Bearing Procurement Analysis Method by Total Cost of Ownership Analysis and Reliability Prediction

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Abstract. In making bearing procurement analysis, price and its reliability must be considered as decision criteria, since price determines the direct cost as acquisition cost and reliability of bearing determine the indirect cost such as maintenance cost. Despite the indirect cost is hard to identify and measured, it has high contribution to overall cost that will be incurred. So, the indirect cost of reliability must be considered when making bearing procurement analysis. This paper tries to explain bearing evaluation method with the total cost of ownership analysis to consider price and maintenance cost as decision criteria. Furthermore, since there is a lack of failure data when bearing evaluation phase is conducted, reliability prediction method is used to predict bearing reliability from its dynamic load rating parameter. With this method, bearing with a higher price but has higher reliability is preferable for long-term planning. But for short-term planning the cheaper one but has lower reliability is preferable. This contextuality can give rise to conflict between stakeholders. Thus, the planning horizon needs to be agreed by all stakeholder before making a procurement decision.

Keywords: Total Cost of Ownership, Maintenance, Reliability Prediction, Bearing

1. Introduction
The total cost of ownership (TCO) is an application of cost accounting that can help decision maker to compare price between the value of a good to choose which one is better [1]. TCO analysis can quantify cost that incurred when transaction activity happens - for example; ordering, transportation, quality control – and cost that incurred because of low quality – for example; rejection, rework, and warranty [2]. TCO facilitates the firm to make the procurement to be more value oriented. Anderson, Glenn, & Sedatole (2000) see that it is important to uses value chain perspective that focuses on TCO then to use selling price to make a procurement decision. Empirical study shows that to get overall cost reduction and performance improvement from a supplier, a firm should not use a selling price criteria only [4]. Using TCO analysis is crucial to evaluate alternative procurement. Thus, in this paper, TCO analysis is used to evaluate bearing alternative that must be procured.

2. Modelling Assumptions
This research tries to identify what cost that can incur when a bearing is procured and model the TCO of bearing procurement. Identifying direct and indirect cost is a crucial step to do TCO analysis [5]. Thus direct and indirect cost is identified to model TCO of bearing. Maintenance activity is the source of direct and indirect cost. The direct cost of maintenance activity is based on cost of preventive and corrective maintenance cost. The indirect cost of maintenance activity is a downtime cost because of the incurrence of corrective maintenance.
A reliability prediction method by Naval Surface Warfare Center [6] is used to get the bearing reliability prediction. This method considers lubricant, water contaminant, operating temperature, service condition (smooth or rough and sudden movement), lubricant contamination, equivalent radial load, and dynamic load rating of the bearing. The latter is informed by bearing manufacturer, while the others are operating context specific. Predicted reliability is used to get the optimal maintenance planning. In this paper, block policy model is used to get the optimal solution [7]. This model considers preventive and corrective maintenance cost, and failure rate of the part to get the optimal maintenance period.

3. The Mathematical Model

3.1. Mathematical Notation

| Symbol | Description |
|--------|-------------|
| $\lambda_{BE}$ | Failure Rate of Bearing, failure/million hours |
| $\lambda_{BE,B}$ | Base Failure Rate of Bearing, failure/million hours |
| $C_Y$ | Multiplying Factor for Applied Load |
| $L_S$ | Dynamic Load Rating, lbf |
| $L_A$ | Equivalent Radial Load, lbf |
| $C_R$ | Life Adjustment factor for Reliability |
| $C_Y$ | Multiplying Factor for Lubricant |
| $C_{CW}$ | Multiplying Factor for Water Contaminant Level |
| $C_t$ | Multiplying Factor for Operating Temperature |
| $C_{SF}$ | Multiplying Factor for Service Conditions |
| $C_C$ | Multiplying Factor for Lubricant contamination |
| $C_b$ | Price of Bearing |
| $C_d$ | Downtime cost $/hr |

Equation (2) is used to find multiplying factor for applied load $C_Y$.

$$C_Y = \left(\frac{L_A}{L_S}\right)^y$$

Where $y = 3$ for ball bearing and 3.3 for roller bearing.

3.2. Reliability Prediction and Maintenance Block Policy Model

This paper uses reliability prediction model developed by Naval Surface Warfare Center. This model considers Dynamic Load Rating ($L_S$) as main reliability characteristic of bearing. In addition, several operating characteristics like radial load, lubricant, water, etc are considered. To predict failure rate of bearing, equation (1) is used.

$$\lambda_{BE} = \lambda_{BE,B} \cdot C_Y \cdot C_R \cdot C_C \cdot C_{CW} \cdot C_t \cdot C_{SF} \cdot C_C$$

Equation (2) is used to find multiplying factor for applied load $C_Y$. 

$$C_Y = \left(\frac{L_A}{L_S}\right)^y$$

Where $y = 3$ for ball bearing and 3.3 for roller bearing.
Maintenance block policy model [7] is used to find the optimal maintenance period. In block policy, every preventive maintenance (PM) activity is a renewal point and interval between two PM activities is defined as one cycle. In that interval, failure(s) can occur and follow failure distribution function \( f(T) \). That failure is repaired by corrective maintenance (CM) activity. Expected cost in one cycle \( ECC(T) \) can calculated by equation (3).

\[
ECC(T) = C_f M(T) + C_p
\]  

(3)

