INSPECTION INTERVAL DETERMINATION FOR MECHANICAL/SERVICE SYSTEMS USING AN INTEGRATED PROMETHEE METHOD AND DELAY TIME MODEL

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ABSTRACT

Optimum inspection maintenance decision problem is a multi-criteria problem which many researchers have viewed as a single criterion problem such as mainly using downtime or cost, as the basis for selecting interval for the task. However, a combination of a number of criteria can yield a more appropriate interval for inspection maintenance task for mechanical/service system. This paper proposes an integrated PROMETHEE technique and delay time concept for implementing optimum inspection interval for mechanical/service systems based on combination of conflicting decision criteria. While the delay time concept is used to model decision criteria, the PROMETHEE method is used to aggregate decision criteria and ranking of alternative inspection interval. The PROMETHEE technique had been enhanced in this paper by incorporating utility function concept into it, in order to embed maintenance practitioners risk perception into the decision making process. The applicability and suitability of this methodology is demonstrated with two case studies.

KEYWORDS: *PROMETHEE technique; Inspection intervals; Delay time model; Mechanical/service system*

1.0 INTRODUCTION

British Standard define maintenance as (BS 1993) "*the combination of all technical and administrative actions, intended to retain an item in, or restore it to a state in which it can perform a required action*". Maintenance of mechanical/service system with so many components is still a challenge across the globe, as the cost vary from 20 to 30 percent of the overall cost of its operation. However having a sound and effective maintenance system in place will help reduce cost of maintenance without compromising system reliability and availability. One of the greatest challenge of mechanical/service system maintenance is the determination of the interval for performing inspection.

The purpose of carrying out inspection activities on mechanical/service systems is to establish their true condition and in the course of performing these activities, if a defect is found, a repair or replacement task is schedule and carried out to prevent the equipment from further deterioration. However failure to perform inspections task, defects may go unnoticed which can result in catastrophic system failure that may have irreversible impact on the company. Even if inspection tasks are carried, defects can still

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occur between successive intervals if they are not properly timed. It is then obvious that the subject of inspection interval determination problem is critical, justifiable and worthy of investigation as it is central to the effective operation of mechanical/service system. Traditionally, maintenance practitioners rely on experience or Original Equipment Manufacturers' recommendation in determining appropriate time interval for carrying out inspection and the result is far from being optimal (Christer et al., 1997).

One of the most reliable technique applied in recent time is the delay time concept and it was introduced by Christer (1982). The delay time is the time between when a defect become noticeable and when the actual failure of the system occur.

Pillay et al. (2001) used the expected downtime model based on the delay time concept to determine optimum inspection intervals for fishing vessel equipment items. The inspection plan was developed with the purpose of reducing vessel downtime as a result of machinery failure that could occur between discharge ports. In order to determine the suitability of the approach, the winch system of the fishing vessel was used as case study. The case study results showed that an inspection period of 12 hours was appropriate for the system. Arthur (2005) applied the delay time model to determine an optimum inspection interval for condition monitoring of an offshore oil and gas water injection pumping system.

The approaches used in the literature based on the delay time concept utilises a single decision criteria in the determination of appropriate interval for performing inspection for mechanical/service systems. However a more appropriate interval can be determine by applying multi-criteria based approaches. To achieve this aim, PROMETHEE method, a Multi-criteria Decision Making (MCDM) tool is integrated with the delay time model in order to formulate a more efficient tool for inspection interval determination for application to mechanical/service systems. In this paper delay time concept is applied in modelling of two decision criteria; cost and downtime while the PROMETHEE method is used to aggregate decision criteria such that, multiple criteria can be used simultaneously in the ranking of alternative inspection interval. However to make the PROMETHEE method more robust, utility function concept is integrated in order for risk perception of the maintenance practitioners to be included in the decision making process.

The rest of the paper is organized as follows: The proposed methodology is presented in section 2. This is then followed with two case studies to illustrate the applicability of proposed method in section 3. Finally the conclusion is presented in section 4.

2.0 METHODOLOGY

2.1 Delay time concept

Inspection task can only be beneficial if there is a sufficient period between the time that the defect is observed and the actual time of failure of the equipment. As previously stated the time interval between when a defect becomes identifiable and the actual time of failure is referred to as the delay time (*h*). Figure 1 is used to illustrate the delay time concept.

