (1999), [illegible] Kumar (2000), Kleyner et. al. (2004) and [illegible] (2007). We consider the cost model of Huang [illegible]. The RI cost increases exponentially as the [illegible] of reliability increases. Suppose that the RI [illegible] given by:

$$[illegible] \left( k \frac{\theta_0 - \bar{\theta}}{\bar{\theta} - \theta_l} \right) \quad for \quad \theta_l < \bar{\theta} < \theta_0$$
$$[illegible] \left( k \frac{\bar{\theta} - \theta_0}{\theta_u - \bar{\theta}} \right) \quad for \quad \theta_0 < \bar{\theta} < \theta_u \quad (3)$$

[illegible] cost per unit, $b$ is a coefficient cost of [illegible] parameter value per unit and $k$ is a technology [illegible]

### [illegible] RI and SS

We describe an integrated model involving RI and SS as follows. The performance measure of the integrated model is the total cost which is defined as sum of the warranty cost and the RI cost. Suppose that the total cost per unit sold is $J_T(\tau,\bar{\theta})$ given by:

$$J_T(\tau,\bar{\theta}) = J_S(\tau,\theta) + J_p(\theta_0,\bar{\theta}) \quad (4)$$

where $J_S(\tau,\bar{\theta})$ is given by Equation (2) and $J_p(\theta_0,\bar{\theta})$ is given by Equation (3). The decision variables of the model are $\tau$ and $\bar{\theta}$.

## 4. MODEL ANALYSIS

We obtain $\tau^*$ and $\theta^*$ which minimize $J_T(\tau,\bar{\theta})$ subject to $0 < \tau \le W$ and $\theta_l < \bar{\theta} < \theta_u$. Theorem 1 and 2 give the characteristics of $\tau^*$ and $\theta^*$. Theorem 1 is adopted from the theorem of Jack and Murthy (2001).

**Theorem 1**

If a repairable item has the increasing failure rate with $t$ then:

i. If $1 < \rho < 1 + R(W,\bar{\theta}) - 2R(W/2,\bar{\theta})$ then there is $\tau^* = d$ where $d \in [0, W/2)$ hence $J_s(d,\bar{\theta}) < C_m R(W,\bar{\theta})$

ii. If $\rho > 1 + R(W,\bar{\theta}) - 2R(W/2,\bar{\theta})$ then $\tau^* = W$ and the optimal servicing strategy is always minimally repaired for all failures and hence $J_s(W,\bar{\theta}) = C_m R(W,\bar{\theta})$

The proof of the Theorem 1 is given in Jack and Murthy (2001).

We will show that $J_T(\tau,\bar{\theta})$ is a convex function of $\bar{\theta}$. By differentiating $J_T(\tau,\bar{\theta})$ with respect to $\bar{\theta}$, we have

$$\frac{\partial J_T(\tau,\bar{\theta})}{\partial \theta} = C_m \left( \frac{\partial}{\partial \theta} \left(J_s(\tau,\theta)\right) - \eta\phi(\bar{\theta}) \right) \quad (5)$$

and

$$\frac{\partial^2 J_T(\tau,\bar{\theta})}{\partial \theta^2} = C_m \left( \frac{\partial^2}{\partial \theta^2} \left(J_s(\tau,\theta)\right) + \eta\psi(\bar{\theta})\phi(\bar{\theta}) \right) \quad [illegible]$$

where $\eta = b / C_m$, $\phi(\theta) = k \frac{\theta_0 - \theta_l}{(\bar{\theta} - \theta_l)^2} \exp\left( k \frac{\theta_0 - \bar{\theta}}{\bar{\theta} - \theta_l} \right)$

and $\psi(\bar{\theta}) = \frac{1}{(\bar{\theta} - \theta_l)} \left( 2 + k \frac{\theta_0 - \theta_l}{(\bar{\theta} - \theta_l)} \right)$

