



Faculty of Manufacturing Engineering

A NEW EQUIPMENT EFFECTIVENESS AND SUSTAINABILITY PERFORMANCE MODEL FOR PALM OIL MILL

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**A NEW EQUIPMENT EFFECTIVENESS AND SUSTAINABILITY
PERFORMANCE MODEL FOR PALM OIL MILL**

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

Faculty of Manufacturing Engineering

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2018

DECLARATION

I declare that this thesis entitled “A New Equipment Effectiveness and Sustainability Performance Model for Palm Oil Mill” 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.

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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.

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Date :

DEDICATION

To my beloved mother and father, I am nothing without them. My brothers and sisters, who indulge me with every comfort and kindness. My nephews and nieces, for your loves and laughs light up my universe. And my teachers, who inspire me to dream, to work, and to reach.

ABSTRACT

The worldwide demands for sustainable palm oil products are in the increasing trend due to rising awareness of the palm oil industry impact on environment. Hence, the urgency to develop a sustainability strategy to overcome these issues is imminent. The objectives of this research are to investigate the current practices and performance of manufacturing sustainability in the Malaysian Palm Oil Mill (POM), identify factors affecting equipment effectiveness in the Malaysian POM, develop a model for equipment effectiveness and sustainability performance, and validate the model using data from the Malaysian POM. The research opted for an exploratory study using the survey instrument on Malaysian POM against the 20 elements of sustainability programs and practices, 18 elements of regulatory compliance, 32 elements of factors affecting equipment effectiveness, and 36 elements of manufacturing sustainability opportunity from equipment effectiveness. Out of 250 questionnaires randomly sent to 426 registered POM in Malaysia, a total of 55 were completed and returned by the surveyed mills. After screening, 51 of those completed with useful information were further analysed, representing 11.97% of the population with a response rate of 20.4%. The research developed a new model for measuring equipment effectiveness and sustainability performance. This model hybrid the concept of Overall Equipment Effectiveness (OEE), equipment reliability and Failure Mode and Effect Analysis (FMEA). In appraising the criticality in terms of sustainability impact of equipment failure occurrence, the model ranks the sustainability performance of the failure mode by using the Sustainability Priority Number (SPN), formulated using Analytical Hierarchy Process (AHP) approach. The performance level of the OEE, reliability and SPN resulting scores translated into a five-point rating system. The model has been tested on a POM as the validation approach to demonstrate the feasibility of the model for equipment effectiveness and sustainability performance analysis. The findings emphasis on the fluctuation in the OEE performance depending on the month, suggest that waiting time, breakdown, and preventive maintenance as the key factors affecting equipment effectiveness. Further, reliability performance of the model exhibits an increasing failure rate indicating that the probability of failure occurrence increases over time for the critical equipment (loading ramp, steriliser, thresher, and boiler). The model determines the performance level of 20 functional failure modes of the critical equipment and the results show that the highest SPN ranking for steriliser, signify as the most critical functional failure mode for sustainability impact in the POM. The model is able to analyse equipment effectiveness and sustainability performance in the POM and provide empirical evidence to support the decision making for POM sustainability. This research can be used as an advantage in POM as well as other organisation from different industries to recognise the opportunities of equipment effectiveness in the efforts to enhance the business profile and corporate reputation, and market growth without disregarding the environmental and social impact.

