



Faculty of Manufacturing Engineering

**PRIORITIZING LIFE CYCLE COST IN DESIGN FOR
REMANUFACTURING USING INTELLIGENT TOOL**

Ahamad Zaki bin Mohamed Noor

Doctor of Philosophy

2018

**PRIORITIZING LIFE CYCLE COST IN DESIGN FOR REMANUFACTURING
USING INTELLIGENT TOOL**

AHAMAD ZAKI BIN MOHAMED NOOR

**A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Philosophy**

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled “Prioritizing Life Cycle Cost in Design for Remanufacturing Using Intelligent Tool” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature :

Supervisor Name :

Date :

DEDICATION

I would like to give a very special appreciation to my beloved friends and family for always being there in my time of need. Thank you for giving me continuous support in order for me to fulfil the needs of my PhD research. To my beloved Mother, Father, Family and Friends, thank you all for this.

ABSTRACT

Sustainable practice is needed in every manufacturing industry. There are three indicators and problem arising with the economy indicator is that the variable used is not finalised during substitution value. Decisions made by decision makers are not synchronised and staff from different departments tend to argue until final decision is made. Different industries prioritize different cost resulting different in final answer. Therefore, this research will make the staff from the industry to substitute value and utilised well the Life Cycle Cost (LCC) equation to identify the suitability of Design for Remanufacturing (DFReM) practice. First objective was to determine parameter's weightage concerning LCC equation. The data obtained from industries are direct overhead cost, indirect overhead cost, spare parts cost and packaging cost. Survey forms were distributed among 20 decision makers resulting in different perceptive and their answers were recorded. To make best cost prioritization from 20 different companies' expenses, second objective is to propose three methods that are used in this experiment. The methods proposed are Fuzzy Analytic Hierarchy Process (FAHP), Artificial Neural Network (ANN) and combination of both techniques. Before the main research was conducted, a preliminary experiment was carried out to identify which FAHP will give answer almost same as AHP. AHP is compared because other FAHP are created based on AHP, therefore AHP will give almost correct but not as accurate as FAHP. The findings of this experiment show that Triangular AHP gives the near sequence and suitable material selection to fabricate a table fan. From this preliminary experiment, Triangular FAHP is implemented for cost selection in DFReM. Next part of experiment is to make decision using ANN. Before this part of experiment is carried out, a small experiment was carried out to determine the number of hidden neuron. The outcome of this experiment for this application, the suitable hidden neuron is 2. The last proposed method for cost prioritizing is combination of both FAHP and ANN. The improvement made is used as output from FAHP and introduced as target file. Input remained the same as previous part of ANN experiment. Final objective is to validate life cycle cost prioritizing through comparison of proposed decision making tool outputs. All proposed method's output were identified and result shows that combination of FAHP and ANN will make the company save more expenses compared to carrying single technique. FAHP manage the company to save up to RM 91,353. The result from ANN makes the company to save up to RM 95,093. However the combination method saves the company to a total of RM 95,633. To conclude, combination of FAHP and ANN is the best technique used for cost selection before substituting in an economy indicator for DFReM. Contribution made towards body of knowledge is to adapt FAHP answer as target file for neural network simulation. Contribution made to industry is that by introducing AI technique, LCC equation gives out profit and make DFReM practice suitable for any manufacturing industry.

