



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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**Master of Engineering
2024**

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

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A thesis submitted

In fulfillment of the requirements for the degree of Master of Engineering

(Mechanical)

Faculty of Engineering
UNIVERSITI MALAYSIA SARAWAK
2024

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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ACKNOWLEDGEMENT

I would like to take this opportunity to those who have contributed directly or indirectly to this thesis.

My sincere gratitude to Dr Magdalene Anak Andrew Munot, for the advice and support given during my period of study in Universiti Malaysia Sarawak.

Finally, I would like to thank the management of the Universiti Malaysia Sarawak for making it possible for me to complete my study here in Sarawak. Thank you all.

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 pemrosesan 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 pemrosesan*

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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 tonnes 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.

- ii. To analyse the main and interaction effects of input process factors (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) on crude palm oil processing time under the assumptions of four industrial scenarios (case A, B, C, D).
- iii. To propose managerial strategies or actions for reducing the crude palm oil processing time based on the findings obtained in (ii).

From this point onwards the input process factors will be termed as process factors.

1.5 Scope of Work

For the first objective, the scope of research work is specified as follows:

- i. Revision of basic conceptual model of CPO production with process factors found from recent literature review observations at the case company.
- ii. Translation of CPO conceptual model to a corresponding simulation model within the ARENA simulation platform version 16.00.00002.
- iii. Coding of simulation model with relevant industrial data.
- iv. Verification and validation of the simulation model.

For the second objective, the scope of research work is specified as follows:

- i. Designing the design of experiment matrix for factors screening experiment using two-level fractional factorial experimental design for Cases A, B, C, D.
- ii. Conducting analysis of variance (ANOVA) to identify process factors that significantly affects the processing time for Cases A, B, C, D
- iii. Designing the design of experiment matrix for full factorial experiment for factors identified in (ii) using the two-level full factorial experimental design for Cases A, B, C, D.
- iv. Conducting analysis of variance (ANOVA) to determine process factors and the interactions between process factors that significantly affect the processing time for Cases A, B, C, D).

For the third objective, the scope of work is specified as follows:

- i. Identifying operational practises related to process factors in (iv) that contribute to a long processing time for crude palm oil.
- ii. Proposing appropriate strategies to achieve short processing time for crude palm oil.

1.6 Research Contributions

This research work contributes in the following ways.

- i. Development of a conceptual model of a crude palm oil (CPO) production system considering process factors based on input from professionals at the case study company and review of the existing literature.

- ii. Development, verification and validation of a simulation model of a crude palm oil production system within the ARENA simulation platform Version 16.00.00002.
- iii. Application of design of experiment (DOE) in designing the simulation experiment matrix for factor screening and full factorial under the assumptions of four (4) different industrial scenarios (case A, B, C, D).
- iv. Application of the simulation model to predict the crude palm oil processing time under the assumptions of four (4) different industrial scenarios (case A, B, C, D).
- v. Application of analysis of variance (ANOVA) to analyse the main and interaction effects of process factors on the crude palm oil processing time.
- vi. Proposal of managerial strategies or actions to manage the crude palm oil processing time.

1.7 Organization of Thesis

This thesis contains 5 chapters. The first Chapter 1 on introduction is divided into seven sections. The first section (1.1) describes the research background, which highlights the existence of process factors that affect the performance of manufacturing and crude palm oil production systems. The second section (1.2) on problem statements highlights the existence of many process factors and possibility of interactions between factors that affect the crude palm oil production system and the requirement of a unique research tools. The third section (1.3) presents the research hypotheses and questions. The fourth section (1.4) listed out the objectives set for this research work, the fifth section (1.5) presents the scope of work specified for each research objectives, the sixth section (1.6) highlights the research contributions, and section (1.7) outlines the organisation of the thesis.

Chapter 2 on literature review consists of six sections. The first section (2.1) introduces the chapter content, the second section (2.2) provides research background on performance analysis and evaluation of manufacturing systems. The third section (2.3) is divided into three subsections; the first subsection (2.3.1) discusses process factors that affect the performance of manufacturing/production systems. The second subsection (2.3.2) discusses process factors that affect the performance of crude palm oil production system. The third subsection (2.3.3) presents the research gap that has been identified through the literature review. The fourth section (2.4) presents fundamental of discrete event simulation (DES) modelling. The fifth section (2.5) presents statistical design of experiment (DOE), factorial experimental design, fractional factorial design and analysis of variance (ANOVA). Finally, the last section (2.6) summarizes the content of Chapter 2.

Chapter 3 on research methodology consists of six sections. The first section (3.1) introduces the chapter content, the second section (3.2) on simulation methodology describes the flowchart for conducting the research. The third section (3.3) describes the steps for defining, validating, and constructing the architecture of the conceptual model. The fourth section (3.4) explains the procedures for developing the simulation model, which include the module required, coding the simulation modules, and verifying the simulation segments. The fifth section (3.5) discusses the method for constructing the design of experiment matrix for validating and executing the simulation model; this section also presents analysis of variance (ANOVA) method for process factors screening and full factorial analysis and determination of number of replications. Finally, the last section (3.6) provides summary for Chapter 3.

Chapter 4 on results and discussions consists of five sections. The first section (4.1) introduces the chapter content, the second section (4.2) is divided into three subsections.

Specifically, subsection (4.2.1) discusses development and validation of the simulation model. Then, subsection (4.2.2) discusses validation of the simulation output against data from the case study company, and subsection (4.2.3) discusses validation of the simulation output data against production theory. The third section (4.3) is divided into five (5) subsections (4.3.1, 4.3.2, 4.3.3, 4.3.4 and 4.3.5) which discusses results of process factors analysis that affect the CPO processing time under four assumed industrial scenarios and combined process factors analysis. The fourth section (4.4) discusses the proposal for managerial strategies and actions that reduces the CPO processing time. The fifth section (4.5) provides the chapter summary.

Chapter 5, which is divided into two sections (5.1 and 5.2); section (5.1) on conclusions is divided into three subsections; subsection (5.1.1), provides conclusions with respect to development and validation of the simulation model. Subsection (5.1.2) provides conclusions with respect to analysis of process factors affecting the CPO processing time and combination of process factors analysis under four industrials settings. Subsection (5.1.3) provides conclusions with respect to managerial strategies and actions to reduce the crude palm oil (CPO) processing time. The second section (5.2) highlights limitations related to the research work and provides recommendations for future research works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This Chapter 2 presents literatures that are relevant to the study. Specifically, section 2.2 provides research background on performance analysis and evaluation of manufacturing systems. Section 2.3 is divided into three subsections, 2.3.1, 2.3.2. and 2.3.3. Subsection 2.3.1 provides literature review on process factors affecting the performance of manufacturing systems. Subsection 2.3.2 provides literature review on process factors affecting the performance of CPO production systems. Subsection 2.3.3 presents the research gap that has been identified through the literature review. Section 2.4 discusses the fundamental of discrete event simulation (DES) modelling which include the pieces of simulation model, verification, validation, warmup period and number of replication and simulation project life cycle. Section 2.5 presents statistical design of experiment (DOE), factorial experimental design, fractional factorial design and analysis of variance (ANOVA). Finally, section 2.6 summarizes the content of Chapter 2.

2.2 Performance Analysis and Evaluation of Manufacturing Systems

As stated in Chapter 1, performance analysis and evaluation of manufacturing systems is important for companies' competitiveness. According to Altioek (2012) analysis of manufacturing system refers to the study of changes in operational factors carried out either using mathematical model or computer simulation model of the system. Altioek (2012) also defines performance evaluation as measuring or estimating the impact of decisions or changes on the system's behaviour. Performance evaluation is very important for any manufacturing firm to assess how well the firm performs against a standard or competitors,

and if necessary, take actions to improve the performance. Improvements in these manufacturing systems may be described in terms of reduced cycle time or lead time, reduction in cost, increase in capacity utilization, and the elimination of bottlenecks (Elizandro & Taha, 2012). For manufacturing industry there are many key performance indicators (KPIs) that could be implemented to evaluate the performance of any manufacturing firms. These KPIs should focus on aspects of organizational performance that are the most critical for current and future success of the firm (Parmenter, 2015). In addition, according to Moktadir et al. (2020), KPIs allow industries to identify those operations that are performing well and those need future enhancements and facilitate to recognize and remodel the performance systems of the manufacturing industries.

Amongst these KPIs, typical indicators used are as reported by Altiok (2012), Kampa et al. (2017), Zhu et al. (2018). Adane et al. (2019), Caggiano (2019) and Banga et al. (2022) are production throughputs (productivity), production or manufacturing lead-time, average inventory levels (inventory levels averaged over a planning horizon), utilization (percentage of time a machine is actually busy), customer service levels (percentage of time customer demand is fully satisfied), average flow times (average time a unit spends in the system), and percentage of down times (percentage of time a machine is under repair), the average waiting time of ready parts, output queue length, work in progress (WIP), the number of deadlock situations, mean tardiness and rate of tardy, plant capacity, and overall equipment efficiency (OEE), among others. To measure or estimate the impact of changes due to decisions or process factors on the behaviour of the system, an analysis of the system is performed either using mathematical or a computer simulation model of the system (Altiok, 2012).