Since $\phi(\bar{\theta}) > 0$ and [illegible] parameter $\bar{\theta}^*$ is obtained if and only if $\frac{\partial J_T(\tau,\bar{\theta})}{\partial \theta} = 0$ or $\frac{\partial}{\partial \theta} J_T(\tau,\bar{\theta}) > 0$. We find $\bar{\theta}^*$ by using Theorem 2 as follows:

**Theorem 2**

If the larger (smaller) of $\bar{\theta}$ produces the worse (better) reliability of an item then:

If $\bar{\theta}_2 > \bar{\theta}_1 \Leftrightarrow f(\tau,\theta_2) > f(\tau,\theta_1)$ then $J_T(\tau,\bar{\theta}_2) > J_T(\tau,\bar{\theta}_1)$ and hence $\frac{\partial}{\partial \theta} J_T(\tau,\bar{\theta}) > 0$. As a result, there exists $\bar{\theta} \in (\theta_l,\theta_0)$ hence $J_T(\tau,\bar{\theta})$ is a convex function of $\bar{\theta}$.

**Proof:**

If $\bar{\theta}_2 > \bar{\theta}_1$ then from Equation (2) we have

$$R(\tau,\bar{\theta}_2) + \int_\tau^W \left(\rho + R(W-x,\bar{\theta}_2)\right)\frac{f(x,\bar{\theta}_2)}{\bar{F}(\tau,\bar{\theta}_2)}dx > R(\tau,\bar{\theta}_1) + \int_\tau^W \left(\rho + R(W-x,\bar{\theta}_1)\right)\frac{f(x,\bar{\theta}_1)}{\bar{F}(\tau,\bar{\theta}_1)}dx \quad (7)$$

Equation (7) can be rewritten as (8).

$$R(\tau,\bar{\theta}_2) - R(\tau,\bar{\theta}_1) + \int_\tau^W \left(\rho + R(W-x,\bar{\theta}_2)\right)\frac{f(x,\bar{\theta}_2)}{\bar{F}(\tau,\bar{\theta}_2)}dx - \int_\tau^W \left(\rho + R(W-x,\bar{\theta}_1)\right)\frac{f(x,\bar{\theta}_1)}{\bar{F}(\tau,\bar{\theta}_1)}dx > 0 \quad (8)$$

Since $R(\tau,\bar{\theta}_2) - R(\tau,\bar{\theta}_1) > 0$ then Equation (8) is satisfied by

$$\int_\tau^W \left(\rho + R(W-x,\bar{\theta}_2)\right)\frac{f(x,\bar{\theta}_2)}{\bar{F}(\tau,\bar{\theta}_2)}dx - \int_\tau^W \left(\rho + R(W-x,\bar{\theta}_1)\right)\frac{f(x,\bar{\theta}_1)}{\bar{F}(\tau,\bar{\theta}_1)}dx > 0 \quad (9)$$

Equation (9) holds when $x = c$, $c$ is a constant and $c \in [\tau, W]$. Then we have

$$\left(\rho + R(W-c,\bar{\theta}_2)\right)\frac{f(c,\bar{\theta}_2)}{\bar{F}(c,\bar{\theta}_2)} - \left(\rho + R(W-c,\bar{\theta}_1)\right)\frac{f(c,\bar{\theta}_1)}{\bar{F}(c,\bar{\theta}_1)} > 0 \quad (10)$$

or

$$\left(\frac{\rho + R(W-c,\bar{\theta}_2)}{\rho + R(W-c,\bar{\theta}_1)}\right)\left(\frac{\bar{F}(\tau,\bar{\theta}_1)}{\bar{F}(\tau,\bar{\theta}_2)}\right)\left(\frac{f(c,\bar{\theta}_2)}{f(c,\bar{\theta}_1)}\right) > 1 \quad (11)$$

Since $R(W-c,\bar{\theta}_2) > R(W-c,\bar{\theta}_1)$ and $\bar{F}(\tau,\bar{\theta}_1) > \bar{F}(\tau,\bar{\theta}_2)$ then Equation (11) is satisfied if and only if $f(c,\bar{\theta}_2) > f(c,\bar{\theta}_1)$.