ABSTRAK

Amalan mampan sangat diperlukan oleh kilang pembuatan. Terdapat 3 sektor tetapi masalah yang timbul adalah pada sektor ekonomi adalah pembolehubah digunakan ketika proses pemindahan. Keputusan yang dibuat oleh pembuat keputusan tidak selari dan staf dari jabatan lain akan bercanggah pendapat sehingga keputusan terakhir yang muktamad di buat. Industri lain akan mengkhususkan kos yang lain menyebabkan perbezaan pada jawapan terakhir. Oleh itu, kajian ini akan membuatkan staf dari industri memindahkan harga dan menggunakan persamaan kos kitaran hayat (KKH) untuk mengenalpasti kesesuaian Design for Remanufacturing (DFReM). Objektif pertama adalah untuk mengenalpasti pemberat parameter yang berkaitan dengan persamaan KKH. Data yang diperlukan dari industri ialah kos perbelanjaan langsung, kos perbelanjaan tidak langsung, kos barang ganti dan kos pembungkusan. Borang kaji selidik diedarkan dan pemberat parameter diberikan oleh 20 pembuat keputusan adalah berbeza dan jawapan mereka direkod. Bagi mengkhususkan satu daripada 20 kos berlainan, objektif kedua harus dijalankan iaitu mencadangkan tiga cara untuk eksperimen ini. Caranya adalah "Fuzzy Analytic Hierarchy Process" (FAHP), Artificial Neural Network (ANN) dan gabungan kedua – dua cara. Sebelum eksperimen utama dijalankan, satu eksperimen sampingan dibuat untuk mengenalpasti FAHP yang memberikan jawapan yang hampir sama seperti AHP. AHP dibandingkan kerana FAHP yang lain dicipta berdasarkan teknik AHP dimana akan memberi jawapan tepat tapi tidak setepat FAHP. Hasil daripada eksperimen ini menunjukkan FAHP jenis segi tiga memberikan susunan dan pemilihan bahan paling sesuai untuk menghasilkan kipas meja. Daripada eksperimen sampingan ini, FAHP jenis segi tiga akan digunakan bagi tujuan memilih kos untuk dibawa ke DFReM. Bahagian seterusnya adalah untuk membuat keputusan menggunakan ANN. Cadangan cara yang terakhir yang diperkenalkan adalah penggabungan 2 cara iaitu FAHP dan ANN. Penambahbaikan yang dilakukan adalah hasil daripada eksperimen FAHP dimasukkan sebagai fail sasaran. Input adalah sama seperti sebelum iaitu eksperimen ANN. Objektif terakhir adalah untuk mengesahkan jawapan pengkhususan KKH melalui perbandingan jawapan oleh tiga cara yang dicadangkan. Semua jawapan dikenalpasti dan didapati bahawa gabungan 2 cara FAHP dan ANN membuatkan kilang jimatkan pembelanjaan daripada menggunakan teknik FAHP dan ANN secara sendirian. FAHP membuatkan kilang jimat sebanyak RM 91,353. Hasil daripada ANN membuatkan kilang jimat sebanyak RM 95,093. Manakala kombinasi 2 teknik menjimatkan sebanyak RM 95,633. Kesimpulannya, Kombinasi FAHP dan ANN adalah teknik terbaik untuk pengkhususan kos sebelum di bawa ke dalam persamaan KKH untuk DFReM. Sumbangan terhadap ilmu adalah mengadaptasi jawapan FAHP sebagai fail target untuk simulasi ANN. Manakala sumbangan terhadap industri adalah memperkenalkan teknik AI membuatkan persamaan KKH memberi jawapan dalam bentuk keuntungan membuatkan DFReM sesuai dijalankan di mana – mana kilang pembuatan.

ACKNOWLEDGEMENTS

First and foremost, I would like to give my greatest gratitude to Almighty God, Allah S.W.T for giving me strength to complete this PhD Research. My sincere acknowledgement to my supervisor and co-supervisor Dr Muhammad Hafidz Fazli Md Fauadi with Dr. Fairul Azni Bin Jafar from Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia, Melaka (UTeM) for their supervision, guidance, support and encouragement towards the completion of this thesis.

I would like to take this opportunity to thank all manufacturing industries for giving me all the information I needed to finish up this experiment. Thanks to all related staff that kept this data and granted their permission by letting me obtain data from their industry. With this data that I have gained, it would be a proof that my theory is successful.

Thank you I wish to both of my parents Zarina Bibi binti Hassan and Mohamed Noor bin Mohamed Ali. My aunty, Maimoon binti Hassan and my uncle Abdul Aziz bin Hassan I wish to thank also for supporting me financially and advised me for any problems occurred during my PhD studies. To my late grandmother Hajah Esah binti Haji Albi that encouraged me to never stop no matter what people may say or do as long I reach my goal in life. To my siblings and friends that have thought me a lot in real life situation.