Caggiano (2019) defines a manufacturing system as a combination of humans, machinery, and equipment that are bound by a common material and information flow. The input into the system are material (raw materials and energy) and information (related to customer demand for the system's products), while the outputs are materials (finished goods and scrap) and information (measures of system performance). To date numerous researches have been conducted to study the effects of process factors on the performance of manufacturing system and CPO production systems; these will be further discussed in the following subsections.

2.3 Related Literatures on Process Factors Affecting Manufacturing and Crude Palm Oil Production Systems

Manufacturing systems are complex in nature because many process factors are present. Next subsections (2.3.1 and 2.3.2) discuss literatures that have investigated the effect of process factors on manufacturing lead-time and production throughput of manufacturing and crude palm oil production systems, respectively. Manufacturing, production lead-time, flow time is defined as the total time required to process a given part or product through the plant, which includes operation and nonoperation time (Pound et al., 2014, Groover, 2016; Choueiri et al., 2020). In this thesis, the performance of a crude palm oil production system is defined as the total time taken to process one batch of fresh fruit bunch into the crude palm oil (i.e. processing time).

2.3.1 Process Factors Affecting Performance of Manufacturing/Production Systems

Mak et al. (2014) studied the effect of production lot-size and its interaction with operator competence on manufacturing lead-time of apparel manufacturing system. The authors developed a simulation model of a U-shaped production line based on real manufacturing data. The model incorporated operator learning curves using a 3-parameter

hyperbolic function. A factorial experiment was conducted by manipulating production lot size (16 levels) and operator competence (3 levels). Performance measures like utilization rates, flow time, and WIP were analysed using a two-way ANOVA at 95% confidence interval. Their simulation results study showed that there is significant main effect of lot-size and its interaction effect with operator competence on manufacturing lead-time, average work-in-progress (WIP) level, machine, and operator utilization rates. All p -values are less than 0.05 which means the two-way interactions are statistically significant on all performance measures.

Ahmarofi et al. (2017) studied the effect of manpower factors (fatigue and pressure) on production time of a semi-automatic audio speaker production line. Causal loop diagrams and stock flow diagrams were developed to simulate the influence of manpower factors, specifically fatigue and pressure, on completion time in a semiautomatic production line. Their results showed that changes in the number of manpower, preparation time of material, and machine breakdown rate significantly affect manpower fatigue, thus affecting the production time. For an ideal production completion rate of 720 audio speakers per hour using 30 workers, 5,040 pieces of material should be prepared within one hour, and the machine breakdown rate should be maintained at 0.0013 to meet the daily target. The preparation time for material contributes the highest percentage of deviation from the completion time base run up with 72.22%.

Ng et al. (2014) investigated the effect of different number of operators, volume of parts, and different flow pattern of parts on the production throughput, machine utilization, and labour utilization of the punching department of a circuit board manufacturing company. A series of discrete event simulation models were developed to analyse the effects of changes

in the shop floor on production performance. Analysis of variance (ANOVA) was used to test and analyse the simulation results. Their simulation results showed that the different number of operators and volume of parts significantly affect the production throughput, machine utilization and labour utilization. All p-values are less than 0.05.

Abrishami et al. (2018) investigated the effect of number of workers and machines on the production throughput of welding unit of a heater manufacturing factory. Their simulation results showed by adding two welding machines and two welding operators could lead to a considerable reduction. For scenario 1, the output is increase to 11,333 units. For scenario 2 the output is increase to 12,506 of the line at welding stations. Also, adding one compressor machine, one testing operator and reducing coal grinding workers could lead to an improvement in production throughput increased by 36.8%.

Abu Jadayil et al. (2017) studied the effect of number of workers running each machine, machines running speed, operating shifts schedule, machines utilization and working environment on the production capacity of plastic packaging manufacturing company. Their results showed that all these factors have significant effect on improving the production capacity, which subsequently improve overall production throughput. Specifically, optimizing machine speed can lead to a improvement in production by 30%. Increasing the number of workers operating bottleneck machines can boost production by 40%. Rescheduling working shifts and hiring additional workers can result in a 7.7% reduction in labour costs while increasing production capacity by 20%. Utilizing machines at optimum speed can enhance production capacity by around 33%. Improving workers' morale can contribute to a 6% increase in production capacity and an 80% reduction in

worker turnover. Enhancing the working environment, particularly by reducing noise levels, can improve production capacity by 9%.

Zahraee et al. (2018) studied the effect of number of workers, failure time of lifter, service rate of delpak mixer and number of permil under different scenarios on productivity of a continuous paint manufacturing system. The authors utilize simulation modelling, response surface methodology (RSM) and design of experiments (DOE) to analyse and improve productivity. Their simulation results study showed that a certain combination of number of workers (26) and failure time of lifter (56.01 minutes) resulted in maximum percentage of productivity (93.5%).

Vilela et al. (2020) studied the effect of human performance (assembly time) during different time of working shifts on the productivity of manual assembly line for electronic board. The Dopplot in Minitab® was used to analyse the total boards produced during various works shifts. Their simulation results study showed that human performance during the different duration of working shifts has significant impact (p -value are less than 0.05 at confidence level of 95%) on the productivity of the assembly line.

Utiyama et al. (2021) studied the effect of machine setup time variability and time between failure of machines on the overall manufacturing lead time of a manufacturing system under two scenarios of variability. The authors used standard mathematical equations from the Factory Physics approach and the maple computing software as the simulation environments in this study. Their simulation results study disclosed that companies with a single server and above 85% utilization could use the worst-case strategy to improve the setup time or time between failures.

Bambura et al. (2020) studied the effect of production process (changing sanding equipment and automating the welding section) on the productivity, material flow and workload utilization of a furniture production system. The authors used Technomatix Plant Simulation software to simulate and analyses the production system. Their simulation results showed that with the addition of a computer numerical control machine the overall productivity of the furniture production system is increased. Total production time was reduced from 34.25 hours down to just 12.02 hours, a 65% reduction. Additionally, unwanted bottlenecks in the system were identified and eliminated enabling a 38% reduction in assembly time.

Mourtzis et al. (2021) investigated the effect of number of machines, buffer capacity and interarrival time of raw materials at final stage of production and number of spinner blocks on the throughput of copper tube manufacturing system. The authors used discrete event simulation to simulate the production system. Their simulation results showed that the interarrival time of products has the highest (62.1%) impact on throughput compared to number of final machines, number of spinner blocks and buffer capacity.

Kumar et al. (2021) investigated the effect of assembly line layout, time loss and non-value-added activity on the production cycle time of a Toyota production system. The authors implemented principles of Toyota Production System with Jishuken problem solving techniques. Their results showed that modifying the arrangement of chute in assembly line and increasing the number of chutes, positioning the torque gun, re-arranging pre-testing of horns, before the final testing process resulted in reducing the production cycle time and operators' ideal time (from 18 seconds per products down to 15 seconds). The production output also increases from 1500 products per shift to 1800 products.

Imeseitf et al. (2019) study the effect of workstation related factors (reliability and cycle time of workstations, the length of a manufacturing line, and the capacity and locations of internal buffers) on the production throughput of a serial line manufacturing system under different settings. The authors used Design of Experiments and Discrete Event Simulation (DES) to analyse and predict the throughput. Their simulation results study showed that buffer location significantly affect the throughput and the optimal internal buffer location is at the middle location. The internal buffer location has a highly significant impact (p -value = 0.000) on improving throughput, more so than buffer capacity (p -value = 0.110). When the buffer capacity (B) is 4, placing the internal buffer in the middle between the bottleneck stations significantly increases the throughput improvement potential (TIP). Positioning the internal buffer at the middle location divides the assembly line into two shorter sublines, close to the bottleneck stations. However, when the internal buffer is placed at the 5th or 9th locations between bottleneck stations, the throughput improvement is not as high as the middle position. This is because when the buffer is not optimally located in the middle, it does not divide the line into shorter balanced sublines near the bottlenecks.

Mindlina and Tempelmeier (2021) investigated the impact of flow line parameters on the production output of a long stochastic flow line system under discrete and continuous time. The flexible (mixed integer) linear programming approach were used to evaluate and optimise the performance of the long stochastic flow line system. Their results showed that the presence of bottleneck machines and system variability affect the optimal material levels for the stochastic flow lines which subsequently affect the production output.

Yang et al. (2020) studied the effect of three assembly transfer strategies (one-to-one, one-to-many, and many-to-many) on throughput and facility utilization of a

reconfigurable flow shop. The authors used plant simulation to simulate the production system. They also used design of experiment (DOE) method to optimize, production process, optimal buffer and vehicle configuration. Their simulation results study showed that after optimisation, the throughput and facility utilization under each strategy increase significantly. The one-to-one strategy compared to the other two strategies resulted in the largest production output, but it requires the most investment cost.

Tu and Lu (2017) studied the effect of lot-size on cycle time of products, total throughput, and the waiting time of WIP by workstation of wafer fabrication system. Simulation model of the semiconductor manufacturing was developed using Flexism simulation software. Their simulation results shown that the cycle time of products is synchronously decreased when the lot size is shrunk; even though the waiting time of WIP is not significantly decreased with lot downsizing. Overall, the best lot-size for cycle time, throughput and waiting time of WIP is different. In other words, there is no lot size that could optimize the cycle time of product, total throughput and waiting time of WIP by workstation.