ABSTRAK

Permintaan untuk produk kelapa sawit yang lestari di seluruh dunia semakin meningkat akibat peningkatan kesedaran mengenai kesan buruk daripada industri kelapa sawit terhadap alam sekitar. Oleh itu, pembangunan strategi kelestarian bagi mengatasi isu-isu ini adalah penting. Objektif penyelidikan ini adalah untuk mengkaji amalan semasa dan prestasi kelestarian pembuatan di Kilang Kelapa Sawit (POM) di Malaysia, mengenal pasti faktor-faktor yang mempengaruhi keberkesanan peralatan di POM Malaysia, membangunkan model keberkesanan peralatan dan prestasi kelestarian, dan mengesahkan model yang dibangunkan dengan menggunakan data daripada POM Malaysia. Daripada 250 soal selidik yang dihantar secara rawak kepada 426 POM berdaftar di Malaysia, sebanyak 55 daripadanya telah di isi dan dikembalikan oleh kilang yang disoal selidik. Selepas pemeriksaan, 51 daripada soal selidik yang siap dengan maklumat berguna telah dijalankan untuk analisis lanjut, mewakili 11.97% populasi dengan kadar tindak balas 20.4%. Kajian ini membangunkan sebuah model baru untuk mengukur keberkesanan peralatan dan prestasi kelestarian. Model ini hibrid konsep Keberkesanan Peralatan Secara Keseluruhan (OEE), kebolehpercayaan peralatan dan Analisis Kegagalan dan Kesan (FMEA). Dalam menilai kritikal dari segi kesan kelestarian kegagalan peralatan, model ini memaparkan prestasi kelestarian mod kegagalan dengan menggunakan Nombor Kelestarian Kelestarian (SPN) yang dirumuskan menggunakan pendekatan Proses Hierarki Analitikal (AHP). Tahap prestasi skor OEE, kebolehpercayaan dan SPN diterjemahkan ke dalam sistem penarafan lima mata. Model ini telah diuji pada POM sebagai pendekatan pengesahan untuk menunjukkan kemungkinan model untuk keberkesanan peralatan dan analisis prestasi kelestarian. Penemuan menekankan terhadap turun naik dalam prestasi OEE bergantung pada bulan, menunjukkan masa menunggu, kerosakan, dan penyelenggaraan pencegahan sebagai faktor utama yang mempengaruhi keberkesanan peralatan. Tambahan pula, prestasi kebolehpercayaan model mempamerkan peningkatan kadar kegagalan yang menunjukkan kebarangkalian kegagalan kejadian meningkat dari masa ke masa untuk peralatan kritikal (ramp memuat, steriliser, thresher dan dandang). Model ini menentukan tahap prestasi 20 kegagalan fungsi peralatan peralatan kritikal dan keputusan menunjukkan bahawa kedudukan SPN tertinggi untuk steriliser, menandakan sebagai mod kegagalan fungsian yang paling kritikal bagi kesan kelestarian di dalam POM. Model ini dapat menganalisis keberkesanan peralatan dan prestasi kelestarian dalam POM dan memberikan bukti empirikal untuk menyokong pihak pengurusan dalam membuat keputusan untuk mencapai kelestarian di POM. Kajian ini boleh digunakan sebagai kelebihan kepada kilang kelapa sawit serta organisasi lain dari industri yang berbeza untuk mengenali peluang keberkesanan peralatan dalam usaha untuk meningkatkan profil perniagaan dan reputasi korporat, dan pertumbuhan pasaran tanpa mengabaikan impak terhadap alam sekitar dan sosial.

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TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	xi
LIST OF APPENDICES	xiii
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xvi
LIST OF PUBLICATIONS	xviii
CHAPTER	
1. INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	3
1.3 Objectives	7
1.4 Scope of Work	8
1.5 Research Contribution	8
1.6 Thesis Organisation	9
2. LITERATURE REVIEW	10
2.1 Introduction	10
2.2 Manufacturing Sustainability	10
2.2.1 Manufacturing Sustainability Definition and Scope	11
2.2.2 Manufacturing Sustainability Programs and Practices	13
2.2.2.1 Environmental Sustainability	14
2.2.2.2 Economic Sustainability	22
2.2.2.3 Social Sustainability	26
2.3 Manufacturing Sustainability in Malaysian Palm Oil Mills	29
2.3.1 Adverse Environmental Impacts and Concerns in Palm Oil Mills	32
2.3.2 Regulations for Palm Oil Mills Sustainability	35
2.3.2.1 Malaysian Laws and Regulations for Environmental Performance	35
2.3.2.2 Malaysian Laws and Regulations for Social Performance	37
2.3.2.3 Malaysian Laws and Regulations for Economic Performance	39
2.3.2.4 Voluntary Standards for sustainable palm oil mill in Malaysia	40