Lastly, I would like to thank the girl that came into my life and changed me entirely, Nur Saidatul Fatimah binti Abdul Rashid who pushed me to move forward till the place I am now. She showed me what my goals are, accompanied me during data collection. She taught me that nothing is impossible when you put your effort into it. She was also there listening to my problems and gave solution when I can't find one.

Thanks to all, without all of you, this thesis will never be completed. My success is due to all that helped directly or indirectly in completion of this thesis. Family and friends, I can never thank you all enough. Thank You.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	xiv
LIST OF FIGURES	viiiiv
LIST OF APPENDICES	xvii
LIST OF ABBREVIATIONS	xviii
LIST OF PUBLICATIONS	xx

CHAPTER

1. INTRODUCTION	1
1.1 Background of Study	1
1.2 Problem Statement	4
1.3 Research Questions	5
1.4 Hypothesis	5
1.5 Objectives	5
1.6 Research Scope	6
1.7 Thesis Structure	7
2. LITERATURE REVIEW	9
2.1 Theory on Design for Remanufacturing	9
2.2 Techniques used in Design for Remanufacturing	14
2.2.1 Indexes	15
2.2.2 Weighted Average	19
2.2.3 Grey Decision Making	21
2.2.4 Fuzzy TOPSIS	23
2.3 Review of Techniques Used for Decision Making in DFReM	25
2.3.1 Review on Indexes Method	25
2.3.2 Review on Weighted Average Method	25
2.3.3 Review on Grey Decision Making Method	26
2.3.4 Review on Fuzzy TOPSIS Method	26
2.3.5 Suggestion for Best Method used in DFReM	26

2.4	Theory Regarding of Fusion between AHP and Fuzzy	27
2.4.1	Theory on Fuzzy Logic	27
2.4.2	Theory on Analytic Hierarchy Process (AHP)	28
2.5	Fusion of Fuzzy AHP to Determine Relative Weight	28
2.5.1	Triangular Fuzzy Analytic Hierarchy Process (AHP)	29
2.5.2	Trapezoidal Fuzzy Analytic Hierarchy Process (AHP)	32
2.6	Fusion of Fuzzy AHP to Obtain Rank or Score	35
2.6.1	Fuzzy TOPSIS	36
2.6.2	Fuzzy VIKOR	38
2.6.3	Fuzzy MOORA	41
2.6.4	Fuzzy ELECTRE	43
2.6.5	Fuzzy PROMETHEE	47
2.6.6	Summary of All Fuzzy AHP	50
2.7	Theory on Artificial Neural Network (ANN)	51
2.8	Summary	55
3.	METHODOLOGY	57
3.1	Overall Procedure	57
3.2	Experiment Procedure – Determine Parameter Weightage	58
3.3	Experiment Procedure - Propose	59
3.3.1	Phase 1: Data Gathering	61
3.3.2	Phase 2: Determine Parameter’s Weightage	63
3.3.3	Phase 3: Computation of Data using FAHP	64
3.3.4	Phase 4: Computation of Data using Neural Network	71
3.3.5	Phase 5: Computation of Data using Both Combination	84
3.4	Experiment Procedure - Validate	85
3.5	Summary	86
4.	RESULT AND DISCUSSION	87
4.1	Analysis Method	87
4.2	Preliminary Experiment: Material Selection for Table Fan	87
4.2.1	Decision Maker’s Survey on Alternatives	88
4.2.2	Calculation Traditional AHP	90
4.2.3	Calculation Triangular AHP	109
4.2.4	Calculation Trapezoidal AHP	126

