Faculty of Engineering

Modeling and Analysis of Process Factors' Effect on Performance in Crude Palm Oil Processing Time: A Simulation-Based Approach

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Crude Palm Oil (CPO) industry has emerged as one of the main agricultural commodities and contributes significantly to the national economy. Studies showed process factors such as fresh fruit bunches (FFBs), workers, process, machines and components and working method affect the performance of a CPO production system. However, there is no study that investigate the performance of CPO production system considering these process factors and the possibility of interactions between these process factors. The first objective is to develop a simulation model of CPO production. Second, to analyse the process factors and simulated processing times using ANOVA to identify significant factors and interactions between factors. Third, to propose managerial strategies to reduce the processing time. The research tools used are discrete event simulation (DES), design of experiment (DOE) and analysis of variance (ANOVA). Four industrial cases are considered; for Case A & Case B the simulated operation time are 8 hours and 16 hours, respectively. While for Case C & D the simulated FFBs quantity are 250 metric tonnes and 1250 metric tonnes, respectively. For Case A & B findings showed process factors such as FFBs quantity, FFBs inter-arrival time and tipping machine repair time are significant. Also, for Case A & B, the interaction between FFBs quantity and inter-arrival time is significant. For Case C & D, tipping machine repair time and weighbridge machine repair time are significant. For Case C, there is no significant interaction between factors, while for Case D, the interaction between weighing time and weighbridge repair time is significant. In sum, availabilities of FFBs quantity and tipping machine are crucial to achieve short processing time. Thus, management of palm oil mill must implement strategies to sustain availabilities of FFBs and tipping machine.

Keywords: Simulation, fresh fruit bunches (FFBs), process factors, crude palm oil (CPO), processing time

Pemodelan dan Analisis Kesan Faktor Proses Terhadap Prestasi Masa di dalam Pemprosesan Minyak Sawit Mentah: Kaedah Berasaskan Simulasi

ABSTRAK

Industri Minyak Sawit Mentah (CPO) telah menjadi salah satu komoditi pertanian utama yang memberikan sumbangan yang penting kepada ekonomi negara. Kajian telah menunjukkan bahawa faktor proses seperti kuantiti tandan buah segar (FFB), pekerja, proses, mesin dan komponen serta kaedah kerja yang mempengaruhi prestasi sistem pemprosesan minyak sawit mentah (CPO). Sehingga kini belum terdapat kajian tentang prestasi sistem pemprosesan (CPO) yang mengambikira pelbagai faktor proses dan kemungkinan interaksi antara faktor proses. Objektif kajian pertama adalah membangunkan satu model simulasi pengeluaran CPO. Objektif yang kedua, adalah menganalisa faktor-faktor proses dan masa pemprosesan yang disimulasikan dengan menggunakan "analysis of varian" (ANOVA) bagi mengenal pasti faktor-faktor proses yang signifikan dan interaksi antara faktor-faktor yang signifikan. Objektif kajian yang ketiga, ialah mencadangkan strategi pengurusan untuk mengurangkan masa pemprosesan minyak sawit mentah. Teknik kajian yang digunakan adalah "discrete event simulation" (DES), "design of experiment" (DOE) dan "analysis of variance" (ANOVA). Empat kes industri telah disimulasikan; untuk Kes A & Kes B, masa pemprosesan yang disimulasi adalah 8 jam dan 16 jam. Manakala untuk Kes C & D, kuantiti tandan buah segar (FFB) yang disimulasi adalah 250 tan metrik dan 1250 tan metrik. Hasil kajian adalah bagi Kes A & B, kuantiti tandan buah segar (FFBs), masa ketibaan buah tandan segar (FFBs), dan masa pembaikan mesin tuangan adalah signifikan. Bagi Kes C & D, masa pembaikan mesin tuangan dan masa pembaikan mesin jambatan timbang adalah signifikan. Secara ringkasnya, ketersediaan kuantiti tandan buah segar (FFBs) and mesin tuangan adalah penting untuk

mencapai masa pemprosesan yang singkat. Maka, pengurusan kilang sawit mesti melaksanakan strategi untuk mengekalkan ketersediaan tandan buah segar (FFBs) dan mesin tuangan.

