Fuzzy Analytic Hierarchy Process (FAHP) for Better Selection during Implementation of Design for Remanufacturing in Economy Indicator

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ABSTRACT

Remanufacturing is a process of repair, reuse or replace parts of a product to extend its life with minimal waste of money and energy during the process. Design of Remanufacturing (DFReM) consists of three indicators namely social, environmental and economic. In this paper, the economic indicator will be improved by implementing Fuzzy Analytic Hierarchy Process (FAHP) during cost selection. More often than not, industries ignore this practice due to time restriction. However, the industries do not realise that with more time spent on classifying costs, the more the revenue a company may reap through proper usage of DFReM. Data from three manufacturing industries that produce steel-reinforced plastic cable tight were acquired in the present investigation. The objective of this study is to identify the best cost selection prior to its substitution in the DFReM economy indicator equation. FAHP is employed to select the minimum cost and distance out of all three options. It was demonstrated from the study that FAHP could determine the optimum selection that yields the highest profit.

Keywords: *Fuzzy Analytic Hierarchy Process, Design for Remanufacturing, Economy Indicator*

Introduction

Design for Remanufacturing (DFReM) is a concept of a manufacturing environment that is developed for future generation of manufacturing and process technology. This is due to the ease of tracking the hierarchal history

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from the first stage until the last stage. It is worth noting that, different important elements that are inter-related include from selection of machine, maintenance, labour, direct and indirect costs. Some department may not know on how the decision being made but eventually the decision made will be mapped on a hierarchy chart for recording purposes in which stage of manufacturing for amendments being made. Returning used product by rework, reassemble, disassemble, inspect, testing, and reprocess, in order to return product's appearance to brand new part are basically what Remanufacturing is all about [1]. The essential values for parts or components can be sustained through remanufacturing process. Quality of reprocesed parts are assured for next life cycle. Parts can be reuse or recycle but industry took an easy way by placing the parts as scrap is a major problem faced. There will be waste of inventory, energy, time and some other lean factors. Some variable from life cycle equation in economical indicator can be manipulated to obtain best cost. Therefore, the objective of this paper is to identify suitable option before substitute in life cycle equation for economical indicator. Therefore to solve this problem, FAHP into DFReM will be made to determine before and after implementation.

Table 1: Scaling for Triangular Fuzzy AHP[7]

Categories	**Triangular Fuzzy AHP**	
Equally Important	1,1,1	1,1,1
Intermediate Preference	1,2,3	$\frac{1}{3},\frac{1}{2},1$
Moderately More Important	2,3,4	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$
Intermediate Preference	3,4,5	$\frac{1}{5},\frac{1}{4},\frac{1}{3}$
Strongly More Important	4,5,6	$\frac{1}{6},\frac{1}{5},\frac{1}{4}$
Intermediate Preference	5,6,7	$\frac{1}{7},\frac{1}{6},\frac{1}{5}$
Very Strong More Important	6,7,8	$\frac{1}{8},\frac{1}{7},\frac{1}{6}$
Intermediate Preference	7,8,9	$\frac{1}{9},\frac{1}{8},\frac{1}{7}$
Extremely More Important	8,9,9	$\frac{1}{9},\frac{1}{9},\frac{1}{8}$

Previous researchers mentioned by [2] carried out a review identifying several techniques used in remanufacturing selection such as index [3], grey decision making[4], the weighted average [5] and fuzzy TOPSIS [6]. The scaling process of indexes and the weighted average that is lack of consistency may result in an inaccurate decision made. These two techniques can be used under certain application or condition. Grey decision making, however, determines the answer from multiple decision makers and can result in different answers depends towards the weight of decision makers. The final answer obtain maybe uncertain and least accurate. TOPSIS method is confusing and lengthy compared to FAHP. However, these techniques have few weaknesses and can be improve using FAHP. FAHP have consistency analysis, fair scaling and very suitable for decision making not optimization. The scale for placing weightage purposes are shown in Table 1 extracted from [7].

Methodology

The quantitative measurement is being done for only the economic indicator. The method carried out in this study begins with the data collection of the variables required in the DFReM. FAHP is implemented in order to determine the best option in order to be substituted in the DFReM formula. Once done computing, the condition of before and after being compared and the justifications are made after obtaining the results. The overall methodology is shown in Figure 1.

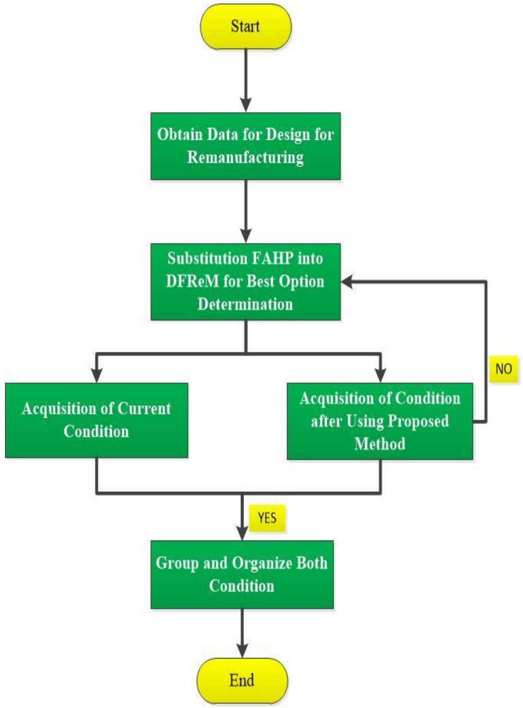

Figure 1: Overall Methodology

Formula for Computation

In this section, the formulae used for the present investigation are listed, and the abbreviations associated with it are explained.