4.2.5 Preliminary Experiment Discussion	136
4.3 Experiment of DFReM using Fuzzy AHP	137
4.3.1 Decision Maker's Survey on Alternatives	142
4.3.2 Direct Overhead: Direct Material	145
4.3.3 Direct Overhead: Direct Labour	148
4.3.3 Direct Overhead: Supplier Distance	151
4.3.4 Indirect Overhead: Accounting	155
4.3.5 Indirect Overhead: Admin Salary	158
4.3.6 Indirect Overhead: Office Expenses	162
4.3.7 Indirect Overhead: Postage and Printing	165
4.3.8 Spare Part: Material Strength	168
4.3.9 Spare Part: Spare Part Cost	172
4.3.10 Spare Part: Supplier Distance	175
4.3.11 Packaging Supplier: Supplier Distance	179
4.3.12 Packaging Supplier: Packaging Cost	182
4.3.13 Criteria: Direct Overhead	186
4.3.14 Criteria: Indirect Overhead	188
4.3.15 Criteria: Spare Parts	189
4.3.16 Criteria: Packaging	191
4.3.17 Discussion Experiment using Fuzzy AHP	193
4.4 Experiment to Determine Hidden Neuron for DFReM	197
4.4.1 MSE and Regression (Training)	197
4.4.2 MSE and Regression (Testing)	199
4.4.3 MSE and Regression (Validation)	201
4.4.4 Summarized Results	202
4.4.5 Discussion for Hidden Neuron Experiment	203
4.4.6 Conclusion for Hidden Neuron Experiment	207
4.5 Experiment of DFReM using Artificial Neural Network	208
4.5.1 Direct Overhead: Direct Material	208
4.5.2 Direct Overhead: Direct Labour	209
4.5.3 Indirect Overhead: Accounting	209
4.5.4 Indirect Overhead: Admin Salary	210
4.5.5 Indirect Overhead: Postage & Printing	211
4.5.6 Indirect Overhead: Office Expenses	211
4.5.7 Spare Parts: Spare Parts Cost	212
4.5.8 Packaging: Packaging Cost	213
4.5.9 Discussion Experiment using Neural Network	213

4.6	Experiment of DFReM using Combination Method	215
4.6.1	Direct Overhead: Direct Material	215
4.6.2	Direct Overhead: Direct Labour	216
4.6.3	Indirect Overhead: Accounting	217
4.6.4	Indirect Overhead: Admin Salary	217
4.6.5	Indirect Overhead: Postage & Printing	218
4.6.6	Indirect Overhead: Office Expenses	219
4.6.7	Spare Parts: Spare Parts Cost	219
4.6.8	Packaging: Packaging Cost	220
4.6.9	Discussion Experiment using Combination Method	221
4.7	Summary	222
5.	CONCLUSION AND RECOMMENDATION	225
5.1	Conclusion	225
5.2	Contribution	226
5.2.1	Contribution towards Body of Knowledge	226
5.2.2	Contribution towards Industry	227
5.3	Recommendation for Future Research	227
	REFERENCES	228
	APPENDICES	246

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Comprehensive criterion evaluation for recycling and disassembly process	15
2.2	Quantity of fasteners types indexes	16
2.3	Design features affecting product remanufacturability	17
2.4	Problem identified from design feature affecting product remanufacturability	17
2.5	Computation of index with respective formula	18
2.6	Crisp value for subjective importance rating	24
2.7	Linguistic rating and its triangular fuzzy number	24
2.8	Triangular fuzzy AHP scaling	29
2.9	Triangular AHP implementation	32
2.10	Trapezoidal fuzzy AHP scaling	33
2.11	Computation of weight	34
2.12	Trapezoidal AHP implementation area	35
2.13	Linguistic term for Fuzzy TOPSIS	36
2.14	Fuzzy TOPSIS implementation area	38
2.15	Linguistic term for Fuzzy VIKOR	39
2.16	Fuzzy VIKOR implementation area	40
2.17	Fuzzy MOORA implementation area	43
2.18	Fuzzy ELECTRE implementation area	47
2.19	Fuzzy PROMETHEE implementation area	49
2.20	Comparative performance of multi - objective decision making method	51