Güçdemir and Selim (2018) investigated the effect of two dispatch rules (classical and customer-oriented) for batches scheduling at machines on the average flow time, percentage of tardy orders, makespan and mean percentage deviation from customer expectations of a make-to-order job-shop manufacturing systems. The authors used a combination of simulation approach and multicriteria decision making in this study. Their simulation results study showed that customer-oriented dispatch rules provide the lowest percentage of tardy orders, makespan and mean percentage deviation from customer expectation compared to classical dispatch rules, when resources utilisation is 90%.

Vinod et al. (2019) studied the effect of due date assignment method, inter-arrival time, scheduling rule and setup time on the average flow time, mean tardiness and percentage of tardy jobs of a dynamic job-shop production system. C programming languages is used to develop the discrete event simulation model and ANOVA is used to analyse the simulation results. Their simulation results study showed that the main effect of all factors are found to be statistically significant at 5% significance level for all performance measures. As for the interaction effects, significant effect (p values are less than 0.05) are found between due date assignment and inter-arrival time, due date assignment and setup time, due date assignment and scheduling rules, setup time and scheduling rules for all performance measures.

Haeussler et al. (2020) studied the effects of two order release rules (fixed lead time and variable lead time) on the throughput time and inventory level of a make-to-order manufacturing system under two scenarios. Their simulation results study showed that under all simulated scenarios, an order release rule with variable lead times resulted in shorter shop floor throughput times and lower inventory levels. Specifically, for constant total demand and constant product mix (total) for allocated clearing function (ACF) (work-in-process (WIP); 19.05, finished goods inventory (FGI), 36.89) and input output control simply round down (IOCSR) -ACF (WIP;-0.27, FGI;-5.00*).

In 2021, Neuner and Haeussler studied the effects of three rule-based order release methods (LUMS-COR, Starvation Avoidance and ConLOAD) and three pool sequencing methods (first come first serve, earliest due date and critical ratio) on cost performance of a semiconductor wafer facility. Their simulation results showed that the Lums-COR model results in lower total cost under all different settings. Specifically, under CR pool sequencing

for product max 60:20:20, Lums-COR resulted in \$147695.58 compared to SAL \$163056.82 and Conload \$167232.76.

Thürer and Stevenson (2021) studied the impact of order release rules, dispatching and resource assignment rules on total throughput time, percentage of tardy and mean tardiness of a make-to-order job shops with multiple resource constraints. A discrete event simulation model of a 6-station job shop was developed in SIMIO with either 3 or 4 different resource constraints. Their results showed that at workload norm of 6 units, when number of resources is 4, a combination of all available (dispatching rule) with longest queue (resources assignment) resulted in the lowest percentage tardy (10.2%) and mean tardiness (2.66) compared to other combinations of dispatching and resources assignment rules.

Thus, performance of manufacturing system is affected by many process factors that include workers, machine, production layout, assembly layout & transfer, workstations, scheduling rules and order release methods. Figure 2.1 conceptualised the process factors discussed above. Outcome of above studies are very significant to the work reported in this thesis because it established there are many process factors that affect the performance of manufacturing system.

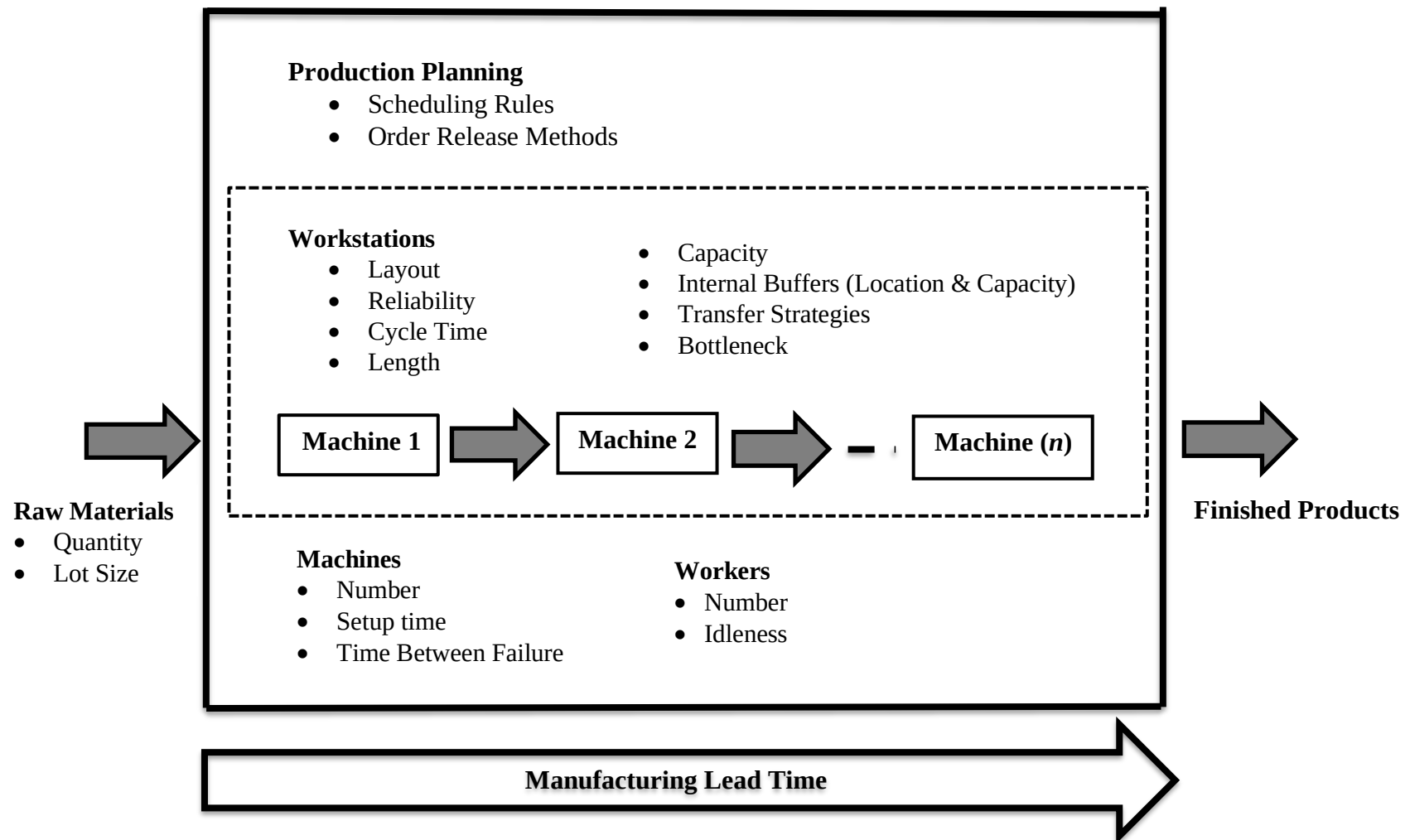


Figure 2.1: Conceptual Framework For Process Factors Affecting Performance Manufacturing System

2.3.2 Process Factors Affecting Processing Performance of Crude Palm Oil Production Systems

This research work studies the performance (processing time) of a crude palm oil (CPO) production system considering many process factors. For any CPO production systems, besides quality of CPO, reducing processing time (thus increase throughput or productivity) is also important. Longer processing time must be avoided because it affects the customer service level. The following paragraphs present previous studies on process factors that affect the processing time and throughput of CPO production system. The CPO processing time is defined as the total time taken to process one batch of fresh fruit bunch into the crude palm oil (henceforth termed CPO processing time)

Mohd-Lair et al. (2012), conducted a simulation-based process improvement study within a palm oil processing system with the aim to increase production throughput and optimise machine utilisation. For the existing palm oil processing system when in operation for 50 hours, simulation results showed that steriliser, tippler and thresher process were blocked, thus having utilization of 83.67%. For the improved processing system with addition of one more identical press machine, simulation results showed that utilization of sterilizer, tippler and thresher were maximum at 100%, and the average system throughput increased from 37.98MT/hour to 45.04MT/hour (increase of 19.54%). The authors have demonstrated the capability of the developed simulation model to be used as a test bed for future studies.

Anyaocha et al. (2018) study three FFB processing routes, industrial (large-scale or mechanised mill), small-scale (semi-mechanised mill) and traditional (small holders) for producing CPO. The authors use analysis of variance, carried out using Statistica 12 software (Dell, USA) to study the effect of these three processing routes on fruit lost and

throughput. Results of their study showed that the industrial routes resulted in high throughput of FFB processed (4156000 kg) per hour, but high fruit lost. Hence, they suggest that to reduce the size of FFB prior to sterilization to ensure complete recovery of the fruits during the threshing operation and supply the threshed EFB from the industrial route to the local labourers for re-threshing and drying process.

Racedo-Gutiérrez et al. (2020) studied the effect of two fresh fruit bunches (FFB) unloading strategies (without and with extra unloading place) on the average and maximum time of a truck waiting at the palm oil mill. They used discrete-event simulation model developed in SIMIO to represent the unloading process at the mill. Results of their simulation study showed that a strategy with extra unloading place for vehicles in the system for more than two hours could reduce the average (1.8 hours) and maximum time (8.0 hours) of a vehicle in mill (thus reducing the overall processing time) by 23% and 35% respectively. The authors have demonstrated with simulation they are able to achieve critical improvements in waiting time and supplier satisfaction without major investments.