2.3.2.6	Social Criteria of Sustainability Voluntary Standards	45
2.3.2.7	Economic Performance Criteria of Sustainability Voluntary Standard	47
2.3.3	To-date Research on Manufacturing Sustainability in the Palm Oil Mills	49
2.3.3.1	Environmental Aspect	50
2.3.3.2	Economic Aspect	52
2.3.3.3	Social Aspect	54
2.4	Manufacturing Sustainability at the Operational Level	56
2.4.1	Equipment Effectiveness toward Achieving Manufacturing Sustainability	56
2.4.1.1	Environmental Conservation	58
2.4.1.2	Social Efficiency	59
2.4.1.3	Economic Enhancement	60
2.4.2	Factors Affecting Equipment Effectiveness	61
2.5	Equipment Effectiveness and Sustainability Model	64
2.6	Research Approach	71
2.6.1	Adaption of Failure Modes Effects Analysis in Manufacturing Sustainability	71
2.6.2	Integrating Analytical Hierarchy Process and Failure Modes Effects Analysis	77
2.6.3	Survey Population and Sampling	80
2.6.4	Questionnaire Survey Analysis	81
2.7	Critical Review	82
2.7.1	Sustainability Programs and Practices	82
2.7.2	Factors Affecting Equipment Effectiveness	83
2.7.3	Sustainability Model based on FMEA	84
3.	RESEARCH METHODOLOGY	86
3.1	Introduction	86
3.2	Research Design	86
3.3	Questionnaire Survey	89
3.3.1	Questionnaires Structure	90
3.3.2	Pilot Survey and Content Validity	91
3.3.3	Sample Population	91
3.3.4	Questionnaire Administration	93
3.3.5	Population and Sampling	94
3.4	Model development and formulation	95
3.4.1	Process Description	96
3.4.2	Equipment Effectiveness Model Formulation	96
3.4.3	Sustainability Performance Model Construction	97
3.5	Initial Model Validation	99
3.6	Model Validation through Case Study	99
3.6.1	Field Observations	100
3.6.2	Company's Documents Review	100
3.6.3	Semi Structured Interview	101
3.7	Summary	102

4.	SURVEY RESULT AND DISCUSSION	103
4.1	Introduction	103
4.2	Objectives of the Survey	103
4.3	Analysis of Sample Demographic	104
4.4	Sustainability Programs and Practices in Malaysian Palm Oil Mills	108
4.4.1	Normality and Binomial Test for Sustainability Programs and Practices	108
4.4.2	Comparison of Mean Score for Sustainability Programs and Practices	111
4.4.3	Correlation Analysis of Sustainability Programs and Practices	116
4.4.4	Factor Analysis for Sustainability Programs and Practices	121
4.5	Sustainability Regulatory Compliance in Malaysian Palm Oil Mills	127
4.5.1	Normality Test and Mean Score of Sustainability Regulatory Compliance	128
4.5.2	Correlation Analysis for Sustainability Regulatory Compliance	135
4.5.3	Binomial Test for Sustainability Regulatory Compliance	139
4.5.4	Factor Analysis for Sustainability Voluntary Standards Compliance	140
4.6	Factors Affecting Equipment Effectiveness in the Malaysian Palm Oil Mills	145
4.6.1	Normality and Binomial Test for Equipment Effectiveness Components	145
4.6.2	Mean score for Factors Affecting Equipment Effectiveness	147
4.6.3	Correlation Analysis for Factors Affecting Equipment Effectiveness	149
4.6.4	Factor Analysis for Factors Affecting Equipment Effectiveness	152
4.7	Manufacturing Sustainability Opportunity from Equipment Effectiveness	158
4.7.1	Normality and Binomial Test for Manufacturing Sustainability Opportunity from Equipment Effectiveness	158
4.7.2	Mean Score for Manufacturing Sustainability Opportunity from Equipment Effectiveness	161
4.7.3	Correlation Analysis of Manufacturing Sustainability Opportunity	166
4.7.4	Factor Analysis for Manufacturing Sustainability Opportunity from Equipment Effectiveness	171
4.8	Summary	176
5.	MODEL DEVELOPMENT AND VALIDATION	178
5.1	Introduction	178
5.2	Model Development	178
5.2.1	Initial Model Framework	179
5.3	Equipment Effectiveness and Sustainability Performance Model	186
5.3.1	Model Phase 1: Process Description	188