Designs for Remanufacturing Formula

The formulae for DFReM with regards to the economic indicator are:

$$C_o = C_W + C_{MR} + C_{DO} + C_{IO} + C_D + C_I \quad (1)$$

where
C_W = Warranty cost
C_{MR} = Maintenance repair cost
C_{DO} = Direct overhead cost
C_{IO} = Indirect overhead cost
C_D = Depreciation cost
C_I = Insurance cost

Then substitute C_o into equation (2);

$$LCC_{RM} = C_{ProdU} + C_{SP} + C_C + C_L + C_T + C_P + C_o \quad (2)$$

where;

LCC_{RM} = Life cycle cost after remanufacture
C_{ProdU} = Used product acquisition cost
C_{SP} = New spare parts cost
C_C = Cleaning parts cost
C_L = Labour cost
C_T = Transport cost
C_P = Packaging cost

Next is to calculate new life-cycle cost (LCC_n)

$$LCC_n = C_{Prod} + C_{Exp} + C_{DP} \quad (3)$$

C_{Prod} = New product acquisition cost
C_{Exp} = Exploitation cost
C_{DP} = Disposal cost

The last step is to calculate cost-effective comparison (ΔLCC). If $\Delta LCC > 0$, this means that better profitability of remanufacturers component due to the life cycle of a new brand component is higher than that of the cost incurred during the life cycle of remanufacturer component.

Conversely, if $\Delta LCC < 0$, it suggests that unprofitable of remanufacturers component due to the life cycle of new brand component are lower that cost incurred during the life cycle of remanufacturer component [4]. This is done by subtracting equation (3) with equation (2).

$$\Delta LCC = LCC_n - LCC_{RM} \tag{4}$$

<u>Triangular Fuzzy AHP</u>

There are six steps in performing Triangular Fuzzy AHP. The first step is performing weight scale by using pairwise comparison method. Place weight according to the scale provided in Table 1 refer Triangular Fuzzy AHP column. The first step is called weight scaling. This process is done by carrying out pairwise comparison by placing whole number to superior criterion and reciprocal judgment for least superior [8].

The second step is to use the fuzzy analytic hierarchy process. According to [9], the basic concept of triangular fuzzy AHP are shown below. From the Table 1, the triangular fuzzy AHP consist of 3 values represented by equation (3). If there is a weaker comparison, equation (4) will be used.

$$a_{ij} = (l_{ij}, m_{ij}, u_{ij}) \tag{5}$$

$$a_{ij}^{-1} = (\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}) \tag{6}$$

A method of extent analysis was introduced by [10] each object was taken analysis were performed for each goal respectively. Hence, m extent analysis values for every object obtained through the following signs:

$$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m, i = 1,2, \dots, n \tag{7}$$

where all $M_g^j (j = 1,2, \dots, m)$ represented as triangular fuzzy numbers. Chang's extent analysis can be breakdown into 4 other steps continuing from seconthe d step.

The third step is to compute the value of fuzzy synthetic extent with respect to ith object which can be defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} \tag{8}$$

In order to obtain $\sum_{j=1}^{m} M_{gi}^j$, fuzzy summation operation of m extent analysis value is performed:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right), i = 1,2, \dots, n \tag{9}$$

and inverse from the vector in equation. (6) is computed by:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (10)$$

The fourth step is to use the FAHP rules by identifying the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$.defined as:

$$V(M_2 \geq M_1) = sup\left[\min(\mu_{M_1}(x), \mu_{M_2}(y))\right]_{y \geq x} \quad (11)$$

equivalently expressed to:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_1}(d) \quad (12)$$

$$= \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(l_1 - m_1) - (u_2 - m_2)}, & otherwise \end{cases} \quad (13)$$

The fifth step is to make sure the degree of possibility of convex fuzzy must be greater than k convex fuzzy. Convex fuzzy must be bigger in value compared to k convex fuzzy $M_i (i = 1,2,3, \ldots., k)$ and this can be defined by:

$$V(M \geq M_1, M_2, \ldots., M_k) = V(M \geq M_1) \text{ and } (M \geq M_2)\ldots\text{and } (M \geq M_k)$$
$$= \min(M \geq M_i), i = 1,2,3, \ldots., k \quad (14)$$

Assume that

$$d'(A_i) = \min V(S_i \geq S_k) \quad (15)$$

For $k = (1,2,3 \ldots \ldots, n)$; $k \neq i$. Then, weight vector is represented by

$$W' = (d'(A_1), d'(A_2), \ldots\ldots, d'(A_n))^T \quad (16)$$

Where $A_i (i = 1,2,3, \ldots\ldots n)$ are the elements present after computation.

The last step which is the sixth step is to normalize by adding the sum of all elements and divide by each object.

$$W = (d(A_1), d(A_2), \ldots\ldots, d(A_n))^T \quad (17)$$

Where W is a non – fuzzy number which provides priority weight of alternative or criteria.