Sembiring and Ramzani (2020) investigated the effect of FFB quality, processing machines and labour skills on production throughput of a CPO plant. For the FFB quality criteria, the specific sub-criteria are fruit origin, transportation, harvest technology and mature fruit quality; for the processing machine the sub-criteria are type of technology and machine hours; while for labour skills the sub criteria are training/education, working hours and work experience. They use analytical network process method to rank the CPO mill productivity criteria. Results of their study showed that for improving production throughput, the highest ranking is FFB quality (0.49065), followed by labour skills (0.18253) and processing machines (0.33222). As for the sub-criteria the highest ranking is mature

fruit quality (0.1460), followed by working hours (0.14335), work experience (0.13636), transportation (0.13605), harvest technology (0.07132), machine hours (0.11121), fruit origin (0.09077), type of technology used (0.07132) and education/training (0.05251). Thus, the highest priority criteria in the productivity of palm oil processing factory is the quality of oil palm fruit with a global weight of (0.49065).

Setiawan and Prasetya (2020) investigated the effect of FFB grading methods (standard image processing and multispectral image processing) on the throughput of a palm oil mill. 19 LEDs with different wavelengths were used as source light. Using these different source lights, the FFB is captured using a camera to obtain the red green blue (RGB) image of the FFB. Results of their study showed that the multispectral image processing (940 nm wavelength) gave the best result for determining the maturity 23 level of the FFB thus increasing the palm oil mill throughput.

Sembiring et al. (2018) studied the effect of implementing engine maintenance schedule and 5s program on machine downtime and work environment in a palm oil mill. The authors used reliability centered maintenance method to determine the maintenance schedule of critical machine components with the application of 5S. Results of their case study showed that there are four components (bearing component at every 37 days, gearbox component at every 97 days, cake breaker conveyor (CBC) pen component at every 35 days, and conveyor pedal component at every 32 days) of the CBC machine that need to be maintained on schedule. With this schedule maintenance, the downtime of the cake breaker conveyor machine is reduced thus reducing the overall processing time. With regards to the 5S program, unused goods need to be moved from the production area and grouped based on their usage, there must be procedure for cleaning the production area and conducting

inspection for use of personnel protection equipment, all these leads to improved work environment.

Marimin and Zavira (2020) studied the effect of production conditions and machines criticality on production quantity of a palm oil mill. The authors goal programming method to define the optimal production and equipment criticality rating to rate the criticality of production components and. Results of their study showed that (i) increasing the productivity of palm oil plantation (11-12%), (ii) increases the CPO yield (0.21-0.23%), (iii) decreases the effect of maturity rate of FFB (2.5%); and (iv) fulfilling the required number of truck, could decreases free fatty acids by 2.43% and increases the number of production quantity by 8408247 tonne. As for the critical machines, results of their study showed that thresher, digester and boiler categorized as very critical; production activity would stop if the equipment from these stations are broken, and maintenance cost is high. The sterilizer is classified as critical; if any of the sterilizer components are broken, the acceptance of FFB would be affected. The engine room and clarifier are classified as quite critical; failure of these machines would have small impact on the production activity. Finally, FFB reception, fat-pit, and water treatment are classified as not critical; even if the components of machines/facilities are broken, production activity would not be impacted. Finally, the authors proposed to (i) improve crop rotation, (ii) rearrange the desired number of trucks from each oil palm plantation and (iii) change the box type for the truck from wood type to iron type which can decrease the FFA level of FFB.

Susilawati et al. (2019) studied the effect of critical factors (re-training the workers, improve worker motivation, increase the number of workers, improve quality work environment, quality of raw materials, replace wear and tear machine components) on the

overall equipment effectiveness (OEE) of the pressing station (hence throughput) of a palm oil mill. The authors use multi-criteria decision-making method based on Fuzzy AHP (Analytical Hierarchy Process) to identify the action needed to minimize the big losses. The causes of losses was also identified by using a fishbone diagram. Result of their case study shows the effectiveness value rate of 62.2% that was below the world class standard of 80%. The value rate of six big losses was set up and adjustment losses of 32.63%, equipment failure losses of 3.31 %, reduces speed losses 1.87% , idling and minor losses 1.87%, reduces yields / scrap losses of 0% and defect and rework losses of 0%. Thus, to handle this problem the authors proposed (i) improving the quality of raw material, (ii) replacing wear and damage of machine components, (iii) avoiding overloading, (iv) re-training the workers, (v) improving quality work environment, (vi) improving workers motivation and (vii) increasing number of workers.

Ishak (2020) investigated the effect of operational factors on the production yield of a palm oil mill that produces refined bleached deodorized palm oil. The authors used cause and effect diagrams to analyse the root cause of the problem and find the potential failures in the process by using failure mode effect analysis. Results of their case study showed that factors related to human (workers not properly setting up the machines with resolution priority value (RPN) of 105% and workers focus during worktime with resolution priority value (RPN) of 252%, raw materials (high free fatty acid content in the CPO with priority value (RPN) of 252% , process (CPO flow retained in the filter with RPN of 210%, filtration process too long with RPN of 90% and the final heating temperature of the blend palm oil did not reach the target with RPN of 288% and work method (duration of repair process with RPN of 224 % , duration of moving CPO input tank with RPN of 140 % and usage of different machine settings with RPN of 175 % RPN) affect the production yield of refined

bleached deodorized palm oil and must be managed properly. The author proposed improvement plan such as (i) ensuring the sorting and receiving of raw material are following standards, (ii) adding communication equipment and (iii) carrying out maintenance and continuous improvement.

Abdullah et al., (2021) investigated crucial factors that affect the overall equipment efficiency (OEE) in oil palm mill. The authors gathered data over a period of 3 years from field observation, production record and discussions. Results of their study indicated that the OEE performance of the palm oil mill ranged from 60% to 85% (at Level 2 relating to the world-class OEE scale) with availability rate of palm oil mill showing the lowest value (58.2%). The key factors that affect the availability rate are long waiting time and unscheduled maintenance activities.

Ishak et al. (2019) studied the effect of operational factors on the performance of palm oil mill. They used lean manufacturing and value stream mapping approach to identify activities that are considered as wastes. Results of their case study showed that fresh fruit bunch (FFB) sorting time at sorting station (1.19 minute), FFB stacking time in loading ramp (27.89 minute), unloading time lorry loads (18.88 minute) and CPO flowing time into storage tank (6.88 minute) are considered as non-value adding activities and need to be managed in order to improve processing time. Comparison with previous observation, shows that a non-value-added activity of 581.38 minutes decrease by 91.91 minutes to 489.47 minutes after improvement and process efficiency increase from 49.01% to 58.21% by 9.2%.

Lubis et al. (2020), studied waste problem in sorting process which involved weighing the palm fruit, moving the palm fruit to the sorting place, waiting for loading, and unloading of the fruit from the truck, loading and unloading and sorting fruit from the truck,

and the sorted fruit is put into the loading ramp door. The authors used value stream mapping (VSM) and process activity mapping (PAM) method to identify wastes in the sorting process. Their study revealed that non-value-added activities accounted for 72% of the total activities and process cycle efficiency of 27.33%. These non-value-added activities are moving oil palm fruit to the sorting area, waiting to be unloaded from trucks, loading, and unloading and sorting from trucks. Their study also showed that by eliminating the non-added-value activities, the value-added-activities increased to 47% and process cycle efficiency increased to 46.9%. The authors proposed improvements in the areas of human, materials, working method and working environment.

Fadilla et al. (2021), conducted case study to investigate the effect of waste activities on time losses, production inefficiencies, and quality damage to fresh fruit bunches (FFBs) and coconut palm oil (CPO). The authors used value stream mapping (VSM) to identify wasteful activities, 5W1H method to identify the causes of waste and the weighted product method (WPM) to determine the order of priority for improvement. Results of their study shows four activities where corrective actions can be taken; these are FFBs temporarily stacked while waiting for empty lorry from threshing station, the lorry waiting to be lifted using a hoisting crane, CPO deposition in the sand trap, and CPO in the storage tank waiting to be filled into the delivery truck. Based on the improved design, results showed that manufacturing lead time decreased from 1185.70 minutes to 1069.73 minutes, and the process cycle efficiency value increased from 67% to 74%.

Pratama and Susilawati (2021) studied the effect of wastes on productivity of CPO. The authors use values stream mapping (VSM) and process activity mapping (PAM) approaches to identify wastes in the process flow of CPO production. Their study showed

wastes are related to FFB quality, work machines/equipment, work environment and work method; the biggest waste contributor was the quality of FFB. After improvements to several stations (sorting, loading rams, sterilizer, purification and storage) the average productivity is 76.67%, and the CPO processing time is reduced from 1.981 seconds/kg to 1.963 seconds/kg.

Rizkya et al., (2020) conducted waste analysis for improving manufacturing lead time of palm oil production process. The authors conducted observations at the palm oil mill, employed value stream mapping (VSM) to identify various wastes and fishbone diagram to analyze causes of waste. Results of their study showed that in terms of manufacturing lead time 47% of activities were value-added, 13% non-value-added, and 40% necessary non-value-added. These wastes are found in the areas of transportation, inventory, motion, and waiting.