5.3.2	Model Phase 2: Assessment of Equipment Effectiveness Performance	189
5.3.2.1	Measurement of OEE Performance	189
5.3.2.2	Estimation of Reliability Performance	192
5.3.3	Model Phase 3: Assessment of Sustainability Performance	195
5.3.4	Performance Level of Sustainability and Equipment Effectiveness	202
5.4	Model Validation	204
5.4.1	Process Description in the POM	204
5.4.2	Equipment Effectiveness Performance in the POM	207
5.4.3	Reliability Analysis of Critical Equipment Machinery in the System	215
5.4.4	Sustainability Performance Assessment in the POM	223
5.4.4.1	Pair-Wise Comparison Consistency of Decision Judgement	226
5.4.4.2	Computational of Global Weights of Each Element and Sub-Element	227
5.4.4.3	Evaluation of Sustainability Performance of Critical Equipment	231
5.5	Summary	240
6.	CONCLUSION AND RECOMMENDATIONS	241
6.1	Introduction	241
6.2	Summary of Research Findings	241
6.3	Research Contributions and Implications	245
6.3.1	Theoretical Contributions	245
6.3.2	Practical Implications	246
6.4	Research Limitations and Recommendation for Future Research	247
	REFERENCES	249
	APPENDICES	299

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Environmental Elements of Manufacturing Sustainability Practices	15
2.2	Economic and Social Elements of Manufacturing Sustainability Practices in the POM	24
2.3	Overview of Sustainability Voluntary Standards for POM	41
2.4	Environmental Criteria of Voluntary Standards for POM Sustainability	43
2.5	Social Performance Criteria of Voluntary Standards for POM Sustainability	46
2.6	Economic Performance Criteria of Voluntary Standard for POM Sustainability	48
2.7	Interruption Events of Equipment Effectiveness	63
2.8	Equipment Effectiveness and Sustainability Model	65
2.9	Sustainability Elements Addressed in the FMEA Model	73
2.10	Population and sampling of previous research on manufacturing sustainability	80
3.1	Design of the Questionnaire Survey	89
3.2	Structure of Questionnaire Survey	90
3.3	List of Information Required from Case Study	101
4.1	Mills Main Product and By-Products	105
4.2	Result of Reliability Analysis	108
4.3	Hypotheses for the Normality Test for Sustainable Manufacturing Practices	108
4.4	Hypotheses for Binomial Test of Sustainable Manufacturing Practices	109
4.5	Summary of Normality and Binomial Test for Sustainability Programs and Practices in Malaysian POM	110
4.6	Correlation for Priority of Sustainability Practices in Malaysian POM	118
4.7	Correlation for Achievement of Sustainability Practices in Malaysian POM	118
4.8	Comparison of Correlation of Sustainability Programs and Practices	119
4.9	Results of KMO and Bartlett's Test for Sustainability Practices in POM	122