Kata kunci: *Simulasi, tandan buah segar (FFB), faktor proses, minyak sawit mentah, masa pemprosesan*

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CBC	Cake Breaker Conveyor
ConLOAD	Continuous CONstant LOAD
CPO	Crude Palm Oil
DES	Discrete Event Simulation
DOE	Design of Experiment
FFB	Fresh Fruit Bunch
FIFO	First In First Out
KER	Kernel Extraction Rate
KPI	Key Performance Indicator
LUMS OR	Lancaster University Management School order release
MPOB	Malaysian Palm Oil Board
MT	Metric Tonne
OEE	Overall Equipment Efficiency
SOP	Standard Operating Procedure
SPSS	Statistical Package for Social Science
TRIA	Triangular
WIP	Work in Progress

CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, manufacturing environment is characterized by globalization, increasing competition, accelerated adoption of technological innovation and growing customer demand for new, complex, and customizable products with shorter life cycles (Cristea & Cristea, 2021). Operating within this volatile environment companies need to properly implement and manage their operations strategies and improve actions to remain competitive and satisfy customers efficiently and effectively (Barbosa & Azevedo, 2018). As such, as emphasized by Neely et al. (1995), assessment of manufacturing systems' performance is important for reviewing objectives and maintaining competitiveness when manufacturing environment is constantly changing. Good performance of manufacturing companies depends on dimensions such as response time, cost, production time, efficiency, service levels, production throughput and quality of products and services (Hopp & Spearman, 2008; Kalita et al., 2019).

In a manufacturing system, the manufacturing processes are interconnected where the output from one process becomes the input to the next process, and in some cases where rework is necessary, the output becomes the input to the previous process. These interconnected manufacturing processes have resulted in many process factors that exist in the manufacturing system (Addo-Tenkorang & Helo, 2016). Battesini et al. (2021) established there are complex causal interrelations among key process factors that influence the performance of manufacturing system. Also, the performance is directly dependent on

the factors and mechanisms associated with the production flow that are present within the manufacturing system itself.

In Malaysia, crude palm oil (CPO) industry has grown rapidly and emerged as one of the main agricultural commodities and contributes significantly to the national economy (Nambiappan et al., 2018). Previous studies (Mohd-Lair et al., 2012; Kumaradevan et al., 2014; Junaidah, et al., 2015; Anyaoha et al., 2018; Sembiring et al., 2018, Susilawati et al., 2019; Ishak et al., 2019; Ishak, 2020; Lubis et al., 2020; Marimin and Zavira, 2020; Racedo-Gutiérrez et al., 2020; Sembiring Ramzani, 2020; Abdullah et al., 2021; Fadilla et al., 2021; Ojeda-Safra et al., 2021; Pakdeechot et al., 2021; Pratama & Susilawati, 2021; Ishak , 2020; Rizkya et al., 2020; Setiawan & Prasetya, 2020; Hermantoro et al., 2023; Minarni et al., 2023; Samri et al., 2023; and Fadhilah et al., 2024) have shown that the performance of CPO production system is affected by many process factors. These process factors are broadly categorised into raw materials (FFBs), machines and components, workers, process and working method/production strategy. Good performance of any crude palm oil (CPO) production is very important for maintaining competitiveness.

1.2 Problem Statement

A crude palm oil (CPO) production system consists of several inter-connected process, with the output from one process becomes the input to the next process. As stated in subsection 1.1, process factors related to raw materials (FFBs), machines and components, workers, process and working method/production strategy do affect the performance of CPO production system. The process factors related to raw materials are arrival, fruit origin, mature fruit quality, grading methods, unloading procedures and processing routes. Process factors related to workers are skills, numbers of, motivation, working hours, work experience

and education & training. For process, factors related are critical or noncritical, FFB input and prediction of CPO based on fresh fruit bunches. As for processing machines and machine components related factors are critical machines, transportation, machine hours, type of technology used, processing time, optimum setting, to sorting, loading ramps, sterilizer station, purification stations and storage stations, maintenance schedule and component replacement. Finally, process factors related to work method are duration of repair process, duration of moving CPO input tank and usage of different machine settings and manual counting of oil palm fresh fruit bunches moving on a conveyor.