Obtain Data for DFReM

The data is obtained for the present investigation is acquired from the industry, rental company and labour office regarding the price, service and other related data for scaling purposes. Table 2 and Table 3 is the information which will be further used in this experiment. Assuming three options represent as three manufacturing industries produce same product using 3D printing machine. These three factories use different option for rental, packaging and spare parts, however, all this industry may save a lot of costs if the DFReM equation were to be utilised.

Table 2: Gathered Data from Dataset

First Remanufacturing Cost, C_o

Insurance Cost, C_w	**Insurance A (I A)**	**Insurance B (I B)**	**Insurance C (I C)**
Contract Period (P)	2 years	1 year	5 year
Accessibility (A)	Highly Accessible	Hardly Accessible	Slightly Easy Accessible
Purchase Cost (C)	RM 74.50	RM79	RM 71.80

Direct Overhead Cost, C_{DO}	**Option 1 (O 1)**	**Option 2 (O 2)**	**Option 3 (O 3)**
Direct Material (DM)	500g - RM 177	700g - RM237	1kg – RM 341
Direct Labor (DL)	RM 265/visit	RM 324/visit	RM 372/visit
Material Handling (MH)	Trolley	AGV	Conveyor
Supplier Distance (SD)	Penang – 468km	Melaka – 47km	Kuala Lumpur – 180km

Indirect Overhead Cost, C_{IO}	**Option 1(O 1)**	**Option 2 (O 2)**	**Option 3 (O 3)**
Accounting, Auditing & Legal Expenses (AAL)	RM 918	RM 823	RM 736
Administrative Salaries (AS)	RM 4452	RM 4016	RM 4202
Postage & Printing (PP)	RM 151	RM 92	RM 253
Office Expenses (OE)	RM 232	RM 304	RM 271

Life Cycle Cost Remanufacture Perspective, LCC_{RM}

New Spare Parts Cost, C_{sp}	**Supplier 1 (S 1)**	**Supplier 2 (S 2)**	**Supplier 3 (S 3)**
Material Type (MT)	ABS	PLA	ABS + Carbon Fibre
Cost (C)	RM 177	RM 179	RM 217
Supplier Distance (SD)	Johor Bharu	Kuala Lumpur	Melaka

Transport Cost, C_T	**Transport 1 (T 1)**	**Transport 2 (T 2)**	**Transport 3 (T 3)**
Loading Area (m) (LA)	$3 \times 1.5 \times 1.8$	$4 \times 1.8 \times 2$	$7.5 \times 2.35 \times 3.63$
Rental Cost (RC)	RM 1350	RM 1830	RM 2650

Packaging Cost, C_P	**Package 1 (P 1)**	**Package 2 (P 2)**	**Package 3 (P 3)**
Packaging Supplier (PS)	Melaka - 38km	Melaka – 7km	Melaka – 21km
Total Unit (TU)	100 mat	200 mat	400mat
Purchase Cost (PC)	RM 3850– 3000 pcs	RM 1240 – 1000 pcs	RM2250 – 2000 unit

Results and Discussion

This section will illustrate the scaling process based on the data obtained in Table 2 and Table 3. The pairwise comparison is represented as shown in Table 1. The computation of FAHP will be carried out to determine which alternative is the best. The alternative will be used to be substituted in Design for Remanufacturing formula. Finally, the formulae will determine the highest maximum profit can be achieved if the option is varied rather than follow the same trend which is stick to same option and supplier for purchasing.

Scaling Process

From the data obtained, the scaling process is carried out. The scaling was performed for insurance cost, direct overhead cost, indirect overhead cost, new spare parts cost, transport cost and packaging cost. The scaling is done based on the desired cost needed in order to obtain maximum profit. For cost scaling, the cheapest cost will be scaled as highest round number, and the expensive cost will use the smallest round number. Same goes for shortest distance scaled as highest round number. The reciprocal number is placed referred to the round number. Table 2 and Table 3 will be referred in order to perform scaling process.

Insurance Cost

There are 3 different insurance packages that are being selected by three different companies. The criteria that being looked into are how long the insurance covered, accessibility through agreement and cheapest cost. Table 4 shows the scaling for insurance cost.

Table 4: Scaling for Insurance Cost

Contract Period			
	IA	**IB**	**IC**
IA	1, 1, 1	1, 2, 3	1/5, 1/4, 1/3
IB	1/3, 1/2,1	1, 1, 1	1/3, 1/2, 1
IC	3, 4, 5	1, 2, 3	1, 1, 1
Accessibility			
IA	1, 1, 1	2, 3, 4	1, 2, 3
IB	1/4, 1/3,1/2	1, 1, 1	1/3, 1/2, 1
IC	1/3, 1/2, 1	1, 2, 3	1, 1, 1
Purchase Cost			
IA	1, 1, 1	1, 2, 3	1/4, 1/3, 1/2
IB	1/3, 1/2,1	1, 1, 1	1/3, 1/2, 1
IC	2, 3, 4	1, 2, 3	1, 1, 1
Criteria			
P	1, 1, 1	2, 3, 4	3, 4, 5
A	1/4, 1/3,1/2	1, 1, 1	2, 3, 4
C	1/5, 1/4, 1/3	1/3, 1/2, 1	1, 1, 1