Minarni et al. (2023), studied the use of computer-based vision to automatically count oil palm fresh fruit bunches (FFB) moving on a conveyor. Computer vision could improve efficiency and accuracy in estimating daily mill throughput capacity. The computer base vision consists of a system Red Green Blue (RGB) camera, a bucket moving conveyor, and a Python based counting program using OpenCV library. Results of the study shows that the detector and tracker algorithms were able to count FFBs with up to 100% accuracy, depending on FFB color and lighting conditions. Also, the average counting accuracy over all 10 videos was 79.35%. The system could be applied in palm oil mills to estimate capacity and improve efficiency.

Solichin et al. (2020), studied prediction of crude palm oil (CPO) production using time series data mining approaches. Specifically, the authors compare three algorithms - multilayer perceptron (MLP), support vector regression (SVR), and linear regression (LR) - to determine the best method for predicting CPO production based on fresh fruit bunches (FFB) input data. The three algorithms are tested in RapidMiner and compared based on predicted trend accuracy (PTA), mean squared error (MSE), mean absolute percentage error (MAPE), and mean absolute deviation (MAD). Results shows that support vector regression achieved the best accuracy with MSE of 1,146, MAPE of 47.5%, MAD of 22.3, and PTA of 0.694 compared to MLP and LR. The SVR algorithm was used to develop a prototype prediction system which achieved a software quality score of 80.2 out of 100.

Ojeda-Safra et al. (2021) proposed a model that integrates 5S philosophy, visual management and control automation & work standardization to increase efficiency of palm oil production. The proposed model was modelled and simulated in ARENA simulator. The proposed model was tested in a palm oil processing company faced with problems of high loss and waste levels, out-of-specification product, and manual station delays. Results of the study showed that after implemented of the proposed model, the extraction rate, increase by 7.1% (from 21.83% to 23.37%) due to the fact that losses were reduced from 3.1% to 1.6%, out-of-specification oil production was reduced from 7.6% to 3.8%, and downtimes were reduced by 30%.

Samri et al. (2023) conducted simulation-based study on production process efficiency of a palm oil production company. The existing production process was modelled within the ProModel simulation platform and used to detect problems. Proposals for solving the problems were incorporated into proposing a new design for the production process.

Results of the simulation showed that improving the production process by reducing from 13 to 8 processes yielded an increase in total production from 79.5% to 98.77%. In terms of total location utilization, simulation results showed that with the new design, the potential efficiency of ramp utilization is 100% (existing is 30.52%), bunch sterilization is 64.58% (existing is 22.73%), bunch threshing is 32.29% (existing is 19.76%), pressing is 2.70% (existing is 61.93%), oil clarification is 33.33% (existing is 8.75%), kernel recovery is 22.92% (existing is 7.77%), purifying is 52.21% (no existing), silo is 50.31% (no existing), and kernel extraction is 21.09% (existing is 7.77%). The authors have demonstrated the benefits of using simulation to increase total production and location utilization.

Fauzi et al. (2021) studied palm oil dilution and clarification in a clarifier with the aim to minimize oil loss at the clarifier outlet. The authors used computational fluid dynamics (CFD) to simulate the fluid condition inside a clarifier. They simulate three parameters which are inlet flow velocity, temperature of the clarifier and inlet oil mass fraction. Comparison of simulation data with actual data showed an error of 12.4%. When simulating the clarifier with average-size mesh, (i) the value of outlet oil mass fraction decreased with temperature, (ii) the value outlet oil mass fraction decreased with inlet flow velocity, and (iii) the outlet oil mass fraction increased with inlet oil mass fraction. They conclude that all input parameters significantly affect the outlet oil mass fraction.

Pakdeechot et al. (2021), investigated sterilisation of palm fruit bunch by direct steaming in mini steriliser combined with a boiler becoming one unit. They experimentally studied the effect of sterilisation time on fruit-bunch separation and crude palm oil yield and quality. The pressure in the steriliser/boiler unit was held constant at $2.5 \text{ bar} \pm 0.2 \text{ bar}$ while sterilisation time was varied at 30, 45, 60 and 75 minutes, including initial heating. Three

FFBs bunches were selected 3 for every condition with similar size, weight and ripeness. Results of their study showed that the percentage of fruit-bunch separation and crude palm oil yield increased when sterilization time was longer. Also, the CPO quality was acceptable by commercial CPO quality standards.

Hermantoro et al. (2023), experimentally studied separation of fiber/mesocarp from the palm kernel before the pressing process with the aim to completely extract the oil in the fruit flesh (mesocarp). The authors experimented with different levels of pressure (60 Bar, 70 Bar, and 80 Bar) to examine the effect on oil lost in fiber (%) during the extraction process. Their experimental results showed that the oil loss percentages varied across the different pressure values. The average oil losses (%) were 13.22%, 9.34% and 7.36% when the pressing pressure were 60 Bar, 70 Bar, and 80 Bar, respectively. Based on the developed regression equation the authors predicted that the minimum oil lost could be obtained at pressure of 220 bar.

Fadhilah et al. (2024), conducted experimental study on the effect of different sludge separator parameters on oil losses. parameters (feeding rates, oil underflow, and temperatures of flow rate) on the amount of oil lost. The authors used random group design method to design the experiment, oil extraction method to test the oil losses and analysis of variance to assess effect of different parameters on oil losses. Results of their studies showed the optimal process parameters values are a feed rate of 23 ton/h, temperature of 90°C, and oil underflow of 5%, resulted in oil losses of 0.54-0.61% (a decrease of oil losses by an average of 0.11%).

Kumaradevan et al. (2014) studied operational parameters that influence the quality (% of FFA in oil) and yield of CPO (% of oil in condensate) extracted during sterilisation process. The operational parameters are FFBs ripeness, number of days before FFBs treatment and the number of pressure peaks applied in the sterilisation process. Results of their experimental study showed that the percentage of FFA and oil increase with the percentage of over ripe fruits. When the percentage of over ripe fruit is 25%, the percentage of FFA and oil in condensate are 4.8% and 4.6% respectively. When the percentage of over ripe fruit is 17%, the percentage of FFA and oil in condensate are 3.7% and 2.9% respectively; the pressure peak were 3. Also, when the storage time is increased from two to three days, the FFA percentage increased from 4.7% to 5.8%. Decreasing the number of pressure peaks resulted in reducing the percentage of oil in condensate; 3.9% when the pressure peaks were two. The authors highlighted the importance of timely processing within two days to maintain acceptable FFA levels. Finally, they proposed that FFBs should be consistent in ripeness and the used of automation to properly distribute and handle FFBs at the loading ramp.

Junaidah, et al. (2015), studied the effect of FFBs sterilisation conditions at different degrees of ripeness on the free fatty acid (FFA). Specifically, the authors experimented with a range of sterilisation temperatures ($100^{\circ} - 120^{\circ}$) and times (20 – 80 minutes) and examined the effect on FFA content for four FFBs ripeness (under ripe, ripe, over ripe, loose). Results of their experimental study showed that for under-ripe and ripe FFBs, the temperature exerted higher and significant ($p < 0.05$) influence on FFA values as compared to time. For both over ripe and loose FFBs, both temperature and time exerted significant influence on FFA values. Furthermore, the optimum sterilising conditions for underripe FFBs and ripe FFBs were at the combination of 100°C for 20min and 100°C for 80min, respectively. Both

overripe FFBs and loose fruits recorded similar optimum condition, i.e. 120°C and 20 min. For these optimum process conditions, the predicted low FFA values were 0.619%, 1.052%, 1.751% and 3.160% for under ripe FFBs, ripe FFBs, over ripe FFBs and loose FFBs, respectively.

Kiggundu and Jjagwe (2021) studied the performance of a motorised oil extraction machine to that of a manual vertical press. The authors design an oil extractor machine that consisted of four major components, the feeding component, extraction component, power component and the frame. The feeding component consisted of the hopper; the extraction component consisted of the worm screw shaft, the perforated frustum barrel (squeezing chamber) and both the oil and residual outlets; the power component consisted of the prime mover (geared motor) and the chain while the frame served as a stand for the machine on which all other components were mounted. Result of showed there were significant differences ($p<0.05$) in oil extraction rate, OER (motorised, 16.20% and manual, 13.53%), oil extraction efficiency, OEE (motorised, 77.13% and manual, 64.44%) and oil extraction loss, OEL (motorised, 18.30% and manual, 24.76%).

Figure 2.2 conceptualised the process factors described above. These process factors are raw materials (arrival, fruit origin, mature fruit quality, grading methods, unloading procedures, processing routes), workers (skills, numbers of, motivation, working hours, work experience, education & training), process (critical or noncritical), processing machines (critical machines, transportation, machine hours, type of technology used, processing time, optimum setting), machine components (maintenance schedule, replacement, criticality), and work method (duration of repair process, duration of moving CPO input tank and usage of different machine settings).