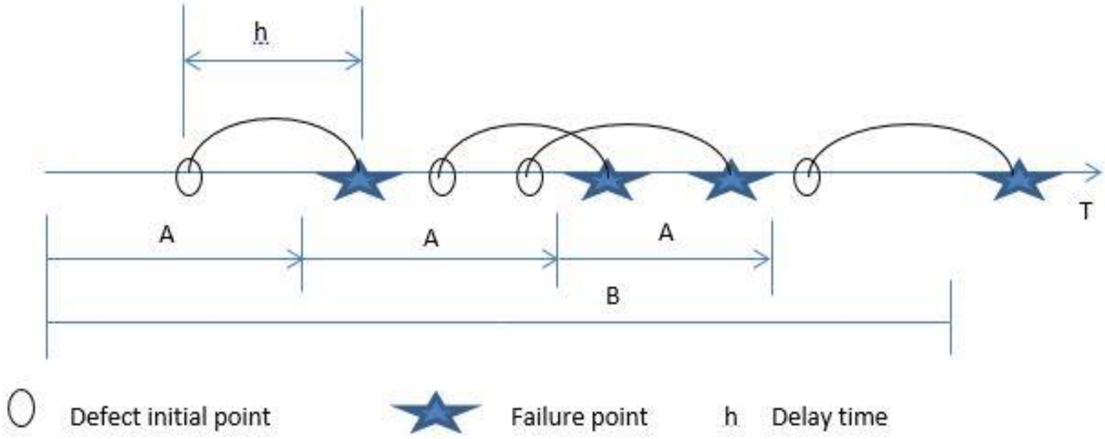


Figure 1. Delay time concept showing a defect's initial points and failure points

Figure 1 shows multiple points of failure, both initial and actual points where failure occurs and also two different inspection plans for a mechanical system. It is obvious from the figure that if the inspection of the system is performed at an interval of B a lot of failures will happen in the system since most of the defects would have resulted in actual failure. Alternatively inspection plan A would result in detecting virtually all of the defects before the actual failure of the system could occur. The key to achieving maximum success in mitigating catastrophic failure of mechanical/service systems is to have a proper understanding of the delay time (h) of the system such that maintenance can be performed within this period.

Based on Christer and Waller (1984), "*a defect occurring within a period of (0, T) in a system has a delay time, h , and h has a probability density function of f(h). If failure of the system occurs at a period (0, T-h) the maintenance (repair or replacement) carried out is referred to as breakdown maintenance otherwise the maintenance is inspection maintenance. For the system, if all possible values of, h, are added up, according to Christer and Waller (1984), the probability of a defect occurring as a breakdown failure is*":

$$B(T) = \int_0^T \frac{T-h}{T} f(h)dh \tag{1}$$

The above Equation was established based on the following assumptions:
(1) Inspection is performed at regular intervals
(2) Defects discovered during inspection are repaired
(3) Perfect inspection meaning all defects are discovered during inspection
(4) Arrival rate of defects is constant

However it is worth noting that some of these assumptions may not be realistic in practical situations. For example, it may not be possible to identify all defects during inspection as some defects could be hidden although the system performance degradation may have started during inspection. Some of these assumptions are made to ease the modelling of the system and for ease of computation of the models.

Since in this paper Weibull distribution is assumed, probability density function of the delay time $f(h)$ is evaluated as:

$$f(h) = \frac{\alpha}{\beta}\left(\frac{h}{\beta}\right)^{\alpha-1} \; exp\left[-\left(\frac{h}{\beta}\right)^{\alpha}\right] \tag{2}$$

Where
α and β represents shape parameter and scale parameter respectively.

2.2 Decision criteria modelling

For this paper two decision criteria; cost and downtime were chosen based on which optimum interval for mechanical/service system is determined. The two decision criteria had been modelled based on the delay time concept (Christer & Waller, 1984) and are discussed as follows:
The downtime criteria which is the expected downtime per unit time $D(T)$ to be suffered when operating an inspection time interval, T, is presented as:

$$D(T) = \frac{\varphi + k_r T B(T) d_a}{T + \varphi} \tag{3}$$

Where

T = Inspection time interval
φ = Downtime as a result of inspection
d_a = Average downtime due to breakdown repair
h = Delay time
k_r= Arrival rate of defects per unit time

The cost criteria which is the expected cost per unit time $C(T)$ of inspection time interval T is presented as:

$$C(T) = \frac{[k_r T\{C_b B(T) \; + C_{ii}[1 - B(T)]\} + I_c]}{T + \varphi} \tag{4}$$

Where
C_b = breakdown repair cost
C_{ii} = inspection repair cost
I_c = inspection cost

2.3 PROMETHEE method

PROMETHEE a multi-criteria decision making method is an acronym for Preference Ranking Organisation METHod for Enrichment Evaluations, developed by Brans, first presented in 1982 (Brans, 1986) and further extended by Brans and Vincke (Brans & Vincke, 1985). It is one of the outranking technique for solving multi-criteria decision problem. There are seven variant of the PROMETHEE method (Behzadian et al., 2010) but PROMETHEE II is the most popular of all the versions and it's fundamental to the implementation of the other versions. The technique have been applied successfully in solving multi-criteria problem such as material selection problem and maintenance strategy selection problem (Emovon et al., 2015b).
The basic steps of the PROMETHEE method can be defined as follows:

(1) Determination of a decision matrix: consider a multi-criteria problem with, *n* number of alternatives i.e. A_1, A_2,…, A_n and *m* number of decision criteria i.e. B_1, B_2,…, B_m upon which the alternatives are evaluated. An example of such problem is the decision matrix in Table 1.

