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An Improved Method Based On Delay Time Model and Compromise Programming for Analysing Maintenance Interval of an Auto Transport Industry Machinery

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ABSTRACT
The purpose of carrying out inspection on vehicle machinery parts such as engine and gearbox system is to establish their true state and in the process of performing these activities, defects are identified and corrective actions implemented in order to avoid catastrophic failure. The main challenge of inspection is the evaluation of the optimum interval for performing the task. The commonly used technique for determining the interval is the delay time concept which is either applied singly or in conjunction with other tools such as Multi-Criteria Decision Making (MCDM) techniques. However, most of the integrated techniques suggested in the literature are computationally intensive. The purpose of this paper therefore, is to develop an integrated tool that can easily be applied for estimating appropriate inspection interval for auto transport company vehicle machinery. The proposed technique combines Compromise Programming method and the delay time model. The efficacy of the method is illustrated with a case of a gearbox system of an auto transport company.
Keywords: *Compromise Programming, inspection interval, delay time, vehicle machinery, decision criteria*

INTRODUCTION
The sustainability of any auto transport company depend solely on the reliability and safety operation of it. This can only be actualised if there is an effective maintenance pattern in place that will constantly retain the vehicle machinery such as the engine and gearbox system, in a state they can effectively carried out their designated functions. One of the element of a maintenance scheme is equipment inspection. The aim of performing inspection task on vehicle machinery is to ascertain their true state and in the process of carrying out these tasks defects maybe identified and corrective action executed in order to eliminate further performance degradation [3].
However, the major challenge of inspection is the determination of the appropriate interval to effect the task. In the literature various techniques have been proposed for estimating the optimum inspection interval. The delay time concept is one of the most effective approach that have been applied in the literature. The delay time is the time between the failure initiation and the time of actual failure [6]. The approach has been applied singly or in combination with other techniques in order to estimate inspection interval time more effectively. Wang and Jia [10] illustrated the application of an empirical Bayesian approach in combination with a delay time concept in estimating industrial boiler inspection time interval. Pillay et al proposed the use of downtime which was modelled with the delay time concept, to estimate the best inspection intervals for equipment items of a fishing vessel [8]. The shortcoming of these approaches is the utilisation of only some single decision criteria in establishing optimum inspection interval whereas the decision process involves more than one criteria.

Nevertheless, in order to avoid the scenario of the use of some single criteria in arriving at a solution, the delay time concept have been used in combination with Multi-criteria Decision Making (MCDM) techniques. [4] applied the delay time model in conjunction with ELECTRE method for the estimation of the best interval for inspection maintenance of marine machinery system. [5] proposed the use of an integrated PROMETHEE method and delay time technique for the evaluation of the most appropriate time for inspection task of a mechanical/service system. The author capture the risk perception of the decision maker into the decision making process and this was made possible by incorporating utility function concept into the PROMETHEE method. The above MCDM techniques applied in aggregating multiple criteria into a single model is challenging in-terms of computation. Hence, in this paper Compromise programming (CP) method is applied in combination with delay time concept in evaluating the best inspection interval for auto transport company vehicle machinery. The CP method was chosen because it requires far less computational effort and time than other MCDM approach. In fact, [1] even stated that the approach is the best choice especially when lesser computational effort is highly required.

2. METHODOLOGY
2.1 delay time concept models
Delay time analysis is a notion in which the time between the failure initiation, u and the time of actual failure is modelled in order to determine the most fit maintenance [6]. The delay time, h, is the most appropriate time to perform inspection or maintenance in order to eliminate total equipment failure [6]. The delay time concept is demonstrated with Figure 1. The concept have been applied in previous research in modelling downtime, cost and company reputation and then aggregated into a single model in order to effectively determine optimum inspection interval [5]

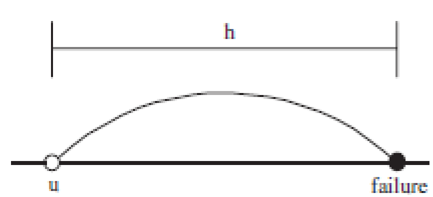

Fig. 1 Delay time concept, duplicated from Jones et al., 2009

Downtime models
The anticipated downtime per unit time of inspection, D(T),

modelled based on delay time concept may be expressed as [2]:

$$D(T) = \frac{g + k_r T E(T) d_a}{T + g} \quad (1)$$

Where

E(T) denotes the likelihood of a defect happening as a breakdown failure and is indicated mathematically as:

$$E(T) = \int_0^T \frac{T-h}{T} \frac{\beta}{\delta}\left(\frac{h}{\delta}\right)^{\beta-1} exp\left[-\left(\frac{h}{\delta}\right)^{\beta}\right] dh \quad (2)$$