3.1	Fundamental linguistic variables used for pairwise rating in AHP	65
3.2	Random consistency index table	66
4.1	Material properties from CES Edupack	88
4.2	AHP price pairwise comparison matrix	91
4.3	Adjusted pairwise comparison matrix	91
4.4	Weightage calculation	92
4.5	Consistency calculation	92
4.6	AHP density pairwise comparison matrix	93
4.7	Adjusted pairwise comparison matrix	94
4.8	Weightage calculation	94
4.9	Consistency calculation	95
4.10	AHP tensile strength pairwise comparison matrix	96
4.11	Adjusted pairwise comparison matrix	97
4.12	Weightage calculation	97
4.13	Consistency calculation	98
4.14	AHP thermal conductivity pairwise comparison matrix	99
4.15	Adjusted pairwise comparison matrix	100
4.16	Weightage calculation	100
4.17	Consistency calculation	101
4.18	AHP electrical resistivity pairwise comparison matrix	102
4.19	Adjusted pairwise comparison matrix	103
4.20	Weightage calculation	103
4.21	Consistency calculation	104
4.22	AHP criteria pairwise comparison matrix	105
4.23	Adjusted pairwise comparison matrix	106
4.24	Weightage calculation	106
4.25	Consistency calculation	107
4.26	AHP grouped data	108
4.27	Triangular AHP price pairwise comparison matrix	110

4.28	Triangular fuzzy vector – price	110
4.29	Triangular AHP density pairwise comparison matrix	112
4.30	Triangular fuzzy vector – density	113
4.31	Triangular AHP tensile strength pairwise comparison matrix	115
4.32	Triangular fuzzy vector – tensile strength	115
4.33	Triangular AHP thermal conductivity pairwise comparison matrix	117
4.34	Triangular fuzzy vector – thermal conductivity	118
4.35	Triangular AHP electrical resistivity pairwise comparison matrix	120
4.36	Triangular fuzzy vector – electrical resistivity	120
4.37	Triangular AHP criteria pairwise comparison matrix	123
4.38	Triangular fuzzy vector – criteria	123
4.39	Triangular AHP grouped data	125
4.40	Trapezoidal AHP price pairwise comparison matrix	127
4.41	Trapezoidal AHP price answers	128
4.42	Trapezoidal AHP density pairwise comparison matrix	129
4.43	Trapezoidal AHP density answers	129
4.44	Trapezoidal AHP tensile strength pairwise comparison matrix	130
4.45	Trapezoidal AHP tensile strength answers	130
4.46	Trapezoidal AHP thermal conductivity pairwise comparison matrix	131
4.47	Trapezoidal AHP thermal conductivity answers	132
4.48	Trapezoidal AHP electrical resistivity pairwise comparison matrix	132
4.49	Trapezoidal AHP electrical resistivity answers	133
4.50	Trapezoidal AHP criteria pairwise comparison matrix	133
4.51	Trapezoidal AHP criteria answers	134
4.52	Trapezoidal AHP grouped data	135
4.53	Comparison results	136
4.54	Real data acquired from manufacturing industries	139
4.55	Normalized data acquired from manufacturing industries	140
4.56	Computation fuzzy scaling by row	145

4.57	Computation fuzzy scaling	146
4.58	Direct material answers	147
4.59	Computation fuzzy scaling by row	148
4.60	Computation fuzzy scaling	149
4.61	Direct labour answers	150
4.62	Computation fuzzy scaling by row	152
4.63	Computation fuzzy scaling	153
4.64	Supplier distance answers	154
4.65	Computation fuzzy scaling by row	155
4.66	Computation fuzzy scaling	156
4.67	Accounting answers	157
4.68	Computation fuzzy scaling by row	158
4.69	Computation fuzzy scaling	159
4.70	Admin salary answers	160
4.71	Computation fuzzy scaling by row	162
4.72	Computation fuzzy scaling	163
4.73	Office expenses answers	164
4.74	Computation fuzzy scaling by row	165
4.75	Computation fuzzy scaling	166
4.76	Postage and printing answers	167
4.77	Computation fuzzy scaling by row	169
4.78	Computation fuzzy scaling	170
4.79	Material strength answers	171
4.80	Computation fuzzy scaling by row	172
4.81	Computation fuzzy scaling	173
4.82	Spare parts cost answers	174
4.83	Computation fuzzy scaling by row	176
4.84	Computation fuzzy scaling	177
4.85	Supplier distance answers	178