Table 1. Decision Matrix

Alternatives (Ai)	Decision criteria (Bj)	
	C(T)	D(T)
A_1	x_{11}	x_{12}
A_2	x_{21}	x_{22}
A_3	x_{31}	x_{32}
-	-	-
-	-	-
A_n	x_{n1}	x_{n2}

(2) Determination of utility functions: The maintenance practitioners' behaviour with respect to risk is put into consideration through utility function, instead of analysing variables in Table 1 directly into the PROMETHEE model. The risk perceptions of the maintenance practitioners are of three categories which are incorporated into the utility function and these are; risk prone, risk neutral and risk averse. According to Ferreira et al. (2009) the maintenance practitioners are risk neutral as regards to cost criterion and as such a linear function is applicable while for the downtime criterion, the maintenance practitioners are risk prone and a negative exponential function is utilised. The utility function for C(T) and D(T) were presented as follows:

$$u(C(T)) = \frac{C(T) - \max C(T)}{\min(C(T) - \max C(T)} \quad (5)$$

$$u(D(T)) = \frac{C(T) - \min D(T)}{\max D(T) - \min D(T)} \ln(0.01) \quad (6)$$

Where

$\max C(T)$ represents the maximum value of elements, $x_{ij,}$ for cost criterion, $\min C(T)$ represents the minimum value of element, $x_{ij,}$ for cost criterion, $\max D(T)$ represents the maximum value of element, $x_{ij,}$ for downtime criterion, $\min D(T)$ represents the minimum value of element, $x_{ij,}$ for downtime criterion. The results are then use to form a utility function decision matrix as shown in Table 2.

Table 2. Utility function

Alternatives (Ai)	Decision criteria (Bj)	
	u(C(T))	u(D(T))
A_1	r_{11}	r_{12}
A_2	r_{21}	r_{22}
A_3	r_{31}	r_{32}
-	-	-
-	-	-
A_n	r_{n1}	r_{n2}

(3) Definition of preference function

Comparison of alternatives *a* and *b* for each criterion are performed based on preference function which transform the difference between the alternatives into a value ranging from 0 to 1. The preference of alternative *a* over *b* for each criterion is represented as:

$$P_j(a, b) = F_j\{\, f_j(a) - \ f_j(b)\} \quad (7)$$

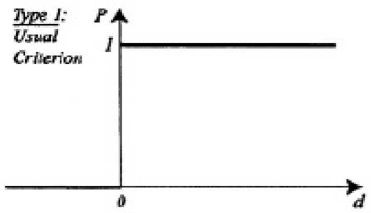
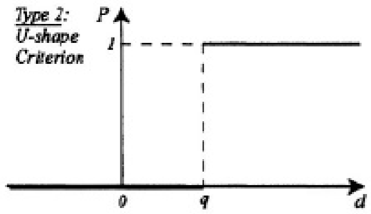
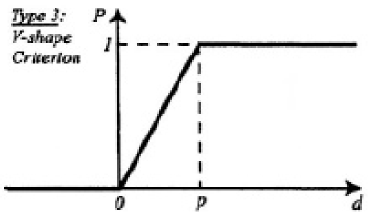
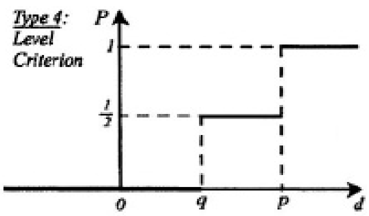
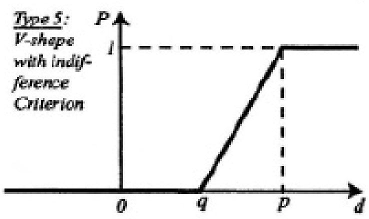
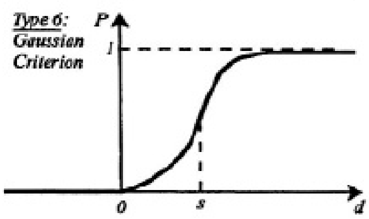
Where F_j is the function of the deviation (d) between alternative *a* and *b*. There are six types of preference function and are presented in Table 3.