T = Inspection time interval

g = Downtime as a result of inspection

d_a = Average downtime due to breakdown repair

k_r = Arrival rate of defects per unit time

δ = the scale parameter and

β = the shape parameter

Cost model

The anticipated cost per inspection unit time, C(T) of a system is indicated as follows [2]:

$$C(T) = \frac{[k_r T\{C_{br} E(T) + C_{ii}[1 - E(T)]\} + C_{ic}]}{T + g} \quad (3)$$

Where

C_{br} = breakdown repair cost

C_{ii} = inspection repair cost

C_{ic} = inspection cost

Reputation model

The effect of failures on the reputation of the auto transport industry have been modelled based on delay time. The reputation model is expressed as [5]:

$$R(T) = \frac{k_r T\{R_d E(T) + R_e[1 - E(T)]\}}{T + g} \quad (4)$$

Where R_d denote reputation of company due to breakdown repair and R_e represent reputation of company due to inspection repair. The authors suggested the application of an ordinal scale of 1 to 10 in the rating of the two factors; R_d and R_e.

2.2 Multi-Criteria Decision Making (MCDM) tools

The MCDM tools is applied in aggregating the three decision model into a single analytical model in order to easily produce an optimum solution. The MCDM tool used for this purpose in this paper is the Compromise Programming (CP) method.

2.2.1 Compromise Programming (CP)

The principle of the CP is based on the selection of the optimum alternative by measuring distance to the ideal solution. The optimum alternative is the one with the shortest distance to the ideal solution. The CP method was developed by Po-lung Yu and Milan Zeleny in 1973 [11] for the purpose of making rational decision in a problem involving conflicting multiple criteria. The technique has been used in the literature in making logical decision. [5] used the CP method in the ranking of failure modes of marine machinery system. [9] applied the technique in making decision concerning forest conservation planning.

The basic steps of the CP method are:

Step 1: Establishment of decision matrix, X, as follows:

$$X = [x_{ij}]_{nxm} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n1} & \cdots & x_{nm} \end{bmatrix} \quad (5)$$

Where

xij typify rating assigned for ith alternative with respect to jth criterion.

n and m denotes the number of alternative inspection interval and decision criteria respectively

Step 2: The decision matrix standardization. The method applicable depend whether the criteria is beneficial or non-beneficial. The beneficial criteria standardization is performed as follow:

$$K_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (6)$$

While the non-beneficial criteria standardization is carried out in two phases. The first phase is to evaluate reciprocal of the non-beneficial criteria as follow:

$$x_{ij}^R = \frac{1}{x_{ij}} \quad (7)$$

In the second phase the linear standardisation method is applied as follow:

$$K_{ij}^R = \frac{x_{ij}^R}{\sum_{i=1}^{m} x_{ij}^R} \quad (8)$$

Step 2 Evaluation of the best, $\overline{x}_j^{\,+}$ and worst, $\overline{x}_j^{\,-}$ values for each criterion and is performed as follows:

$$K_j^+ = \max_i K_{ij}, \quad K_j^- = \min_i K_{ij} \quad (9)$$

Step 3. Determination of the technique performance index (Cp) as follows:

$$Cp_i = \left[\sum_j^n w_j^p \left| \frac{K_j^+ - K_{ij}}{K_j^+ - K_j^-} \right|^p \right]^{\frac{1}{p}} \quad (10)$$

Where wj is the weight of jth criterion and can be evaluated with technique such as Analytical Hierarchy process (AHP) and standard deviation methods

The value of p ranges from 1 to ∞ but is generally set at [9,11].