4.10	Factor Analysis of Sustainability Practices in Malaysian POM	125
4.11	Hypotheses for Normality Test of Sustainability Regulatory Compliance	128
4.12	Summary of Normality Test, Mean and Standard Deviation for Sustainability Regulatory Compliance in Malaysian POM	130
4.13	Correlation for Priority of Sustainability Regulatory Compliance	136
4.14	Correlation for Achievement of Sustainability Regulatory Compliance	137
4.15	Comparison of Correlation for Priority and Achievement of Sustainability Regulatory Compliance in Malaysian POM	138
4.16	Hypotheses for Binomial Test of Sustainability Regulatory Compliance	139
4.17	Summary Results of Binomial Test for Sustainability Regulatory Compliance in Malaysian POM	140
4.18	Results of KMO and Bartlett's Test for Sustainability Voluntary Standards Compliance	141
4.19	Factor Analysis of Sustainability Voluntary Standards Compliance in Malaysian POM	142
4.20	Normality Test Hypotheses for Factors Affecting Equipment Effectiveness	145
4.21	Binomial Test Hypotheses for Factors Affecting Equipment Effectiveness	145
4.22	Normality and Binomial Test for Factors Affecting Equipment Effectiveness	146
4.23	Correlation of Factors Affecting Equipment Effectiveness in Malaysian POM	150
4.24	Correlation Strength Comparison	151
4.25	KMO and Bartlett's Test for Factors Affecting Equipment Effectiveness	152
4.26	Results of Factor Analysis for Equipment Effectiveness in the POM	154
4.27	Hypotheses for Normality Test for Manufacturing Sustainability Opportunity	158
4.28	Hypotheses for the Binomial test for Manufacturing Sustainability Opportunity	158
4.29	Malaysian POMs' Priority and Current Achievement of Performance of Manufacturing Sustainability Opportunity	159
4.30	Correlation for Priority of Manufacturing Sustainability Opportunity from Equipment Effectiveness	167
4.31	Correlation for Achievement of Manufacturing Sustainability Opportunity from Equipment Effectiveness	168
4.32	Comparison of Correlation for Priority and Achievement of Manufacturing Sustainability Opportunity from Equipment Effectiveness	169
4.33	Results of KMO and Bartlett's Test for Sustainability Opportunity from Equipment Effectiveness	171
4.34	Factor Analysis of Manufacturing Sustainability Opportunity from Equipment Effectiveness for Malaysian POM	173

5.1	Description of Codes in the Hierarchy Model	196
5.2	Corresponding Score of Technical, Environmental, Economic, and Social Factors of Failure Occurrence, Os	199
5.3	Corresponding Score of Technical, Environmental, Economic, and Social Factors of Failure Severity, Ss	200
5.4	Corresponding Score of Technical, Environmental, Economic, and Social Factors for Failure Detection, Ds	201
5.5	The Benchmark of the OEE Performance Level	202
5.6	Shape Parameter (β) Constitutes Failure Behaviour	203
5.7	Reliability Performance Level	203
5.8	RPN and SPN Performance Level	203
5.9	Company Profile for Model Validation	204
5.10	Overall Equipment Effectiveness from POM for 2014	208
5.11	Overall Equipment Effectiveness from POM for 2015	209
5.12	Overall Equipment Effectiveness from POM for 2016	210
5.13	Summary of Reliability Analysis of Critical Equipment in the POM	222
5.14	Pairwise Comparison Scale (Ocampo and Clark, 2015)	224
5.15	Pair-Wise Comparison of the Occurrence, Severity, and Detection	225
5.16	Priority Weights of the Occurrence, Severity, and Detection	225
5.17	Average Random Consistency Index (RI) Based on Matrix Size (Saaty, 1994)	226
5.18	Rank of the Matrix of Level 1	227
5.19	Pair-Wise Comparison Matrix for Sub-Elements of Probability of Os	227
5.20	Standardised Matrix for Sub-Elements of Probability of Os	228
5.21	Synthesis of Priorities for Sub-Elements of Probability of Os	228
5.22	Pair-Wise Comparison Matrix for Sub-Elements of Ss	228
5.23	Standardised Matrix for Sub-Elements of Ss	228
5.24	Synthesis of Priorities for Sub-Elements of Ss	229
5.25	Pair-Wise Comparison Matrix for Sub-Elements of Probability of Ds	229
5.26	Standardised Matrix for Sub-Elements of Probability of Ds	229
5.27	Synthesis of Priorities for Sub-Elements of Probability of Ds	229
5.28	Weightage of Sustainability Factor	230
5.29	Failure Mode, Cause and Effect of Loading Ramp	232
5.30	Failure Mode, Cause and Effect of Steriliser	233
5.31	Failure Mode, Cause and Effect of Thresher	234
5.32	Failure Mode, Cause and Effect of Boiler	235
5.33	Sustainability Performance of the Critical Equipment in the POM	237
5.34	Comparison of Priority Level of the Traditional RPN and Proposed SPN	238