(2) Determination of numerical weights of criteria: This is a measure of the relative importance of each criterion. There different methods for evaluating decision criteria weight such as Analytic Hierarchy Process (AHP), entropy method and variance method. In this paper AHP method was chosen because of its capability to incorporate both quantitative and qualitative information. The normalisation of the weight is carried out as follows:

$$\sum_{j}^{m} w_j = 1 \quad (8)$$

Where w_j is the weights of criteria *j*

Table 3. Preference functions, adapted from (Figueira et al., 2005)

Generalised criterion	Definition	Parameters to fix
	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases}$	–
	$P(d) = \begin{cases} 0 & d \leq q \\ 1 & d > q \end{cases}$	q
	$P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{d}{p} & 0 \leq d \leq p \\ 1 & d > p \end{cases}$	p
	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{1}{2} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{d-q}{p-q} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$	s

(5) Evaluation of the overall preference index of a over b, $\pi(a,b)$: The weighted average of all the preference functions $P_j(a, b)$ for all criteria is mathematically defined as follows:

$$\pi(a,b) = \sum_{j=1}^{m} w_j \; P_j(a,b) \tag{9}$$

The net flow ϕ is then determined, which is the measure of the performance of the alternatives. The net flow which is the difference between the positive flow $\emptyset^+$ and the negative flow $\emptyset^-$, is computed as follows:

$$\phi(a) = \emptyset^+(a) - \emptyset^-(a) \tag{10}$$

Where

$$\emptyset^+(a) = \frac{1}{m-1}\sum_{b \neq a} \pi\,(a,b) \tag{11}$$

$$\emptyset^-(a) = \frac{1}{m-1}\sum_{b \neq a} \pi\,(b,a) \tag{12}$$

The alternatives (inspection intervals) are ranked on the basis of the net flow and the higher the value the better the alternative.

The steps for the proposed methodology for optimum inspection interval determination are as follows:

1.
2.
3. Decision maker determination of both alternatives inspection interval and decision criteria
4. Modelling of decision criteria based on delay time concept
5. Determination of the parameters of the decision criteria (C(T) and D(T)) such as delay time distribution and associated parameters, cost of inspection, cost of breakdown repair and cost of inspection repair
6. Evaluation of D(T) and C(T) for every alternative inspection interval T
7. Evaluation of weights of D(T) and C(T) using AHP
8. Ranking of alternative inspection interval using PROMETHEE

3.0 CASE STUDY

3.1 Case study 1: Marine diesel engine-sea water cooling pump

To illustrate the suitability of the proposed integrated PROMETHEE method and the delay time model, the sea water cooling pump is used. The sea water pump is one of the equipment item of the central cooling system of the marine diesel engine and it has been established that scheduled inspection is the most appropriate maintenance strategy use to mitigate it failure (Emovon et al., 2015b). The data used as input into the delay time model were obtained from logged records, expert's opinion, ongoing PhD research and from the work of Cunningham et al. (2011). The data obtained from these sources are:

Breakdown repair cost (c_b) = £52,500
Inspection repair cost (c_{ii}) = £10,500
Inspection cost (I_c) = £210
Shape (α) = 10
Scale (β) = 5
Downtime due to inspection = 12.5 minutes
Downtime due to breakdown repair = 168 hours
Arrival rate of defects = 1277 per 10^6 hour
The possible intervals of inspection of the equipment also need to be determined and were obtained with the aid of an expert with several years of marine diesel engine maintenance experience. The possible inspection intervals arrived at are 1 hour to 28 hours in steps of 1 hour.

3.1.1 Data analysis

The above data were used as input into Equation 3 and 4 to determine cost and downtime for different inspection intervals. The results obtained for downtime and cost are presented in Figures 2 and 3 respectively.