## 5. NUMERICAL EXAMPLES

We consider that $F(t;)$ is Weibull with scale and shape parameter, $\alpha$ and $\beta$ respectively. We consider the shape parameter for improving the reliability with $\theta = \beta$ at $\theta_0 = 2$ and $\alpha = 1$ and hence the distribution function is given by $F(t;2,1) = 1 - \exp(-t^2)$. We assume that $C_m = \$100$, $\theta_{min} = 1.5$, $\bar{a} = 0.05$ and $k = 1.1$. To show [illegible] integrated model we consider four [illegible] warranty cost.

Strategy 0: All failures under [illegible] repaired

In this strategy, the value of [illegible] is equal to the initial value $\theta = \theta_0$ and [illegible] of this strategy is given by

$$J_T(\tau,\bar{\theta}) = C_m R(W,\theta_0)$$

Strategy 1: Using the SS of Jack [illegible]

In this strategy, we use the [illegible] (2001) as we discussed it in Section [illegible] function of variable $\tau$ at $\theta = \theta_0$ and [illegible] (2).

Strategy 2: Improving the reliab[illegible] warranty are minimal[illegible]

In this strategy, we use [illegible] decreasing the parameter from [illegible] function of $\bar{\theta}$ at $\tau = W$ and it is g[illegible]

$$J_T(W,\bar{\theta}) = C_m\left[\bar{a} + \eta\exp\left(k\frac{\theta_0}{\bar{\theta}} \cdot \frac{\bar{\theta}}{\theta_0}\right)\right] + [illegible]$$

where $\bar{a} = a / C_m$.

Strategy 3: Integrating the RI [illegible] Murthy (2001)

In this strategy, RI [illegible] simultaneously as discussed in [illegible] a function of variables $\tau$ and [illegible] (4).

Table 1 shows the total cost of the [illegible] $\rho = 2$, $\eta = 0.1$.

Table 1: The total cost of [illegible] $\rho = 2$, $\eta = 0.1$, $\theta_0 = 2$ [illegible]

| Strategy | $\tau^*$ (year) | [illegible] | [illegible] |
|---|---|---|---|
| 0 | 3 | 2 | [illegible] |
| 1 | 1.212 | 2 | [illegible] |
| 2 | 3 | 1.75 | [illegible] |
| 3 | 1.146 | 1.75 | [illegible] |

In Table 1, the Strateg[illegible] The integrated model (Strateg[illegible] those of other strategies in [illegible] 2 gives the total cost of the [illegible]

[illegible] $\rho = \{2,3,5\}$ and $\eta = \{0.1, 0.3\}$.

[illegible] 2. The total cost of the Strategy 3 for $\rho = \{2,3,5\}$, $\eta = \{0.1, 0.3\}$, $\theta_0 = 2$ an[illegible] $W = 3$

| [illegible] | $\tau^*$ (year) | $\theta^*$ | $J_3(\tau^*, \theta^*)$ |
|---|---|---|---|
| [illegible] | 1.146 | 1.778 | 556.2 |
| [illegible] | 1.149 | 1.776 | 655.8 |
| [illegible] | [illegible] | 1.700 | 704.4 |
| [illegible] | 1.175 | 1.870 | 592.3 |
| [illegible] | 1.178 | 1.870 | 692.2 |
| [illegible] | [illegible] | 1.753 | 778.9 |

[illegible] indicates that the optimal value of parameters [illegible] are affected by the values of $\rho$ and $\eta$. The total [illegible] as the value of $\rho$ or $\eta$ increases.

## [illegible]SION

[illegible] paper, we have studied an integrated strategy [illegible] improvement and servicing strategy [illegible] the total cost i.e. the sum of the RI cost [illegible] warranty cost). From the numerical examples, [illegible] model provides the least total cost than those [illegible]

[illegible] model which considers preventive [illegible] is interesting to research and this topic [illegible]

## [illegible]


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