The calculation shown is the steps to obtain weightage of period criterion:

$$S_i = \sum_{j=1}^{3} M_{gi}^{j} \otimes \left[\sum_{i=1}^{3} \sum_{j=1}^{3} M_{gi}^{j} \right]^{-1}$$

$$\text{RS}_{\boldsymbol{IA}} = \sum_{j=1}^{N} M_{gIA}^{j} = (1,1,1) \oplus (1,2,3) \oplus (1/5, 1/4, 1/3\ )$$
$$= (2.2, 3.25, 4.33)$$
$$\text{RS}_{\boldsymbol{IB}} = \sum_{j=1}^{N} M_{gIB}^{j} = (1/3, 1/2,1) \oplus (1,1,1) \oplus (1/3, 1/2, 1\ )$$
$$= (1.67, 2, 3)$$
$$\text{RS}_{\boldsymbol{IC}} = \sum_{j=1}^{N} M_{gIC}^{j} = (3,4,5) \oplus (1,2,3) \oplus (1,1,1\ )$$
$$= (5, 7, 9)$$

$$\text{RS}_{\boldsymbol{IA}} \oplus \text{RS}_{\boldsymbol{IB}} \oplus \text{RS}_{\boldsymbol{IC}} = (2.2, 3.25, 4.33) \oplus (1.67, 2, 3) \oplus (5, 7, 9)$$

$$\text{RS}_{IA} \oplus \text{RS}_{IB} \oplus \text{RS}_{IC} = (8.867, 12.25, 16.33)$$

$[\mathrm{RS}_{\boldsymbol{IA}} \oplus \mathrm{RS}_{\boldsymbol{IB}} \oplus \mathrm{RS}_{\boldsymbol{IC}}]^{-1} = \left(\frac{1}{16.33}, \frac{1}{12.25}, \frac{1}{8.87}\right)$

$\mathrm{S}_{\boldsymbol{IA}} = \mathrm{RS}_{\boldsymbol{IA}} \otimes [\mathrm{RS}_{\boldsymbol{IA}} \oplus \mathrm{RS}_{\boldsymbol{IB}} \oplus \mathrm{RS}_{\boldsymbol{IC}}]^{-1}$

$= [(1,1,1) \oplus (1,2,3) \oplus (1/5, 1/4, 1/3)] \otimes \left(\frac{1}{16.33}, \frac{1}{12.25}, \frac{1}{8.867}\right)$

$= (2.2, 3.25, 4.33) \otimes \left(\frac{1}{16.33}, \frac{1}{12.25}, \frac{1}{8.867}\right)$

$= (0.135, 0.265, 0.489)$

$\mathrm{S}_{\boldsymbol{IB}} = \mathrm{RS}_{\boldsymbol{IB}} \otimes [\mathrm{RS}_{\boldsymbol{IA}} \oplus \mathrm{RS}_{\boldsymbol{IB}} \oplus \mathrm{RS}_{\boldsymbol{IC}}]^{-1}$

$= [(1/3, 1/2, 1) \oplus (1,1,1) \oplus (1/3, 1/2, 1)] \otimes \left(\frac{1}{16.33}, \frac{1}{12.25}, \frac{1}{8.867}\right)$

$= (1.67, 2, 3) \otimes \left(\frac{1}{16.33}, \frac{1}{12.25}, \frac{1}{8.867}\right)$

$= (0.102, 0.163, 0.338)$

$\mathrm{S}_{\boldsymbol{IC}} = \mathrm{RS}_{\boldsymbol{IC}} \otimes [\mathrm{RS}_{\boldsymbol{IA}} \oplus \mathrm{RS}_{\boldsymbol{IB}} \oplus \mathrm{RS}_{\boldsymbol{IC}}]^{-1}$

$= [(3,4,5) \oplus (1,2,3) \oplus (1,1,1)] \otimes \left(\frac{1}{16.33}, \frac{1}{12.25}, \frac{1}{8.867}\right)$

$= (5, 7, 9) \otimes \left(\frac{1}{16.33}, \frac{1}{12.25}, \frac{1}{8.867}\right)$

$= (0.306, 0.571, 1.02)$

According to equation (12) and (13);

If $m_{IA} \geq m_{IB}$ $V(IA \geq IB) = 1$

$$V(IA \geq IC) = \frac{0.306 - 0.489}{(0.306 - 0.571) - (0.489 - 0.265)} = 0.3736$$
$$V(IB \geq IC) = \frac{0.306 - 0.338}{(0.306 - 0.571) - (0.338 - 0.163)} = 0.0731$$
$$V(IB \geq IA) = \frac{0.135 - 0.338}{(0.135 - 0.265) - (0.338 - 0.163)} = 0.6662$$

$V(IC \geq IA) = 1$
$V(IC \geq IB) = 1$
$d'(A) = \min(1{,}0.3736) = 0.3736$
$d'(B) = \min(0.0731, 0.6662) = 0.0731$
$d'(C) = \min(1, 1) = 1$

Therefore the weight vector was given as

$W' = (0.3736, 0.0731, 1)$

After normalization process, the weight vector for insurance period were found to be

$W = (0.2582, 0.0505, 0.6912)$

The same systematic approach is considered for other evaluations, and priority weights are expressed according to scale in table 2.