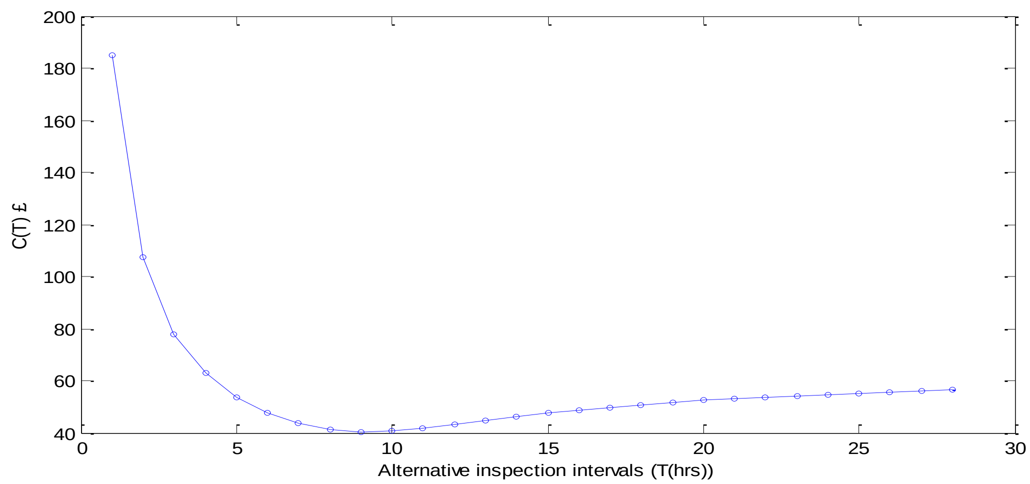


Figure 2. Inspection interval and cost effect

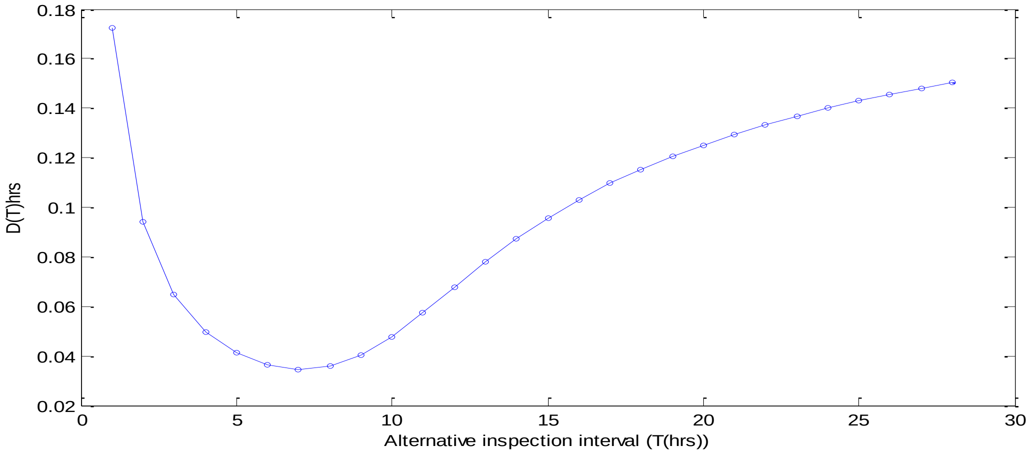


Figure 3. Inspection interval and downtime effect

From the results of the two decision criteria; cost and downtime in Figures 2 and 3 respectively, it is obvious that there is conflict among them. For example the optimum solution for the cost criteria is inspection interval of 9 hours while that of downtime is 7 hours. To determine the most appropriate inspection interval, PROMETHEE method is utilised in this study. The first step in obtaining a solution using the PROMETHEE method is to form a decision matrix. Although there are a total of 28 alternative inspection interval as in 1 hour to 28 hours in a step of an hour only the first 10 alternatives are considered since the optimum solution for both cost and downtime lies within this range. The decision matrix formed from the two decision criteria results are shown in Table 4.

Table 4. Decision matrix of the sea water cooling pump

Alternative inspection intervals (hrs)	C(T) £	D(T) hrs
1	184.8950	0.1724
2	107.2421	0.0943
3	78.0135	0.0650
4	62.7330	0.0498
5	53.4584	0.0411
6	47.4421	0.0362
7	43.5487	0.0345
8	41.2698	0.0358
9	40.3398	0.0403
10	40.5326	0.0477

Since the PROMETHEE technique does not determine decision criteria weights, AHP method is utilised to determine the weights. The criteria weights obtained for criteria C(T) and D(T) using AHP method are 0.35 and 0.65 respectively. The utility function values of C(T) and D(T) are then determined using Equations 5 and 6 respectively and the results are presented in Table 5.

Apart from weight determination of decision criteria, there is also the need to established preference function for each decision criteria. Type five and type three preference function in Table 3 was chosen for C(T) and D(T) respectively. The net flow of each inspection interval is then evaluated using Equation 10 which is the difference between the positive flow and the negative flow and results are presented in Table 6.

Table 5. Utility function of the sea water cooling pump

Alternative inspection intervals (hrs)	u (C(T))	u (D(T))
1	0.0000	0.0100
2	0.5372	0.1357
3	0.7394	0.3611
4	0.8451	0.5999
5	0.9092	0.8022
6	0.9509	0.9448
7	0.9778	1.0000
8	0.9936	0.9575
9	1.0000	0.8239
10	0.9987	0.6435

Table 6. PROMETHEE performance index for sea water pump inspection interval

Alternative inspection interval (hrs)	$\emptyset^{-}$	$\emptyset^{+}$	ϕ	Rank
1	0.9580	0.0000	-0.9580	10
2	0.0895	0.0692	-0.0204	9
3	0.0216	0.1151	0,0935	8
4	0.0063	0.1209	0,1146	7
5	0.0016	0.1273	0.1257	5
6	0.0002	0.1326	0.1325	3
7	0.0000	0.1350	0.1350	1
8	0.0001	0.1332	0.1331	2
9	0.0013	0.1280	0.1268	4
10	0.0049	0.1222	0.1173	6

From Table 6 the optimum inspection interval for the sea water pump is 7 hours. This is closely followed with inspection interval of 8 and 6 hours respectively. The worst solution is the inspection interval of 1 hour.