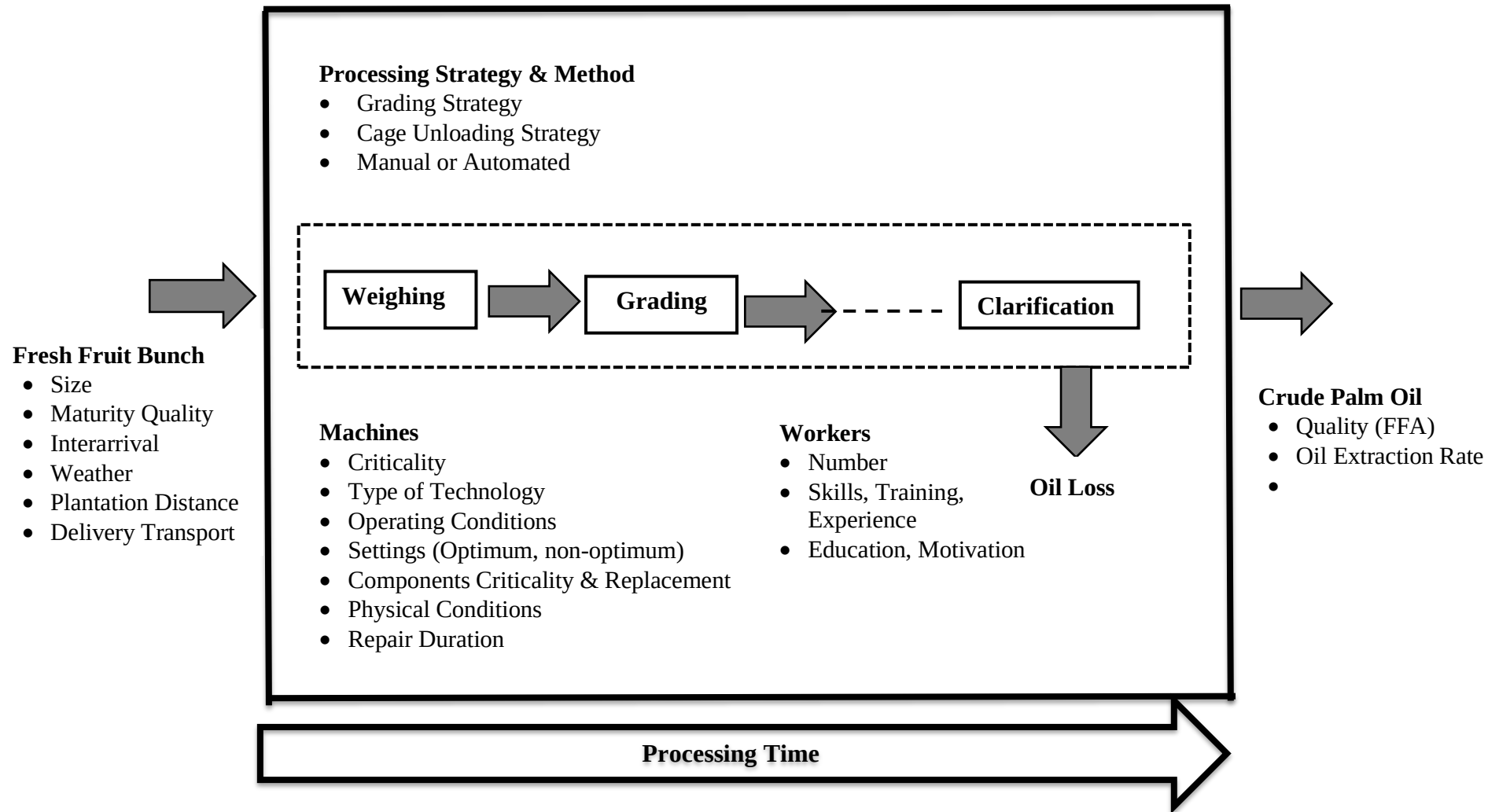


Figure 2.2: Conceptual Framework For Process Factors Affecting Performance of Crude Palm Oil Production System

2.3.3 Identification of Research Gap

As stated above in subsection 2.3.2, it is established that (i) there are many process factors that exist within the CPO production system, as conceptualised in Figure 2.2, (ii) these process factors affect the performance of CPO production system in terms of processing time, production quantity (throughput), free fatty acid (FFA) content, oil losses and oil extraction rate (OER), (iii) individual effect of these process factors on performance of CPO production system have been widely studied (iv) interaction between process factors effect on performance of CPO production system has not been widely studied, (v) research tools used have been mostly fit for research gap (analysis of variance, value stream mapping approach combined with process activity mapping, analytical network process method, goal programming, RGB image processing, equipment criticality rating, fuzzy analytical hierarchy process, caused and effect diagrams, computer vision combined with programming, time series data mining, experiment).

Given the (i) existence of many process factors within the CPO production system, (ii) performances of CPO production system are affected by these process factors, (iii) lack of studies on interactions between process factors effect, then there is a need to study these many process factors amongst other factors (multiple process factors). To effectively study this multiple process factors with possibility of interactions amongst them, would require a unique approach than those in previous studies cited in subsection 2.3.2.

This unique approach needs to be able to allow (i) modelling the overall CPO production process, (ii) modelling multiple process factors simultaneously, (iii) conducting systematic experiment with the CPO production system stated in (i), (iv) conducting systematic statistical analysis of CPO processing time. In this sense, combination of discrete

event simulation modelling, design of experiment (DOE) and analysis of variance (ANOVA) is the unique research approach proposed. Thus, a study that models, experiments and analyse multiple process factors that employs a combination of discrete event simulation modelling with design of experiment (DOE) and analysis of variance (ANOVA) becomes the research gap for this study. The outcome of this study would benefit the palm oil industry greatly production planning and control activities.

Figure 2.3 illustrates the identification of research gap for this study. As stated in subsection 1.2, 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 measures this this is defined as the total time taken to process one batch of fresh fruit bunches (FFBs) to crude palm oil, henceforth the termed CPO processing time will be adopted throughout the thesis.

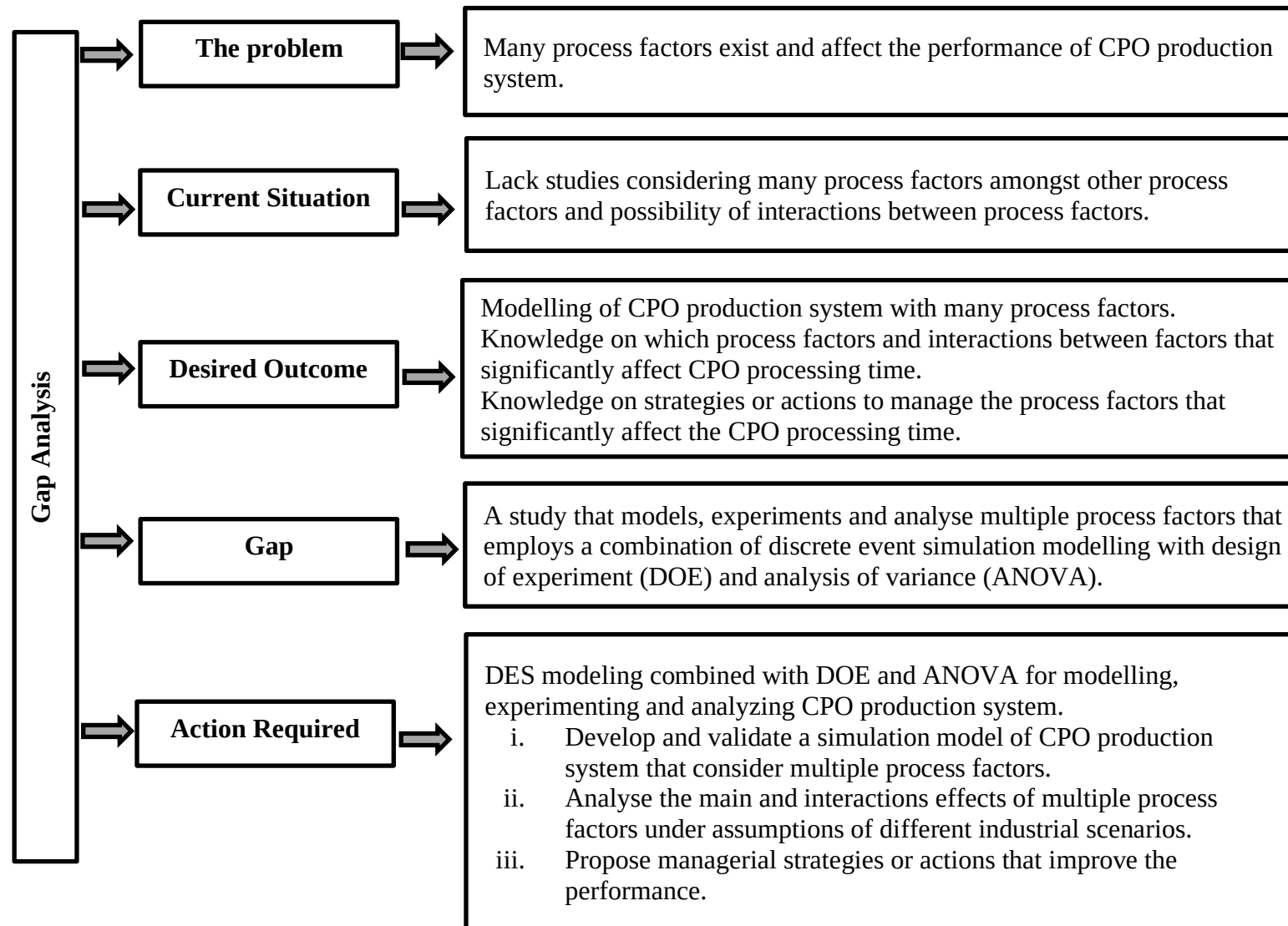


Figure 2.3: Framework for Identification of Research Gap

2.4 Discrete Event Simulation (DES) Modelling

2.4.1 Application of Discrete Event Simulation (DES) Modelling in Various Industries

Simulation technique is widely used in modeling and analysis of decision-making models for industries such as manufacturing and service industries. This wide usage is due to the simulation's ability to allow the analyst to manipulate variable factors and observe changes in key performance indicators of interest (Kelton et al., 2015; Sturrock, 2019; Mourtzis, 2020).