Accessibility: $W = (0.6006, 0.0815, 0.3179)$
Purchase Cost: $W = (0.2621, 0.1499, 0.5880)$
Criteria: $W = (0.7199, 0.2801, 0)$

$I_A = 0.2582(0.7199) + 0.6006(0.2801) + 0.2621(0) = 0.3541$
$I_B = 0.0505(0.7199) + 0.0815(0.2801) + 0.1499(0) = 0.0592$
$I_C = 0.6912(0.7199) + 0.3179(0.2801) + 0.5880(0) = 0.5866$

In terms of period, Insurance C is selected due to longest contract period. For accessibility, Insurance A is superior in comparison to the rest. It is also evident that in terms of cost, the cheapest insurance plan is Insurance C. After multiplying criteria with weightage, it was demonstrated that Insurance C is the cheapest and should be selected in order for the company to achieve maximum profit. Figure 2 is the results obtained after weightage computation of three insurance plans.

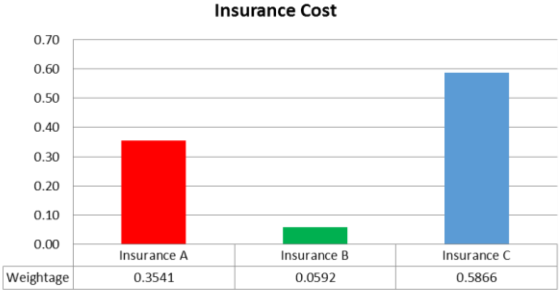

Figure 2: Weightage of Insurance Cost

It could be observed that, Insurance B offers RM 79 per year, however, Insurance C offers RM 71.80 for 5 years renewed every year. Therefore, Insurance C should be selected for further processing into DFReM equation.

Direct Overhead Cost

There are 3 options that can be selected by a company to achieve the highest profit. There are the same types of raw material but being sold in three different weights. Hiring labour with the cheapest cost is also necessary if a company would like to gain profit. The labour is charged per visit and is also responsible to perform machine service and maintenance. Material handling plays an important role in manufacturing layout. Many companies most likely utilise automated transportation for seamless operation. The scaling process for supplier distance must be nearby to the production area. Table 5 shows the scaling for the direct overhead cost.

Table 5: Scaling for Direct Overhead Cost

Direct Material				
	O1	**O2**	**O3**	
O1	1, 1, 1	1/3, 1/2, 1	1/4, 1/3, 1/2,	
O2	1, 2, 3	1, 1, 1	1/3, 1/2, 1	
O3	2, 3, 4	1, 2, 3	1, 1, 1	
Direct Labor				
O1	1, 1, 1	1, 2, 3	2, 3, 4	
O2	1/3, 1/2, 1	1, 1, 1	1, 2, 3	
O3	1/4, 1/3, 1/2,	1/3, 1/2, 1	1, 1, 1	
Material Handling				
O1	1, 1, 1	1/5, 1/4, 1/3	1/3, 1/2, 1	
O2	3, 4, 5	1, 1, 1	1, 2, 3	
O3	1, 2, 3	1/3, 1/2, 1	1, 1, 1	
Supplier Distance				
O1	1, 1, 1	1/4, 1/3, 1/2	1/3, 1/2, 1	
O2	2, 3, 4	1, 1, 1	1, 2, 3	
O3	1, 2, 3	1/3, 1/2, 1	1, 1, 1	
Criteria				
DM	1, 1, 1	1/3, 1/2, 1	1, 2, 3	2, 3, 4
DL	1, 2, 3	1, 1, 1	2, 3, 4	3, 4, 5
MH	1/3, 1/2, 1	1/4, 1/3, 1/2	1, 1, 1	1, 2, 3
SD	1/4, 1/3, 1/2	1/5, 1/4, 1/3	1/3, 1/2, 1	1, 1, 1

Direct Material: $W = (0.0769, 0.3563, 0.5668)$
Direct Labor: $W = (0.5668, 0.3563, 0.0769)$
Material Handling: $W = (0, 0.6783, 0.3217)$
Supplier Distance: $W = (0.0769, 0.5668, 0.3563)$
Criteria: $W = (0.3452, 0.5026, 0.1552, 0)$

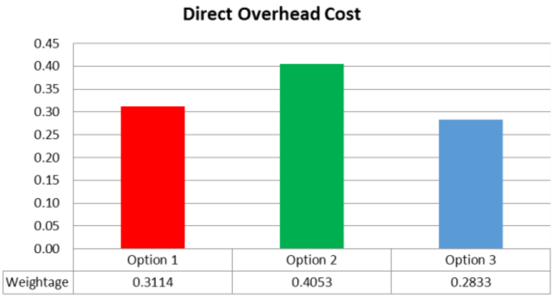

Figure 3: Weightage of Direct Overhead Cost

For direct material, 100g of filament material's cost is cheaper compared to Option 1 and Option 2. However, for labour visit, Option 1 is the cheapest in terms of service and maintenance option. Material handling that achieves the criteria of automated is Automated Guided Vehicle (AGV). Therefore AGV is selected as best material handling transport. The same goes to supplier distance; the closest distance has the highest weightage due to cut down time in terms of transportation. From Figure 3, Option 2 should be selected since it provided the highest weightage with a value of 0.4053.

Indirect Overhead Cost

There are 3 options that can be selected by a company to achieve the highest profit. The cost that needs to be selected must be cheap. Accounting, auditing and legal expenses can be explored for the cheapest rate. Administrative salaries include human resource worker, clerk, and finance people are to be selected based on the cheapest salary offered to them. Postage and printing are done monthly according to rates given by express postage company. Office expenses such as stationaries, bills and A4 papers should be reduced. Table 6 shows the scaling of indirect overhead cost.