3.1.2 Comparison of proposed ranking tools with VIKOR method

The ranking tool used in this paper is the PROMETHEE technique and in order to validate the method for application in prioritising alternative inspection intervals another MCDM tool, VIKOR, was used in solving the sea water pump inspection decision problem. Although VIKOR method had not been previously applied in solving inspection interval decision problem but has been successfully use in addressing problems such as risk prioritisation, material selection and selection of outsourcing providers (Liou and Chuang, 2010, Emovon et al., 2015a, Anojkumar et al., 2014). The ranks of the ten alternative inspection intervals obtained using PROMETHEE and VIKOR methods are presented in Table 7.

Table 7. Comparison of ranking methods

Alternative inspection interval (hrs)	PROMETHEE	VIKOR
1	10	10
2	9	9
3	8	8
4	7	7
5	5	5
6	3	3
7	1	1
8	2	2
9	4	4
10	6	6

Table 7 showed that both techniques produces the same ranking for the 10 alternative inspection intervals and invariably the same optimum solution for the sea water pump. It is evident that both ranking techniques can individually be use in the ranking of alternative inspection intervals. The result has validated the proposed PROMETHEE technique as a tool for solving inspection interval decision problem.

3.2 Case study 2: Gearbox maintenance decision problem

To further illustrate the applicability of the proposed methodology, a case study of a gear box system of an Automobile Company based in Hong Kong is applied. The data for the investigation of the optimum inspection interval for the gear boxes of the Company is taken from the work of Leung and Kit-leung (1996). The data are as follows:

Breakdown repair cost (c_b) = \$23,000
Inspection repair cost (c_{ii}) = \$18,400
Inspection cost (I_c) = \$1,920
Shape (α) = 1.34
Scale (β) = 46.9
Downtime due to inspection = 0.0625
Downtime due to breakdown repair = 5 days
Arrival rate of defects = 0.839 gearbox per day

Leung and Kit-leung (1996) utilise only cost model, C(T), in the determination of optimum inspection interval for the gear box system but in this paper both cost model, C(T), and downtime model, D(T), are simultaneously use to obtain optimum solution.

3.2.1 Data analysis

Applying the maintenance decision data into Equation 3 and 4 results of the cost and downtime for various possible inspection intervals were obtained and are presented in Figures 4 and 5 respectively.