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Performance Scope of the Manufacturing Sustainability (Liyanage et al., 2009)	12
2.2	Annual Production Capacity of Certified Sustainable Palm Oil (RSPO, 2016)	30
2.3	Examples of POM Wastes and Environmental Effects	33
2.4	Regulatory Principles for POM Sustainability	36
2.5	Translating OEE Measure into Manufacturing Sustainability	58
2.6	Basic AHP Model (Subramanian and Ramanathan, 2012)	78
3.1	Flowchart of Research Methodology	87
3.2	Phases of the Model Developed	95
3.3	Flowchart of FMEA-AHP Approach for the Model	98
4.1	Demographic Analysis of the Survey	106
4.2	Comparison of Mean Score for Sustainability Programs and Practices	112
4.3	Normality Test for Mean Sustainability Programs and Practices Priority	114
4.4	Normality Test for Mean Sustainability Programs and Practices Achievement	114
4.5	Results of Two-Sample T Test for Sustainability Programs and Practices	115
4.6	Box plot of Mean Comparison Sustainability Programs and Practices	116
4.7	Scree Plot of Factor Analysis of Sustainability Practices in Malaysian POM	124
4.8	Mean Score Difference between Priority and Achievement	129
4.9	Normality Test for Mean Sustainability Regulation Compliance Priority	132
4.10	Normality Test for Mean Sustainability Regulation Compliance Achievement	133
4.11	Results of Mann-Whitney Test for Sustainability Regulation Compliance	134
4.12	Box plot of Median Comparison Sustainability Regulation Compliance	134
4.13	Scree Plot of Sustainability Voluntary Standards Factor Analysis	142

4.14	Mean score of Factors Affecting Equipment Effectiveness in Malaysian POM	148
4.15	Scree Plot of Equipment Effectiveness Factor Analysis	154
4.16	Comparison of Mean Score Manufacturing Sustainability Opportunity from Equipment Effectiveness	162
4.17	Normality Test for Mean Sustainability Benefits Priority	163
4.18	Normality Test for Mean Sustainability Benefits Achievement	164
4.19	Results of Mann-Whitney Test for Sustainability Benefits	165
4.20	Box plot of Median Comparison for Sustainability Benefits	165
4.21	Scree Plot of Manufacturing Sustainability Opportunity from Equipment Effectiveness for Malaysian POM	173
5.1	Organisational Model for Asset Sustainability (Ossai et al., 2014)	180
5.2	Initial Framework for Equipment Effectiveness and Sustainability at Plant Department	182
5.3	The Model Structure Constructed as in IPO	185
5.4	Equipment Effectiveness and Sustainability Performance Model	187
5.5	Bathtub Curve for Failure Rate (Wang et al. 2002)	192
5.6	Hierarchy Model for Weightage of Sustainability Criteria Based on FMEA Criteria	196
5.7	Material and Process Flow of the POM	206
5.8	Availability Rate, Performance Rate and Quality Rate of POM	211
5.9	Overall Equipment Effectiveness Performance of POM Compared to the World Class OEE	212
5.10	Frequency of Equipment Failure in the POM	216
5.11	Graphical summary of Loading Ramp TBF	217
5.12	Graphical Analysis of Steriliser TBF	218
5.13	Graphical Analysis of Thresher TBF	218
5.14	Graphical Analysis of Boiler TBF	219
5.15	PDF, Goodness-Of-Fit, Survival, and Hazard Rate Plot of Loading Ramp	220
5.16	PDF, Goodness-Of-Fit, Survival, and Hazard Rate Plot of Steriliser	220
5.17	PDF, Goodness-Of-Fit, Survival, and Hazard Rate Plot of Thresher	221
5.18	PDF, Goodness-Of-Fit, Survival, and Hazard Rate Plot of Boiler	221
5.19	Functional Block Diagram of Loading Ramp	232
5.20	Functional Block Diagram of Steriliser	233
5.21	Functional Block Diagram of Thresher	234
5.22	Functional Block Diagram of Boiler	235