For example, studies by Kumaradevan et al. (2014), Susilawati et al. (2019), Sembiring and Ramzani (2020), Pratama and Susilawati (2021) and Ishak (2020) have established that process factors related to raw materials do affect the performance of CPO production system. For process factors related to machines and components, studies by Mohd-Lair et al. (2012), Sembiring et al. (2018), Susilawati et al. (2019), Marimin and Zavira (2020), Sembiring and Ramzani (2020), Abdullah et al. (2021), Pratama and Susilawati (2021) and Minarni et al., (2023) have established the effect on performance of CPO production system. For process factors related to workers, studies conducted by Susilawati et al. (2019), Ishak (2020) and Sembiring and Ramzani (2020) have established the effect on performance of CPO production system. Studies conducted by Ishak et al. (2019), Ishak (2020), Fadilla et al. (2021) and Samri et al. (2023) have established that process factors related to process do affect the performance of CPO production system. Finally, for process factors related to working method/production strategy, studies by Kumaradevan et al. (2014), Junaidah, et al. (2015), Anyaoha et al. (2018), Ishak et al. (2019), Ishak (2020), Lubis et al. (2020), Racedo-Gutiérrez et al. (2020), Rizkya et al. (2020), Setiawan and Prasetya (2020), Abdullah et al. (2021), Fadilla et al. (2021), Pratama and

Susilawati (2021), Ojeda-Safra et al. (2021), Pakdeechot et al. (2021), Hermantoro et al. (2023), Minarni et al. (2023), and Fadhilah et al. (2024) have established the effect on performance of CPO production system. Detail review of these studies is provided in subsection 2.3.2.

Thus, it can be emphasised that major problems faced by CPO production system are the presence of these process factors and corresponding effect on CPO production system's performance. However, most studies cited above have failed to consider the presence of many process factors and the possibility of interactions between these process factors which affect the performance of CPO production system. In addition, in most studies cited above the research tools used was adequate to address the requirements of their research work, which might not be adequate for modelling, experimenting, and analysing the presence and interactions of many process factors within the CPO production system. Given the problems of (i) many process factors and their effect on performance, (ii) possibility of interactions between these factors and their effect on performance, (iii) a unique research tool to solve problem (i) and (ii), then work reported in this thesis aims to study the performance of CPO production system considering many process factors using discrete event simulation (DES) combined with design of experiment (DOE) and analysis of variance (ANOVA). In this thesis, the CPO production system to be studied is in Belaga, Sarawak. Upon consultation with management team, it has been decided that processing time is crucial than other performance measures and is defined as the total time taken to process one batch of fresh fruit bunches (FFBs) to crude palm oil. Henceforth this will be known as CPO processing time and will be used in the thesis.

1.3 Research Hypotheses and Questions

The research hypotheses and questions are as follows.

Research hypotheses:

i. There are process factors related to raw materials, workers, machines, process, and maintenance which affect the crude palm oil processing time.
ii. There are two-way interactions between any two process factors (such as raw materials and workers, raw materials and machines, raw materials and process, raw materials and maintenance, workers and machines, workers and process, workers and maintenance, machines and process, machines and maintenance, process, and maintenance) which affect the crude palm oil processing time.
iii. There are managerial strategies or actions related to raw materials, workers, machines, process, maintenance that could be used to reduce the crude palm oil processing time affected by process factors and interactions between process factors identified in (i) and (ii).

Research questions;

i. What are the process factors that have main effect on the crude palm oil processing time for case A, B, C and D?
ii. What are the interactions between process factors that have effect on the crude palm oil processing time for case A, B, C and D?
iii. How are the managerial strategies or action implemented to manage the crude palm oil processing time affected by process factors and interaction between process factors identified in (i) and (ii) for Case A, B, C and D?

1.4 Research Objectives

The general objective of this research work is to apply discrete simulation, design of experiment (DOE) and analysis of variance (ANOVA) techniques to study the processing time of a crude palm oil (CPO) production system under the effect of many input process factors. The input process factors referred to in objectives (i) and (ii) are fresh fruit bunches (FFBs) quantity, FFBs inter-arrival time, number of weighbridge machine, weighing time, weighbridge machine repair time, number of grading machine, grading time, number of workers at loading station, loading time, number of steriliser machine, sterilising time, tipping machine repair time, number of digester machine and number of presser machine.

The main effect of input process factor stated in objective 2 (for example FFBs quantity) is defined as the change in response (CPO processing time) produced by a change in the level of FFBs quantity. For the interaction effect, this is defined as the effect of one independent variable (for example FFBs quantity) changes depending on the level of another independent variable (for example FFBs inter-arrival time). The main and interactions effect analyses of these input process factors were carried out under the assumptions of four industrial scenarios (Case A; 8 hours operation, Case B; 12 hours operations, Case C; 250 metric tonnes of FFBs, and Case D; 1150 metric tonness of FFBs). Data collection was carried out over a duration of 2.5 years (2019-2021) in a local case-study mill located in Belaga, Sarawak that has been operating for 20 years. Specifically, the objectives of this research work are to:

i. To develop and validate a simulation model for crude palm oil production system considering many input process factors.