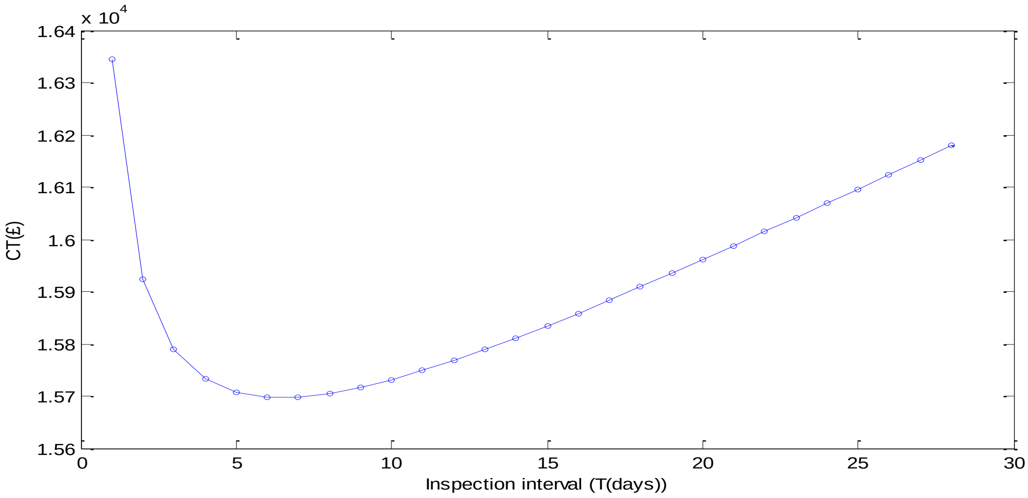


Figure 4. Inspection interval and cost effect

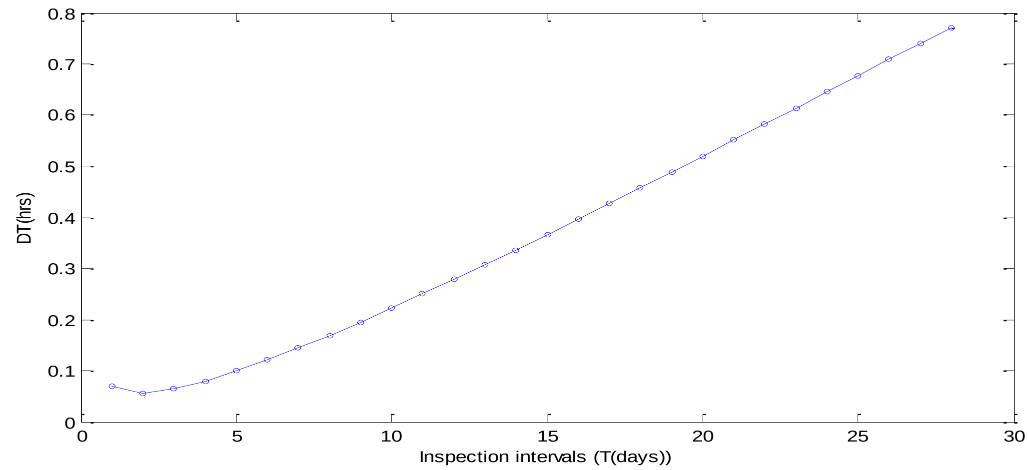


Figure 5. Inspection interval and downtime effect

From the results of the two decision criteria; cost and downtime in Figures 4 and 5 respectively it is obvious that there is conflict among them. For example the optimum solution for the cost criteria is inspection interval of 6 days while that of downtime is 2 days. To reach a compromise solution MCDM tool is utilised in this study. Although there are a total of 28 alternative inspection interval as in 1 day to 28 days in a step of a day only the first 10 alternatives are considered since the optimum solution for the cost and downtime lies within this range. In order to apply the MCDM tool, there is need to form a decision criteria. The decision matrix formed from the results of the two decision criteria are shown in Table 8. The criteria weights obtained for criteria C(T) and D(T) using AHP method are 0.80 and 0.20. The utility function values of C(T) and D(T) are determined using Equation 5 and 6 respectively and the results obtained are presented in Table 9. Type six and type three preference function in Table 3 are utilise for C(T) and D(T) respectively. The net flow is then evaluated using Equation 10 and results are presented in Table 10.

Table 8. Decision matrix for the Gearbox system

Alternative inspection intervals (Days)	C(T) £	D(T) days
1	16345.49	0.0685
2	15923.93	0.0555
3	15789.74	0.0642
4	15731.99	0.0798
5	15706.13	0.0991
6	15696.87	0.1209
7	15697.52	0.1444
8	15704.62	0.1692
9	15716.23	0.1952
10	15731.13	0.2221

Table 9. Normalised decision matrix for the Gearbox system

Alternative inspection interval	u(C(T))	u (D(T))
1	0.0000	0.6981
2	0.6499	1.0000
3	0.8568	0.7862
4	0.9459	0.5108
5	0.9857	0.2996
6	1.0000	0.1640
7	0.9990	0.0857
8	0.9881	0.0432
9	0.9702	0.0210
10	0.9472	0.0100

Table 10. PROMETHEE performance index of gear box inspection interval

Alternative inspection intervals (days)	$\emptyset^{-}$	$\emptyset^{+}$	ϕ	Rank
1	0.0380	0.0028	-0.0352	10
2	0.0039	0.0068	0.0029	7
3	0.0007	0.0071	0.0064	1
4	0.0008	0.0066	0.0058	2
5	0.0013	0.0062	0.0049	3

6	0.0018	0.0059	0.0041	4
7	0.0022	0.0057	0.0035	5
8	0.0024	0.0054	0.0030	6
9	0.0025	0.0051	0.0026	8
10	0.0027	0.0048	0.0021	9

The result in Table 10 reveals that the optimum inspection interval for the gear box is 3 days having rank first among the 10 alternative inspection intervals. The worst solution is the inspection interval of 1 day since it occupies the last position. Leung and Kit-leung (1996) obtained 6 days as the optimum solution while considering only cost without putting into consideration downtime effect. Downtime is an important criteria that should be considered in addressing problem of inspection interval especially in Service industries were plant system downtime may result to company reputation being damage irreversibly. The 3 days optimum solution obtained using the proposed method will be more ideal as it will result to lower downtime for the system while still maintaining an optimum cost.

3.2.2 Comparison of proposed ranking tools with VIKOR method

The ranking of the 10 alternative inspection intervals for the gear box system using PROMETHEE method is compared with VIKOR method and results are presented Table 11.