In addition to literatures discussed in subsection 2.3.1, examples of literatures on simulation technique for modelling and analysis of decision-making models for manufacturing system are published by Jilcha et al. (2015); Packianather et al. (2016); Ali and Zulkifli (2017); Kumar et al. (2018); Kusoncum et al. (2018); Neeraj et al. (2018); Nithin et al. (2018); Sarda and Digalwar (2018); Yuan and Zhang (2018); Almamlook et al. (2019); Baihaqy (2019); Riskadayanti et al. (2019); Sharma and Jayant (2019); Sime et al. (2019); Yasir et al. (2019); Abdulatif et al. (2020); Ashenafi and Geremew (2020); Banga et al. (2020); Calderón-Andrade et al. (2020); Filz et al. (2020); Pattar et al. (2020); Sujova et al. (2020); Zabidi et al. (2020); Al-Tahat et al. (2021); Laroque et al. (2021); Moreira and Silva (2021). For literatures on simulation modeling and analysis of service providing system, these can be found in publications by Baril et al. (2020); Hasugian (2020); Hasugian and Supriadi (2020); Jayaprakash and Teshome (2020); Kamarudeen et al. (2020); Tasar et al. (2020); Pérez et al. (2021); Su et al. (2021); Shakoor et al. (2021); Yemane et al. (2021); Szufel et al. (2022); Tamizhinian and Pillai (2022). However, there is very limited literature that report on the application of simulation technique to study the performance of crude palm

oil production system; these few examples are publications by Mohd-Lair et al. (2012), Escallón-Barrios et al. (2020); Racedo-Gutiérrez et al. (2020) and Ojeda-Safra et a. (2021).

2.4.2 Fundamental of Discrete-event simulation (DES) modelling

Discrete-event simulation (DES) refers to modelling of a system in which the state variables of the system change instantaneously at separate points in time, when an event has occurred (Choi & Kang, 2013; Banks et al., 2014; Law, 2015). DES are commonly used as a tool for modelling the operations of queueing-based manufacturing systems.

A simple queueing system (Figure 2.4) reported in Choi and Kang (2013) consists of a machine and a buffer in a factory. The dynamic of the system may be described as follows; (1) a job arrives at the system with an inter-arrival time of t_a , and the job is loaded on the machine if it idle; otherwise, the job is put into the buffer; (2) the loaded job is proceed for a service time of t_s and unloaded; (3) when a job is unloaded, the next job is loaded if the buffer is not empty. In this Figure 2.2, the state variables of the system are q and m , where q is the number of jobs in the buffer and m denotes the status (Idle or Busy) of the machine, and the events are Arrive, Load and Unload.

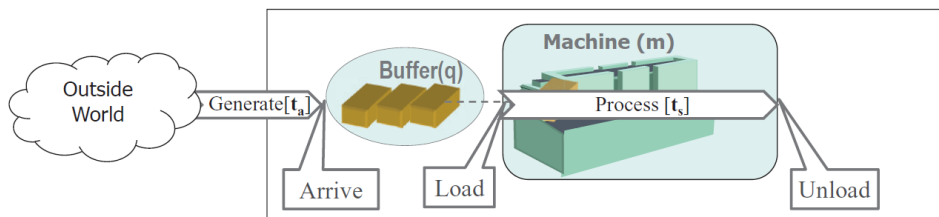


Figure 2.4: A single server system model

Law (2015) specifically described simulation process of a single server queueing system (Figure A2.1, Appendix A) as follows; (i) the simulation process would begin in the

“empty- and-idle” state i.e., no customers are present, and the server is idle, (ii) At time 0, would be waiting for the arrival of the first customer, which will occur after the first interarrival time, A_1 , (iii) assuming the n th customers have entered the service and completed their delays in queue, then simulation would stop. The *time* the simulation ends is a random variable, that depends on the observed values for the interarrival and service-time random variables.

Law (2015) also stated that the performance of this system could be measured through three quantities, namely, (i) the expected average delay in queue of the n customers completing their delays during the simulation, (ii) expected average number of customers in the queue (but not being served), (iii) the expected utilization of the server (the expected proportion of time during the simulation, from time 0 to time $T(n)$, that the server is busy (i.e., not idle), and is thus a number between 0 and 1.

In addition, Kelton et al. (2015) stated that for simulation of production / processing system, the output performance measures are (i) total production (the higher the better), (ii) average waiting time in queue of parts, (iii) maximum waiting time in queue of parts (the smaller the better), (iv) time-average number of parts waiting in the queue (the smaller the better), (v) the maximum number of parts that were ever waiting in the queue (the smaller the better), (vi) average and maximum total time in system, also called cycle time (the time that elapses between a part’s arrival and its departure), the smaller the better, (vii) the utilization of the resource (machine), defined as the proportion of time it is busy during the simulation, close to 1 (high is better).

There are numerous areas in which discrete event simulation is used for decision making related to design, analysis, and evaluation of the system of interest. Examples are

manufacturing, communication, transportation industries, inventory management (Banks et al., 2014; Law (2015), service, defense, mining industry and supply chain Law (2015), emergency response, criminal justice, and insurance claim system Kelton (2015).

Banks et al. (2014) stated that DES mimic what happens in the real system and provide the modeler the output data based on the real system input data. Also, DES provide a good solution for design or analysis of any system, allow modeler to simulate very detail of operation for manufacturing and supply chain, and better and easier modelling of human activities. In addition, according to Law et al. (2015) DES enable investigation of complex-real world system, allow performance estimate of an existing system under some assumed set of operating conditions, better control over experimental conditions compared to experimenting with the system itself, and allow long time or compressed time study of a system.

On the other hand, DES is without disadvantages. Law et al. (2015) pointed out that simulation models are often expensive and time consuming to develop, each run of a stochastic simulation model produces only estimate of a model's true characteristics for a particular set of input parameters, the persuasive impact of a realistic animation often creates a tendency to place greater confidence that the result is justified, and unless the model is valid, it will provide little useful information about the actual system.

2.4.3 Pieces of a simulation model

Pieces of a simulation model

The concepts of the simulation model are usually explored in the different parts or pieces of the simulation model. According to Kelton et al. (2015) and Rossetti (2016) the different pieces of a simulation model are entities, attributes, global variables, resources,

queues, statistical accumulators, events, simulation clock, and starting and stopping. These are further elaborated as follows.

Entities are (i) created, move around and then disposed of as they leave, (ii) dynamic object that change status, affect, and affected by other entities, (iii) represent the “real” thing in a simulation, can come from a group and then processes individually, or they might start out as individual units that are formed into groups. An **attribute** (i) is one of the common characteristics of all entities and is different from one entity to another, (ii) have different values for different entities, as their value are tied to specific entities. The global variable is defined as a piece of information that reflect a few characteristics of the system.

Variables (i) can be many but each one is unique, (ii) not tied to any specific entity and can be access by all entities at a large system, (iii) can define as something that can change during the simulation run and acting as vectors or matrices to organize the information as list or two-dimensional tables. **Resources** represent personnel, equipment, space in a storage area.

Queues (i) occur when entity can’t move on, when it needs to seize a unit of a resources which is being tied up by another entity, then it needs a place to wait, (ii) represent capacities that have limited floor space for a buffer. The **statistical accumulator variables** (i) are intermediate variable that needed to be kept track of, (ii) could represent the number of parts produces, the total of the waiting time in queue and the longest of the time spent in queue.

An **event** happened at an instant of (simulated) time that will change the attributes, variables, or statistical accumulators. Three types of **events** are (i) Arrival, (ii) Departure and (iii) The End. An Arrival event can be described as a new part that enter the system. The

departure event represents a finishes part at its service and leave the system. The End event also can be represented as change things and can be used to stop a simulation when the simulation stopped at time. The **simulation clock** (i) is the current value of time in the simulation and held in a variable, (ii) lurches from the time of one event to the time of the next event scheduled to happen, interacts closely with the event calendar. Finally, the start and stop determine how the simulation starts and stops.

2.4.4 Verification, Validation, Warm Up Period and Number of Replications

Verification is the process of making sure that the simulation model behaves in the way it was intended according to the modelling assumption made, also known as debugging the model (Kelton et al., 2015). This is very important to ensure that the conceptual model's assumptions have been correctly translated (coded) into a computer "program or the computer program are without errors; errors could be improper flow control or entity creation, failure to release resources, and incorrectly observed statistics (Rossetti, 2016). An easy verification method is allowing a single entity to enter the system and using the widely popular technique, animation to observe the entity to make sure that the model logic and data are correct. Verification can be done by conducting long simulation runs which can cover many years for different data and observing results for potential problems.

