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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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, pembangunkan 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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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
ERPN	-	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
SOCSO	-	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
UNFCC	-	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
λmax	-	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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