Table 6: Scaling for Indirect Overhead Cost

Accounting, Auditing & Legal Expenses			
	O1	**O2**	**O3**
O1	1, 1, 1	1/3, 1/2, 1	1/4, 1/3, 1/2,
O2	1, 2, 3	1, 1, 1	1/3, 1/2, 1
O3	2, 3, 4	1, 2, 3	1, 1, 1

Administrative Salaries			
O1	1, 1, 1	1/5, 1/4, 1/3	1/4, 1/3, 1/2
O2	3, 4, 5	1, 1, 1	1, 2, 3
O3	2, 3, 4	1/3, 1/2, 1	1, 1, 1
Postage & Printing			
O1	1, 1, 1	1/3, 1/2, 1	2, 3, 4
O2	1, 2, 3	1, 1, 1	3, 4, 5
O3	1/4, 1/3, 1/2	1/5, 1/4, 1/3	1, 1, 1
Office Expenses			
O1	1, 1, 1	3, 4, 5	2, 3, 4
O2	1/5, 1/4, 1/3	1, 1, 1	1/3, 1/2, 1
O3	1/4, 1/3, 1/2	1, 2, 3	1, 1, 1

Criteria				
AAL	1, 1, 1	1/3, 1/2, 1	1, 2, 3	2, 3, 4
AS	1, 2, 3	1, 1, 1	2, 3, 4	3, 4, 5
PP	1/3, 1/2, 1	1/4, 1/3, 1/2	1, 1, 1	1, 2, 3
OE	1/4, 1/3, 1/2	1/5, 1/4, 1/3	1/3, 1/2, 1	1, 1, 1

Accounting, Auditing & Legal Expenses: $W = (0.0759, 0.3567, 0.5674)$
Administrative Salaries: $W = (0, 0.616, 0.384)$
Postage & Printing: $W = (0.384, 0.616, 0)$
Office Expenses: $W = (0.8163, 0, 0.1837)$
Criteria: $W = (0.3541, 0.5155, 0.1303, 0)$

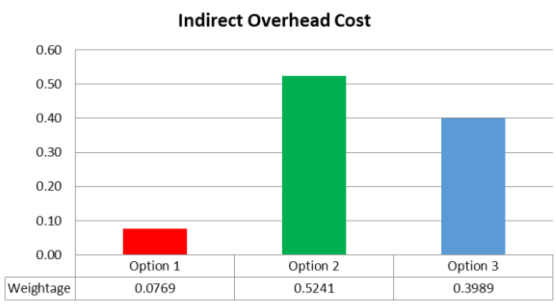

Figure 4: Weightage of Indirect Overhead Cost

For the indirect overhead cost, total salaries, expenses option 2 provided the cheapest solution compared to option 1 and 3. Figure 4 shows the computed weightage, and it is evident that option 2 should be selected for further computation in DFReM equation.

New Spare Part Cost

There are 3 options that can be selected by a company. The material needed should have high strength, and apparently, the product fabricated from the material should last longer. The second criteria that are being looked into is the cheapest cost and nearby supplier distance. Table 7 shows the scaling made for the new spare part cost.

Table 7: Scaling for New Spare Part Cost

Material Type			
	O1	**O2**	**O3**
O1	1, 1, 1	1, 2, 3	1/4, 1/3, 1/2
O2	1/3, 1/2,1	1, 1, 1	1/3, 1/2, 1
O3	2, 3, 4	1, 2, 3	1, 1, 1
Cost			
O1	1, 1, 1	1, 2, 3	1/4, 1/3,1/2
O2	1/3, 1/2, 1	1, 1, 1	1/5, 1/4, 1/3
O3	2, 3, 4	3, 4, 5	1, 1, 1
Supplier Distance			
O1	1, 1, 1	1/3, 1/2, 1	1/5, 1/4, 1/3
O2	1, 2, 3	1, 1, 1	1/4, 1/3,1/2
O3	3, 4, 5	2, 3, 4	1, 1, 1
Criteria			
MT	1, 1, 1	1/3, 1/2, 1	2, 3, 4
C	1, 2, 3	1, 1, 1	3, 4, 5
SD	1/4, 1/3,1/2	1/5, 1/4, 1/3	1, 1, 1

Material Type: $W = (0.3118, 0.1398, 0.5483)$
Cost: $W = (0.1837, 0,\ 0.8163)$
Supplier Distance: $W = (0, 0.1837, 0.8163)$
Criteria: $W = (0.384, 0.616, 0)$

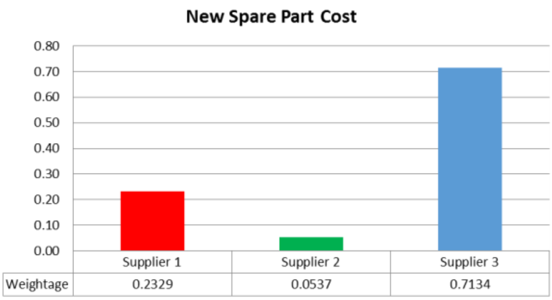

Figure 5: Weightage of New Spare Part Cost

The best material is selected by combining both ABS and Carbon Fiber. It is proven to have better tensile strength compared to single material such as ABS or PLA. The cost is slightly expensive but serves the purpose of having good quality spare parts and nearby distance. Figure 5 shows the weightage whereby supplier 3 with weightage 0.7134 should be selected for further computation in DFReM equation.