4.86	Computation fuzzy scaling by row	179
4.87	Computation fuzzy scaling	180
4.88	Supplier distance answers	181
4.89	Computation fuzzy scaling by row	183
4.90	Computation fuzzy scaling	184
4.91	Packaging cost answers	185
4.92	Computation fuzzy scaling by row	186
4.93	Computation fuzzy scaling	187
4.94	Direct overhead answers	187
4.95	Computation fuzzy scaling by row	188
4.96	Computation fuzzy scaling	188
4.97	Indirect overhead answers	189
4.98	Computation fuzzy scaling by row	190
4.99	Computation fuzzy scaling	190
4.100	Spare parts answers	190
4.101	Computation fuzzy scaling by row	191
4.102	Computation fuzzy scaling	192
4.103	Packaging answers	192
4.104	Weightage of company	193
4.105	Weightage of criteria	194
4.106	Final result	195
4.107	Training value for MSE and regression	198
4.108	Testing value for MSE and regression	199
4.109	Validation value for MSE and regression	201
4.110	Values for regression	202
4.111	Weightage of 20 companies for direct material	208
4.112	Weightage of 20 companies for direct labour	209
4.113	Weightage of 20 companies for accounting	210
4.114	Weightage of 20 companies for admin salary	210

4.115	Weightage of 20 companies for postage and printing	211
4.116	Weightage of 20 companies for office expenses	212
4.117	Weightage of 20 companies for spare part cost	212
4.118	Weightage of 20 companies for packaging cost	213
4.119	Weightage of 20 companies for direct material	216
4.120	Weightage of 20 companies for direct labour	216
4.121	Weightage of 20 companies for accounting	217
4.122	Weightage of 20 companies for admin salary	218
4.123	Weightage of 20 companies for postage and printing	218
4.124	Weightage of 20 companies for office expenses	219
4.125	Weightage of 20 companies for spare part cost	220
4.126	Weightage of 20 companies for packaging cost	220

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Indicators of sustainable manufacturing	2
2.1	Performance measure in Design for Remanufacturing	10
2.2	Overall chart of review techniques	14
2.3	Colour scale for recyclability index	15
2.4	An assessment system for remanufacturing of initial product design	18
2.5	Structure of remanufacturability assessment	19
2.6	Example prioritization of cleaning process	20
2.7	Classification using grey decision matrix	23
2.8	The intersection between M_2 and M_1	31
2.9	Simplified model of biological neuron	52
2.10	Simplified model of biological neuron in MATLAB	52
2.11	Overfitting example of performance plot	53
2.12	Data scattered on regression plot	54
2.13	MATLAB interface of MSE and regression values	55
3.1	Overall research process flow	58
3.2	Framework of Design for Remanufacturing (Economy Indicator)	60
3.3	Data gathering flow chart	61
3.4	Process flow of DFReM experiment	62
3.5	Determine parameter's weightage flow chart	64
3.6	FAHP computation using MATLAB flow chart	67
3.7	Call function in MATLAB	68
3.8	Representative of equation (19) and (20)	69