To find corrective maintenance and preventive maintenance cost, bearing price, downtime cost, and technician cost is considered. Thus the equation to find \( C_f \) and \( C_p \) are

\[
C_f = C_b + (C_{mf} + C_d) D_f
\]  

(4)

\[
C_p = C_b + (C_{mp} + C_d) D_p
\]  

(5)

The optimal solution \( T^* \) is the period of a cycle that gives zero value for the derivative function of expected cost per unit time \( ECC(T)/T \). Jiang & Murthy (2008) approximate the optimal solution \( T^* \) by equation (6).

\[
T f(T) - F(T) = C_p (C_f)^{-1}
\]  

(6)

Failure distribution is assumed follows the exponential distribution with mean time to failure \( \beta = 1/\lambda_{BE} \). Thus \( f(T) \) and \( F(T) \) are probability density function and cumulative probability function of the exponential distribution with mean \( \beta = \lambda_{BE}^{-1} \).

4. Numerical Example

Two alternatives of bearing (1&2) are considered to be chosen. The TCO of those bearing is calculated and bearing with lesser TCO is chosen. Consider the following bearing characteristic, operational characteristic, and maintenance characteristic parameter in Table 1.

| Table 1. Bearing, Operational, and Maintenance Parameter |
|---------------------------------------------------------|
| Bearing Characteristic                                  | Operational Characteristic |
| \( L_{S1} = 267.523 \text{ lbf} \)                     | \( \lambda_{BE,B} = 1 \) |
| \( L_{S2} = 229.305 \text{ lbf} \)                     | \( \lambda_R = 1 \) |
| \( C_{b1} = 7.110 \text{ $/unit} \)                    | \( \lambda_V = 0.947 \) |
| \( C_{b2} = 4.444 \text{ $/unit} \)                    | \( \lambda_{CW} = 1 \) |
| Maintenance Characteristic                              | \( c_t = 1 \)            |
| \( C_{mf} = 137.5 \text{ $/hr} \)                      | \( C_{SF} = 1 \)          |
| \( C_{mp} = 68.75 \text{ $/hr} \)                      | \( C_c = 1.4 \)           |
| \( D_f = 30 \text{ hr} \)                              | \( L_A = 184.047 \)       |
| \( D_p = 6 \text{ hr} \)                               | \( C_d = 500 \text{ $/hr} \) |

These characteristic parameters are calculated based on the equation (1) – (6). The output of the model are listed in table 2

| Table 2. Model Output |
|-----------------------|
| Bearing 1             | Bearing 2             |
| \( \beta = 14.852 \text{ hr} \)  | \( \beta = 8.930 \text{ hr} \)  |
| \( C_p = 7.522 \text{ $} \)    | \( C_p = 4.856 \text{ $} \)    |
| \( C_f = 11.235 \text{ $} \)  | \( C_f = 8.569 \text{ $} \)  |
| \( T^* = 43.183 \text{ hr} \) | \( T^* = 16.976 \text{ hr} \) |
| \( ECC(\text{Yr}) = 6.183 \text{ $/yr} \)  | \( ECC(\text{Yr}) = 8.846 \text{ $/yr} \)  |
From the result, it can be concluded that, although bearing 1 has higher bearing price, corrective and preventive maintenance cost, it has longer optimal maintenance period than bearing 2. Thus, bearing 1 has a lower expected cost per year than bearing 2. So bearing 1, the more expensive and reliable bearing, is preferable than bearing 2, the cheaper and the unreliable one.

To know whether the statement, more expensive and reliable bearing is preferable than the cheaper and unreliable bearing, holds true in every context, a sensitivity analysis is conducted. Downtime cost and maintenance period are considered as independent variables in sensitivity analysis. First, downtime cost is considered to be a variable and everything is fixed. The result is the higher the downtime the higher expected cost per year gap between bearing 1 and bearing 2, as can be seen in fig 1. So in every downtime cost, the statement holds true.

![Figure 1. Sensitivity Analysis by Downtime Cost (C_d)](image)

Second, maintenance period is assumed as a variable. Unlike before, the maintenance period policy for bearing 1 is assumed same with bearing 2 and it acts as an independent variable instead of a dependent variable. It is known, that the statement does not always hold true in every $T^* = T_1^* = T_2^*$. It is known that for $T^* > 6000$, the $ECC(Yr)_1 < ECC(Yr)_2$. Thus, when $T^* > 6000$, the statement holds true. But it does not hold true for $T^* < 6000$ because when $T^* < 6000$ the $ECC(Yr)_2 < ECC(Yr)_1$. Thus, from sensitivity analysis, it can be concluded that more expensive and reliable bearing is preferable than the cheaper and unreliable bearing in the relatively long planning horizon.
5. Conclusion
The TCO analysis can give insight to decision maker which one bearing is better to be procured. TCO analysis considers not only buying price, but also the direct and indirect cost of bearing’s reliability. A block policy maintenance model is used to find optimal maintenance period and calculated the direct and indirect cost. To predict bearing’s reliability from its dynamic rating, a reliability prediction model is used. For relatively long planning horizon, a more expensive and has higher dynamic rating is preferable than the other. But for relatively short-term planning, the cheaper and has lower dynamic rating is preferable.

This paper shows that the statement, the more expensive and reliable one is better, is contextual. It depends on horizon planning. This contextuality can give rise to conflict between an operational manager and a strategic manager. It happens because the operational manager has a short-term objective while the strategic manager has a long-term objective. Thus, the planning horizon needs to be agreed by all stakeholder before making a procurement decision.

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