Transportation Cost

There are 3 options for transportation cost can be selected by a company. The biggest loading area with lowest rental cost should be selected for any company. Table 8 shows the scaling made for transport cost.

Table 8: Scaling for Transport Cost

Loading Area			
	T1	**T2**	**T3**
T1	1, 1, 1	2, 3, 4	3, 4, 5
T2	1/5, 1/4, 1/3	1, 1, 1	1/3, 1/2, 1
T3	1/4, 1/3,1/2	1, 2, 3	1, 1, 1
Rental Cost			
T1	1, 1, 1	1, 2, 3	2, 3, 4
T2	1/3, 1/2, 1	1, 1, 1	1/3, 1/2, 1
T3	1/4, 1/3,1/2	1, 2, 3	1, 1, 1
Criteria			
LA	1, 1, 1	1/3, 1/2, 1	
RC	1, 2, 3	1, 1, 1	

Loading Area: $W = (0.816, 0, 0.184)$
Rental Cost: $W = (0.643, 0, 0.357)$
Criteria: $W = (0.307, 0.693)$

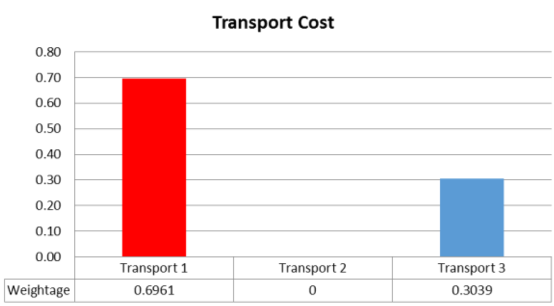

Figure 6: Weightage of Transport Cost

Transport 1 is selected because the products are not so big and does not need big space. Moreover, transport 1 have the cheapest rental cost for transport. Figure 6 shows the weightage whereby Transport 1 should be selected for further computation in DFReM equation.

Packaging Cost

There are 3 options that can be selected by a company. The distance of packaging supplier should be nearby. In addition, the total number of the product that can fit in a package should be more. The purchase cost should also be cheaper so that a company may save money and purchase less so that there will be no waste of packaging product. Table 9 shows the scaling for packaging cost.

Table 9: Scaling for Packaging Cost

Packaging Supplier			
	P1	**P2**	**P3**
P1	1, 1, 1	1/4, 1/3,1/2	1/3, 1/2, 1
P2	2, 3, 4	1, 1, 1	3, 4, 5
P3	1, 2, 3	1/5, 1/4, 1/3	1, 1, 1
Total Unit			
P1	1, 1, 1	3, 4, 5	1/4, 1/3,1/2
P2	1/5, 1/4, 1/3	1, 1, 1	1/6, 1/5, 1/4
P3	2, 3, 4	4, 5, 6	1, 1, 1
Purchase Cost			
P1	1, 1, 1	1/4, 1/3,1/2	1/5, 1/4, 1/3
P2	2, 3, 4	1, 1, 1	1, 2, 3
P3	3, 4, 5	1/3, 1/2, 1	1, 1, 1
Criteria			
PS	1, 1, 1	1/3, 1/2, 1	1/4, 1/3,1/2
TU	1, 2, 3	1, 1, 1	1/5, 1/4, 1/3
PC	2, 3, 4	3, 4, 5	1, 1, 1

Packaging Supplier: $W = (0, 0.8388, 0.1612)$
Total Unit: $W = (0.2805, 0, 0.7195)$
Purchase Cost: $W = (0, 0.5192, 0.4808)$
Criteria: $W = (0, 0.1614, 0.8386)$

Figure 7: Weightage of Packaging Cost

The distance shown is intermediate compared to other two packages but the total unit can be packed is 400 mat of product. The purchase cost is the cheapest. Per unit of the package is the total cost divided by 2000 unit will give the price of per package product. Figure 7 shows the weightage whereby Package 3 should be selected for further computation in DFReM equation.

To summarise, for new spare part cost, option 3 is the best. As for Direct and Indirect Overhead cost, Option 2 is to be selected for further substitution in DFReM formula. Insurance cost and packaging cost are better off if option 3 is considered for further usage. Lastly, transport cost for having the cheapest rental and larger space is option 1. Figure 8 shows the overall weightage for the entire variable that is suitable to be substituted in DFReM economy indicator formula.

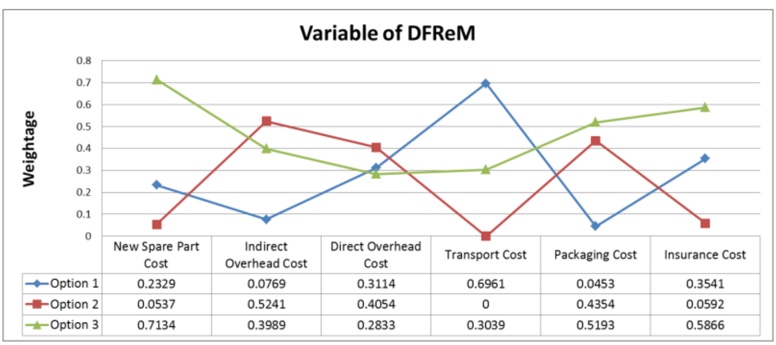

Figure 8: Overall weightage for all DFReM variables

Acquisition of Current Condition

Once all have been scaled, the best option is determined. The calculation is being done according to option. This is to identify current condition without FAHP is implemented. Three different industries have different costs for exploitation, disposal and new product acquisition. Assume averages of three values which were new product acquisition cost, exploitation cost and disposal costs are RM 850, RM 10,970 and RM 110 respectively.