Table 11. Comparison of ranking methods

Alternative inspection interval (hrs)	PROMETHEE	VIKOR
1	10	10
2	7	9
3	1	2
4	2	1
5	3	3
6	4	4
7	5	5
8	6	6
9	8	7
10	9	8

From Table 11, both PROMETHEE and VIKOR methods produces almost completely the same ranking for the 10 alternative inspection interval for gear box system. The Spearman rank correlation between both methods were evaluated to further establish the relationship between them. The Spearman rank correlation coefficient of 0.950 was obtained and this again shows that the two technique are strongly correlated. This has further validated the proposed PROMETHEE techniques as a viable tool for ranking of alternative inspection interval. Generally the advantage of using MCDM tool for ranking of alternative inspection intervals is that more than one decision criteria can be applied simultaneously in arriving at optimum solution, instead of utilising a single criteria for a multi-criteria problem which is the current practice in most shipping industry. The various MCDM tools has one limitation or the other, their individual use will depend on the maintenance practitioners' and/or analysts' choice which may be guided by ease of implementation and suitability (Løken, 2007). The PROMETHEE technique was chosen as a ranking tool in this paper mainly because of the availability of software that will aid maintenance practitioners in solving inspection decision problem with much ease.

4.0 CONCLUSIONS

One of the popularly used maintenance strategy is the scheduled inspection. However the major challenge with the approach is the determination of the optimum interval for performing the task. In addressing this problem, PROMETHEE and AHP methods were integrated and then combine with Delay time model such that an optimum inspection interval for any mechanical/service system can be determined based on multiple criteria as oppose to single criteria currently being applied by most industrial maintenance practitioners. The PROMETHEE technique had been enhanced in this paper by incorporating utility function concept such that the risk perception of maintenance practitioners can be embedded in the decision making process. The approach have been demonstrated with two case studies; the sea water pump of a central cooling system of a marine diesel engine and a gear box system of an Automobile Company and the results revealed that the technique is capable of addressing the inspection interval problem of any mechanical/service system that requires maintenance. Further work can be done by including more decision criteria such as safety and availability in the decision making process.

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6.0 REFERENCES

Anojkumar, L., Ilangkumaran, M. & Sasirekha, V. (2014). Comparative analysis of MCDM methods for pipe material selection in sugar industry. *Expert Systems with Applications, 41***,** 2964-2980.

Arthur, N. (2005). Optimization of vibration analysis inspection intervals for an offshore oil and gas water injection pumping system. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 219***,** 251-259.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A. & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research, 200***,** 198-215.

Brans, J.-P. (1986) L'élaboration d'instruments d'aide à la décision [The development of the decision support tools], Raymond Nadeau et Maurice Landry, Les presses del L' Université Laval, Québec.

Brans, J.-P. & Vincke, P. (1985). A preference ranking organisation method: (The PROMETHEE method for multiple criteria decision-making). *Management Science, 31***,** 647-656.

Christer, A. H. (1982). Modelling inspection policies for building maintenance. *Journal of the Operational Research Society***,** 723-732.

Christer, A. H. & Waller, W. M. (1984). Delay time models of industrial inspection maintenance problems. *Journal of the Operational Research Society***,** 401-406.

Christer, A. H., Wang, W., Sharp, J. M. & Baker, R. D. (1997). Stochastic maintenance modelling of high-tech steel production plant. *Stochastic Modelling in Innovative Manufacturing.* Springer, 445, 196-214.

Cunningham, A., Wang, W., Zio, E., Wall, A., Allanson, D. & Wang, J. (2011). Application of delay-time analysis via Monte Carlo simulation. *Journal of Marine Engineering & Technology, 10***,** 57-72.

Emovon, I., Norman, R. A., J, M. A. & Pazouki, K. (2015a). An integrated multicriteria decision making methodology using compromise solution methods for prioritising risk of marine machinery systems. *Ocean Engineering, 105***,** 92-103.

Emovon, I., Norman, R. A. & Murphy, A. J. (2015b). Hybrid MCDM based methodology for selecting the optimum maintenance strategy for ship machinery systems. *Journal of Intelligent Manufacturing*. Retrieved from http://dx.doi.org/10.1007/s10845-015-1133-6

Ferreira, R. J. P., De Almeida, A. T. & Cavalcante, C. A. V. (2009). A multi-criteria decision model to determine inspection intervals of condition monitoring based on delay time analysis. *Reliability Engineering & System Safety, 94***,** 905-912.

Figueira, J., Greco, S. & Ehrgott, M. (2005). *Multiple criteria decision analysis: state of the art surveys,* Springer Science & Business Media.

Leung, F. & Kit-Leung, M. (1996). Using delay-time analysis to study the maintenance problem of gearboxes. *International Journal of Operations & Production Management, 16***,** 98-105.

Liou, J. J. H. & Chuang, Y.-T. (2010). Developing a hybrid multi-criteria model for selection of outsourcing providers. *Expert Systems with Applications, 37***,** 3755-3761.

Løken, E. 2007. Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews, 11***,** 1584-1595.

Pillay, A., Wang, J. & Wall, A. (2001). Optimal inspection period for fishing vessel equipment: a cost and downtime model using delay time analysis. *Marine Technology, 38***,** 122-129.