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Survey Questionnaire	299
B	Assessment of Questionnaire (Pre-Test)	311
C	Survey Respondents	315
D	Assessment of Proposed Model (Initial Model Validation)	318
E	Background of Panels for Semi-Structured Interview	322
F	Semi-Structured Interview Questions for Assessment of Sustainability-FMEA	323
G	Factor Analysis	330
H	Experts' Judgement of AHP Pairwise	361

LIST OF ABBREVIATIONS

AHP	-	Analytical Hierachy Process
BOD	-	Biochemical Oxygen Demand
CDF	-	Cumulative Density Function
CDM	-	Clean Development Mechanism
CI	-	Consistency Index
COD	-	Chemical Oxygen Demand
CPKO	-	Palm Kernel Oil
CPO	-	Crude Palm Oil
CR	-	Consistency Ratio
CSR	-	Corporate Social Responsibility
D	-	Detection
DJSI	-	Dow Jones Sustainability Index
EFB	-	Empty Fruit Bunches
EPF	-	Equity Corporation and The Employees Provident Fund
EQA	-	Environmental Quality Act
ERP	-	Extended Risk Priority Number
EU-RED	-	European Union's Renewable Energy Directive
FBD	-	Functional Block Diagram
FELDA	-	Federal Land Development Authority
FFA	-	Free Fatty Acid
FFB	-	Fresh Fruit Bunches
FMA	-	Factory And Machinery Act
GHG	-	Greenhouse Gasses
HACCP	-	Hazard Analysis Critical Control Point
IPO	-	Input-Process-Output
ISCC	-	International Sustainability And Carbon Certification
ISO	-	International Organization For Standardization
KeTTHA	-	Ministry of Energy, Green Technology And Water
KMO	-	Kaiser-Meyer-Olkin
K-S	-	Kolmogorov-Smirnov
LCA	-	Life Cycle Assessment
LCC	-	Life Cycle Costing
LCIA	-	Life Cycle Impact Assessment
MCDM	-	Multi-Criteria Decision-Making

MEOMA	-	Malayan Edible Oil Manufacturers' Association
MLE	-	Maximum Likelihood Estimation
MOHR	-	Ministry of Human Resource
MPOB	-	Malaysian Palm Oil Board
MSPO	-	Malaysian Sustainable Palm Oil
MTBF	-	Mean Time Between Failure
MYR	-	Malaysian Ringgit
O	-	Occurrence
OEE	-	Overall Equipment Effectiveness
OER	-	Oil Extraction Rate
OSHA	-	Occupational Safety And Health Administration
PDF	-	Probability Density Function
PK	-	Palm Kernel
PME	-	Palm Oil Methyl Ester
POM	-	Palm Oil Mill
POME	-	Palm Oil Mill Effluent
PORAM	-	Palm Oil Refiners Association of Malaysia
PROMETHEE	-	Preference Ranking Organization Method for Enrichment Evaluation
RI	-	Random Consistency Index
RPN	-	Risk Priority Number
RSB	-	Roundtable On Sustainable Biofuels
RSPO	-	Roundtable On Sustainable Palm Oil
S	-	Severity
SIRIM	-	Standards and Industrial Research Institute of Malaysia
SOCISO	-	Social Security Organization
SPN	-	Sustainability Priority Number
SPSS	-	Statistical Package for the Social Sciences
TBF	-	Time Between Failure
TBL	-	Triple Bottom Line
TOPSIS	-	Similarity to Ideal Solution
TPM	-	Total Productive Maintenance
UFOP	-	Union for The Promotion of Oil and Protein Plants
UKM	-	Universiti Kebangsaan Malaysia
UNFCCC	-	United Nations Framework Convention on Climate Change
USD	-	United States Dollar
USDA	-	United States Department of Agriculture
UTeM	-	Universiti Teknikal Malaysia Melaka
WBCSD	-	United Nations Global Compact, and World Business Council For Sustainable Development
WCED	-	World Commission on Environment and Development
WIP	-	Work In Progress
WWF	-	World Wildlife Fund