$LCC_n = C_{Prod} + C_{Exp} + C_{DP}$
$LCC_n = 850 + 10,970 + 110$
$LCC_n = 11,930$

<u>Option 1</u>
$C_o = C_W + C_{MR} + C_{DO} + C_{IO} + C_D + C_I$
$C_o = 300 + 690 + 427 + 5,650 + 670 + 74.50$
$C_o = 7,811.50$
$LCC_{RM} = C_{ProdU} + C_{SP} + C_C + C_L + C_T + C_P + C_o$
$LCC_{RM} = 550 + 177 + 240 + 450 + 350 + 1,284 + 7,811.50$
$LCC_{RM} = 10,862.50$
$\Delta LCC = LCC_n - LCC_{RM}$
$\Delta LCC = 11,930 - 10,862.50$
$\Delta LCC = 1067.5$

<u>Option 2</u>
$C_o = 300 + 690 + 530 + 5,200 + 670 + 79$
$C_o = 7,469$
$LCC_{RM} = 550 + 179 + 240 + 450 + 500 + 1,240 + 7,469$
$LCC_{RM} = 10,628$
$\Delta LCC = 11,930 - 10,628$
$\Delta LCC = 1302$

<u>Option 3</u>
$C_o = 300 + 690 + 690 + 5,400 + 670 + 71.80$
$C_o = 7,808.8$
$LCC_{RM} = 550 + 217 + 240 + 450 + 650 + 1,125 + 7808.8$
$LCC_{RM} = 11,040.80$
$\Delta LCC = 11,930 - 11,040.80$
$\Delta LCC = 889.20$

Acquisition of After Using Proposed Method

The proposed method is done by selecting best option and labelled as "with FAHP". Shown are the profits calculated according to the best options.

<u>With FAHP</u>
$C_o = 300 + 690 + 530 + 5,200 + 670 + 71.80$
$C_o = 6821.80$
$LCC_{RM} = 550 + 217 + 240 + 450 + 350 + 1,125 + 6821.80$

$$LCC_{RM} = 9753.80$$
$$\Delta LCC = 11{,}930 - 9{,}753.80$$
$$\Delta LCC = 2{,}176.20$$

To summarise the final answers, Figure 9 represents all the option in the form of bar chart.

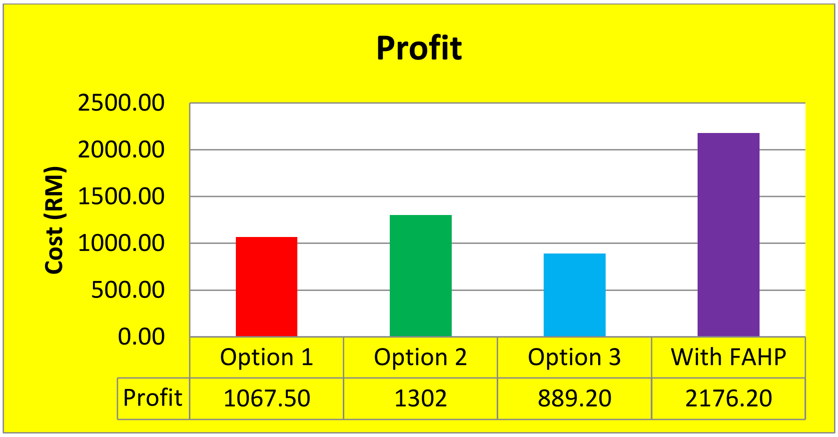

Figure 9: Comparison Profit between 4 Options

FAHP have the highest profit compared to other available options. All options show that they are profitable and no loss obtain by carrying out DFReM process in industries. From Figure 9, illustrate big difference can be made with the implementation of FAHP to select cost in DFReM.

Conclusion

It could be concluded that in order to have sustainable in manufacturing layout, the insurance plan for the machine should be cheap and covered for a longer duration. Similarly, the direct, indirect overhead, spare part, transport and packaging cost should also be cheap. Some may prefer suppliers to be located close to factory. FAHP have solved this problem by selecting the best alternative or almost best. From the present investigation, a company could make a better judgment and consider better options prior to any form of investment. FAHP shows better scaling in comparison to index and weighted average. It has been demonstrated that FAHP is also good for classification and decision making rather than grey decision-making method. This is primarily due the subjective nature of grey decision-making method. As for TOPSIS, the steps are lengthy eventually waste time computing compared to

FAHP. Based on the results obtained from the present study, industries may apply remanufacturing practice and compute their expenses prior to expenditure. This practice also can save energy resulting from labour working, machine operations instead just replacing, repair or reuse other parts from a different product. As a closing remark, FAHP can be used to solve multi solutions and provide better profit yield to the company by implementing DFReM.

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