3.9	Representative of equation (23)	69
3.10	Representative of equation (25)	70
3.11	Representative of equation (26)	70
3.12	NN computation using MATLAB flow chart	71
3.13	MATLAB interface neural network training tool	73
3.14	Flow chart of plot observation	73
3.15	Flow chart of MSE and regression values	74
3.16	First step of NN computation	75
3.17	Second step of NN computation	76
3.18	Third step of NN computation	76
3.19	Fourth step of NN computation	78
3.20	Fifth step of NN computation	79
3.21	Neural network diagram	79
3.22	Sixth step of NN computation	80
3.23	Seventh step of NN computation	80
3.24	Interface of train network	80
3.25	Eighth step of NN computation	81
3.26	Ninth step of NN computation	82
3.27	Tenth step of NN computation	83
3.28	Last step of NN computation	83
3.29	FAHP and NN computation using MATLAB flow chart	84
3.30	Validation process flow chart	85
4.1	Analysis flow chart	87
4.2	Weightage of criteria	89
4.3	AHP overall illustration	108
4.4	Triangular AHP overall illustration	126
4.5	Trapezoidal AHP overall illustration	135
4.6	Tree structure of FAHP computation in DFReM experiment	141
4.7	Decision maker's prioritization in direct overhead variable	142

4.8	Decision maker's prioritization in indirect overhead variable	143
4.9	Decision maker's prioritization in spare part variable	143
4.10	Decision maker's prioritization in packaging variable	144
4.11	Readings of MSE – training	198
4.12	Readings of regression – training	199
4.13	Readings of MSE – testing	200
4.14	Readings of regression – testing	200
4.15	Readings of MSE – validation	201
4.16	Readings of regression – validation	202
4.17	Readings of regression – all	203
4.18	Performance plot for 2 hidden neurons	204
4.19	Performance plot for 6 hidden neurons	204
4.20	Performance plot for 20 hidden neurons	205
4.21	Regression plot for 2 hidden neurons	206
4.22	Regression plot for 6 hidden neurons	206
4.23	Regression plot for 20 hidden neurons	207
4.24	Concept proof of three techniques in DFReM	224

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A1	Direct Overhead: Direct Material	246
A2	Direct Overhead: Direct Labour	247
A3	Direct Overhead: Supplier Distance	248
A4	Indirect Overhead: Accounting	249
A5	Indirect Overhead: Admin Salary	250
A5	Indirect Overhead: Office Expenses	251
A7	Indirect Overhead: Postage and Printing	252
A8	Spare Part Cost: Material Strength	253
A9	Spare Part Cost: Purchase Cost	254
A10	Spare Part Cost: Supplier Distance	255
A11	Packaging Cost: Packaging Supplier	256
A12	Packaging Cost: Purchase Cost	257
A13	Criteria pairwise comparison	258
B	MATLAB Programming	259
C	Permission Letter	271
D	Decision Maker Survey Form	272
E1	Data Collection Sheet – Page 1	273
E2	Data Collection Sheet – Page 2	274

LIST OF ABBREVIATIONS

DFReM	- Design for Remanufacturing
AHP	- Analytic Hierarchy Process
FAHP	- Fuzzy Analytic Hierarchy Process
ANN	- Artificial Neural Network
NN	- Neural Network
MSE	- Mean Square Error
AI	- Artificial Intelligence
LCC	- Life Cycle Cost
LCA	- Life Cycle Assessment
CD	- Compact Disk
TOPSIS	- Technique for Order Performance by Similarity to Ideal Solution
VIKOR	- ViseKriterijumska Optimizacija I Kompromisno Resenje
MOORA	- Multi – Objective by Ratio Analysis
ELECTRE	- Elimination and Choice Expressing Reality
PROMETHEE	- Preference Ranking Organization Method for Enrichment Evaluation
CR	- Consistency Ratio
CI	- Consistency Index
RI	- Random Index
PP	- Polypropylene
HDPE	- High – Density Polyethylene
LDPE	- Low – Density Polyethylene
C	- Company
DM	- Direct Material

RM	- Ringgit Malaysia
DMs	- Decision Makers
DL	- Direct Labour
DOSD	- Direct Overhead Supplier Distance
A	- Accounting
AS	- Admin Salary
P&P	- Postage and Printing
OE	- Office Expenses
SPC	- Spare Part Cost
SPSD	- Spare Part Supplier Distance
MS	- Material Strength
PPC	- Packaging Purchase Cost
PS	- Packaging Supplier
MSE	- Mean Square Error