LIST OF SYMBOLS

CO_{2eq}	-	Carbon Dioxida Equivalents
$(Decf)_j$	-	Failure Detection for Economic Element for Equipment j
$(Denf)_j$	-	Failure Detection for Environmental Element for Equipment j
$(Dsf)_j$	-	Failure Detection for Social Element for Equipment j
$(Dtec)_j$	-	Failure Detection for Technical Element for Equipment j
$(Oecf)_j$	-	Failure Occurrence for Economic Element for Equipment j
$(Oenf)_j$	-	Failure Occurrence for Environmental Element for Equipment j
$(Osf)_j$	-	Failure Occurrence for Social Element for Equipment j
$(Otec)_j$	-	Failure Occurrence for Technical Element for Equipment j
$(Secf)_j$	-	Failure Severity for Economic Element for Equipment j
$(Senf)_j$	-	Failure Severity for Environmental Element for Equipment j
$(Ssf)_j$	-	Failure Severity for Social Element for Equipment j
$(Stec)_j$	-	Failure Severity for Technical Element for Equipment j
DW_T	-	Downtime
Ds_j	-	Failure Detection of Sustainability Perspective for Equipment j
OER_A	-	Actual OER Achieved by the Mill
OER_I	-	Ideal OER
OP_T	-	Net Operating Time
OUT_A	-	Actual Production Output Per Hour
OUT_S	-	Scheduled Production Output Per Hour
Os_j	-	Failure Occurrence of Sustainability Perspective for Equipment j
PM_T	-	Scheduled Preventive Maintenance
PS_T	-	Planned Shutdown
SPN_j	-	Sustainability Priority Number for Equipment j
ScO_T	-	Scheduled Operating Time
Ss_j	-	Severity rating of sustainability perspective for equipment j
A	-	Positive Reciprocal Square Matrix
exp	-	Exponential
$f(t)$	-	Probability Density Function
$F(t)$	-	Cumulative Distribution Function
$H(t)$	-	Hazard Rate Function
kWh/ton	-	Kilowatt Hours per Ton
MJ/ton	-	Mega Joule per Ton
$R(t)$	-	Reliability Function

$w1$	-	Weightage Probability of Failure Occurrence for Technical Factor
$w2$	-	Weightage Probability of Failure Occurrence for Environmental Factor
$w3$	-	Weightage Probability of Failure Occurrence for Economic Factor
$w4$	-	Weightage Probability of Failure Occurrence for Social Factor
$w5$	-	Weightage Probability of Failure Severity for Technical Factor
$w6$	-	Weightage Probability of Failure Severity for Environmental Factor
$w7$	-	Weightage Probability of Failure Severity for Economic Factor
$w8$	-	Weightage Probability of Failure Severity for Social Factor
$w9$	-	Weightage Probability of Failure Detection for Technical Factor
$w10$	-	Weightage Probability of Failure Detection for Environmental Factor
$w11$	-	Weightage Probability of Failure Detection for Economic Factor
$w12$	-	Weightage Probability of Failure Detection for Social Factor
W_i	-	Priority Weight
λ_{\max}	-	Largest Eigenvector
t	-	Time
β	-	Shape Parameter
η	-	Scale Parameter
n_0	-	Sample Size
m	-	Value of Selected Alpha Level of 0.05
s	-	Estimate of Standard Deviation of the Population
d	-	Acceptable Margin of Error
n_1	-	Required Return Sample Size Because Sample > 5% of Population

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