3. CASE STUDY

The appropriateness of the CP method was illustrated with an example of a gear box system of Auto Transport Company obtained from the research work of [7]. The authors applied gear box system parameters data into Eq. 1 and 3 to generate downtime and cost values and the results are indicated in Table 1. Taking a cue from the work of [4] company's reputation criteria was included into the decision making process and values of 1 and 10 was assigned to reputation parameters; R_d and R_e respectively. This values were applied as input data into Eq. 4 to obtained company's reputation for each inspection interval time and the results generated are also indicated in Table 1. Having defined the decision matrix with values of C(T), D(T) and R(T), the next phase is the application of the CP method in the evaluation of the matrix. In the CP analysis, the first step is the standardisation of the decision matrix using Eq. 6 for beneficial criteria; R(T) and applying Eq. 7 and 8 for the non-beneficial criteria; C(T) and D(T). The standardised decision matrix is shown in Table 2. Next, is the determination of the best and worst values of each decision criteria using Eq. 9 and the results are illustrated in Table 2. The criteria weights is then estimated using AHP method and results also indicated in Table 2. The criteria weights are applied together with the best and worst values, as input data into Eq. 10 for the evaluation of the performance of each inspection interval. The result of each inspection interval performance and corresponding rank are presented in Table 3 and Figure 2.

Table 1: decision matrix for gear box system

Inspection interval (days)	C(T)	D(T)	R(T)
1	16345.49	0.0685	0.8071
2	15923.93	0.0555	0.8590
3	15789.74	0.0642	0.9006
4	15731.99	0.0798	0.9421
5	15706.13	0.0991	0.9849
6	15696.87	0.1209	1.0294
7	15697.52	0.1444	1.0755
8	15704.62	0.1692	1.1231
9	15716.23	0.1952	1.1722
10	15731.13	0.2221	1.2224

Table 2 Standardised decision matrix

Inspection interval (days)	C(T)	D(T)	R(T)
1	0.1034	0.1438	0.1232
2	0.1008	0.1774	0.1158
3	0.0999	0.1534	0.1105
4	0.0995	0.1234	0.1056
5	0.0994	0.0994	0.1010
6	0.0993	0.0815	0.0966
7	0.0993	0.0682	0.0925
8	0.0994	0.0582	0.0886
9	0.0994	0.0504	0.0849
10	0.0995	0.0443	0.0814
Best solution	**0.1034**	**0.1774**	**0.1232**
Worst solution	**0.0993**	**0.0443**	**0.0814**
Criteria weights	**0.1**	**0.5**	**0.4**

Table 3 Performance value and rank

Inspection interval (days)	CP	Rank
1	0.1265	2
2	0.0964	1

3	0.1745	3
4	0.2804	4
5	0.3754	5
6	0.4524	6
7	0.5145	7
8	0.5658	8
9	0.6095	9
10	0.6473	10

Table 4 Effect of changes of values of P on ranking of inspection interval

Inspection interval (days)		**P = 1**	**P= 2**	**P = 3**	**P = 4**	**P = 5**	**P = 6**	**P = 7**	**P = 8**	**P = 9**	**P = 10(∞)**
1	CP	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127
	Rank	1	2	2	3	2	2	2	3	3	3
2	CP	0.369	0.096	0.086	0.035	0.079	0.077	0.077	0.075	0.074	0.055
	Rank	2	1	1	1	1	1	1	1	1	1
3	CP	0.546	0.174	0.147	0.070	0.131	0.127	0.127	0.124	0.124	0.098
	Rank	3	3	3	2	3	3	3	2	2	2
4	CP	0.683	0.280	0.241	0.137	0.218	0.213	0.213	0.208	0.207	0.173
	Rank	4	4	4	4	4	4	4	4	4	4
5	CP	0.777	0.375	0.330	0.212	0.304	0.300	0.300	0.296	0.295	0.257
	Rank	5	5	5	5	5	5	5	5	5	5
6	CP	0.845	0.452	0.401	0.277	0.372	0.368	0.368	0.363	0.362	0.323
	Rank	6	6	6	6	6	6	6	6	6	6
7	CP	0.897	0.515	0.457	0.330	0.425	0.419	0.419	0.414	0.413	0.373
	Rank	7	7	7	7	7	7	7	7	7	7
8	CP	0.937	0.566	0.503	0.374	0.466	0.459	0.459	0.453	0.451	0.412
	Rank	8	8	8	8	8	8	8	8	8	8
9	CP	0.970	0.609	0.542	0.412	0.500	0.492	0.492	0.484	0.482	0.443
	Rank	9	9	9	9	9	9	9	9	9	9
10	CP	0.997	0.647	0.575	0.445	0.529	0.520	0.520	0.510	0.507	0.468
	Rank	10	10	10	10	10	10	10	10	10	10

Table 4 Comparative analysis result

Inspection interval	Proposed method	ELECTRE (net inferior)	MAUT
1	2	3	8
2	1	1	3
3	3	2	1
4	4	4	2
5	5	5	4
6	6	6	5
7	7	7	6
8	8	8	7
9	9	9	9
10	10	10	10

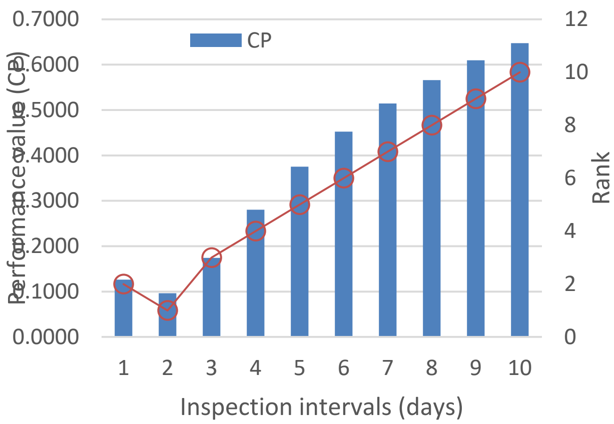

Fig. 2 Performance value and rank

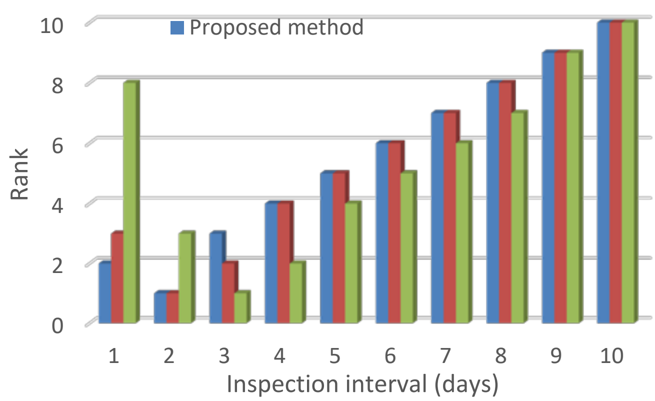

Fig. 3 Comparative analysis result

From Table 3 and Figure 2, inspection interval of 2 days is the best alternative having rank 1 while the worst alternative is the inspection interval of 10 days, having rank in the last position.

The effect of the changes in the p values on the ranking of inspection interval is determined next. For values of p from 1 to 10, each inspection interval performance were evaluated and the results obtained are shown in Table 4. From Table 4, the best inspection interval of 2 days remain un-changed for all p values except for p = 1 where the best alternative was inspection interval of 1 day. However, for all values of p the worst alternative was the same. It is obvious from this study, that the value of p used in the analysis of the CP method have little or no effect on the ranking of alternative inspection interval.

In order to validate the CP method as an appropriate tool for the prioritisation of alternative inspection interval for gear box system maintenance, the results generated from the technique when p was set at 2 are compared with results generated from other MCDM tools; ELECTRE and MAUT methods. The results of the comparative analysis are illustrated in Table 4 and Figure 3.

From Table 4 and Figure 3, it is obvious that the CP method produces almost completely same result with the ELECTRE method, with both techniques having same rank with at least 80% of the total alternative inspection interval. The CP and MAUT method generated same rank for 50% of the total alternative inspection intervals while about 40 % inspection intervals are having one rank difference in between with the exception of inspection interval of 1 day. The CP method having strong correlation with the ELECTRE method, is an indication that the tool is a viable mechanism for the prioritisation of inspection intervals of an auto transport company vehicle machinery.

4. CONCLUSION

This paper presented an integrated delay time model and Compromise Programming (CP) method for the prioritisation of alternative inspection interval for auto transport company vehicles machinery. Three decision criteria; cost, downtime and company reputation were modelled using delay time concept and are aggregated with the CP technique into a single analytical model for generating the performance of each inspection interval. The results of the CP method were compared with that of ELECTRE and MAUT methods. The comparative analysis indicated that the CP method although simpler in terms of application, generated similar results with that of ELECTRE and MAUT, thereby validating the CP approach for application in analysing optimum inspection interval for auto transport company vehicle machinery. The study also showed from the sensitivity analysis of CP that the performance of each inspection interval remained almost un-affected for values of, P, ranging from 1 to 10.

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