Validation is an important process to ensure the simulation model behaves the same way as the real system and enables the modeler to find any bottlenecks in the simulation model that does not happen in the real system (Kelton et al., 2015). This is conducted by statistically compare the output performance from the simulation model to the output collected from the real system and analyze whether there is a significant difference between the two (Rossetti, 2016). If record or results from the real system does not exist, then

validation can still be done using sensitivity analysis which involves changing the values of the input and internal parameters of a model to determine the effect on the model's behaviour or output (Sargent, 2020), this known as qualitative method. This method assumes that qualitative knowledge about certain parts of a simulation model is known and the direction in which certain factors affect the response variables.

In any simulation run, the model will initially start out empty of entities and all the resources are in idle state. During this initial period, the output performance from any simulation model would be biased, either on the low or high value (Kelton et al., 2015). To avoid this biased output, the simulation model needs to be initialised in a state that is better or beyond the empty and idle state. In other words, the simulation model is run and allowed to warm-up for a while until the effects of initial conditions have worn off. The after this warm-up period, the value of any output would be stable or not biased.

One method to determine the warm-up period is the graphical method introduced by Welch (Law, 2015). In this method, (i) make n replications (say $n=10$) with replication length (m) as large as practical, m should be larger than the anticipated value of I , (ii) plot any key output from the simulation model for all n replications and observe the smallest window, w ($m-l$) or longest warm-up period (l) and the plot appear to stabilize, (iii) if no value of w or l in step 2 is satisfactory then repeat step 1 and 2. In addition, the average key output obtained from using appropriate n replications and warm-up period must have small half-width (Chung, 2003). The warm-up period should be done for each key output if the modeler wants to investigate multiple output performance. In addition, the warm-up period and replication length should be determined for different alternatives of simulation models.

2.4.5 Simulation Project Life Cycle

There are six important phases in the general simulation project life cycle, as shown in Figure 2.3 (Rossetti, 2016). Complying to these six phases would ensure that the simulation project would be carried out successfully and achieve the project objectives.

The first phase, problem formulation starts with problem definition which involves representing the problem as accurately and concisely as possible. Also, the system under investigation must be defined with corresponding output performance metrics, the conceptual model is defined and developed and assumptions are documented.

The second phase, simulation model development, starts with translating the conceptual model into the equivalent simulation model. This involves coding the simulation model with relevant input data. Next the simulation model is verified and validated. The validation could be done using a technique known as the sensitivity analysis. This analysis refers to a technique used to assess the impact of changes in input parameters or assumptions on the output of a simulation model. This sensitivity analysis would help in understanding how variations in input parameters affect the simulation output.

The third phase, experimental design, and analysis, involves preliminary runs, if the preliminary runs are insufficient to achieve the project objectives, then design of experiment need to be revised. Then the final experiments are executed, followed by statistical analysis of results.

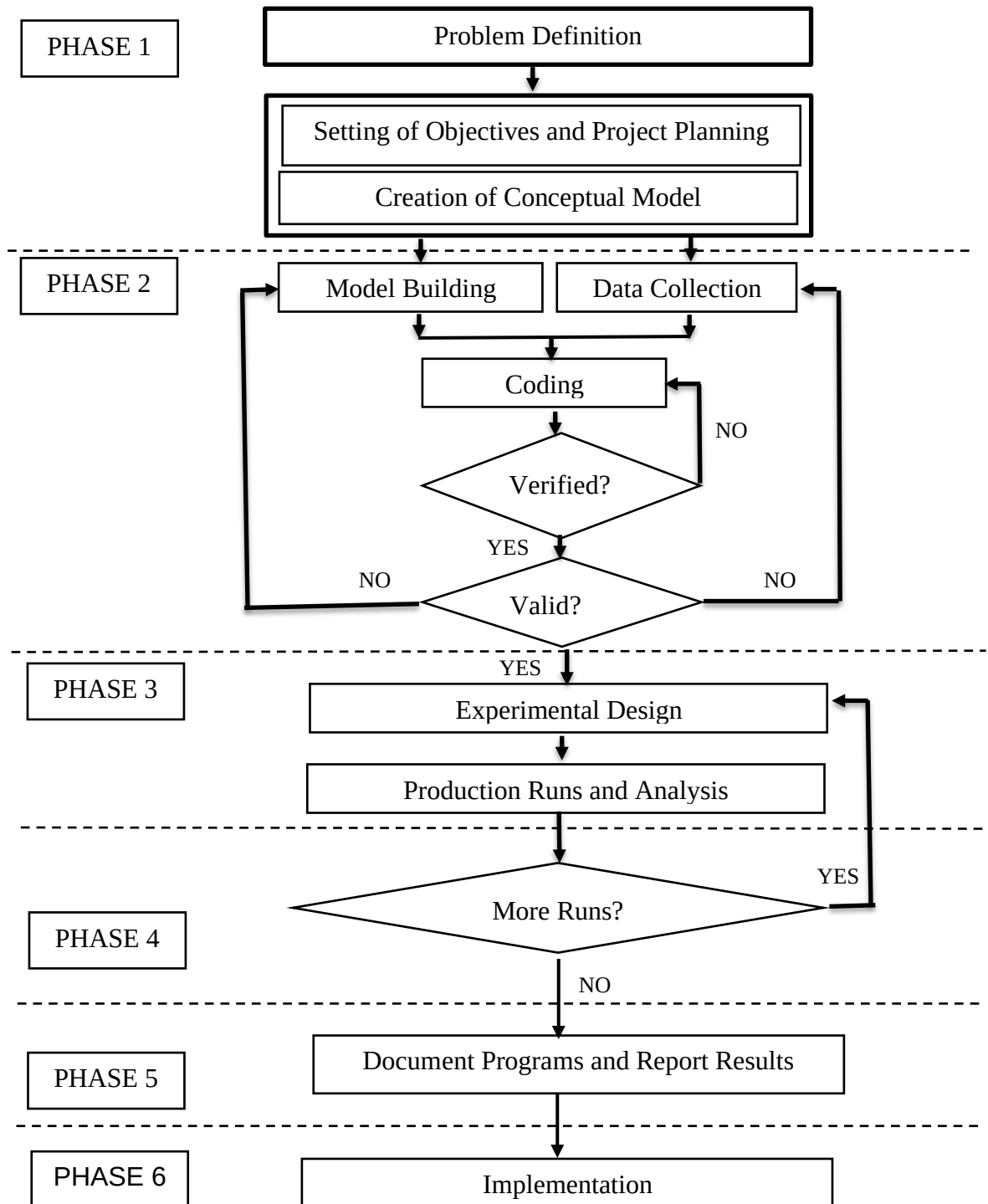


Figure 2. 5: General methodology for simulation project life cycle

If simulation has achieved the objectives, then the programs can be documented in a technical and user manual and reporting the results. If not, then iteration is necessary which involves, additional data, models, experimentation, or analysis.

Finally, the last phase involves implementing the recommended solutions, and evaluating if the intended objectives are achieved after implementation.

2.5 Statistical Design of Experiment (DOE), Factorial Experimental Design, Fractional Factorial Design and Analysis of Variance (ANOVA)

2.5.1 Statistical Design of Experiment (DOE)

Statistical design of experiments is a process to planning the experiment so that appropriate data will be collected and analyzed by statistical methods, resulting in valid and objective conclusions (Montgomery, 2020). The outcomes of this experiments lead to improved process yield, reduced variability in the process and nearer target requirements, reduced design and development time and reduced cost of operation Montgomery and Runger (2018). It also allows experimenters to determine which subset of the process variables has the greatest influence on the process performance (Montgomery & Runger, 2018).

In Engineering some of the typical applications of statistically designed experiments are evaluation and comparison of basic design configurations, evaluation of different materials, selection of design parameters and determination of key product design parameters (Montgomery & Runger, 2018). For the service industry, typical applications logistics, marketing, retail, healthcare, education, and after sales (Anthony, 2014).

The experiments are usually carried out sequentially (Montgomery & Runger, 2018), where the first experiment (screening experiment) has many controllable variables designed

to determine those variables that are most important. Next, experiments are used to refine this information and determine which adjustments to these critical variables are required to improve the process. Finally, experiments are carried out to determine those levels of the critical variables that result in the best process performance. The general approach to planning and conducting the experiment is known as experimentation strategy; for experiments with several factors the strategy is factorial design. In design of experiment, factors refer to the process variable which could be controlled or could not be controlled, whereas response variables are the output performance of interest. The factor levels refer to the high and low values of process variables being investigated.

2.5.2 Factorial Experimental Design

A factorial experiment is defined as an experiment where in each complete trial or replicate of the experiment, all possible combinations of the levels of the factors are investigated (Montgomery & Runger, 2018). The simplest factorial design, known as the 2^2 factorial design, has two factors with each factor has two levels. In general, if there are k factors, each with at two levels, the factorial design would require 2^k runs. When the number of factors in a 2^k factorial design increases, the number of runs required for a complete replicate of the design rapidly increases. For more than four or five factors, it is not necessary to run all possible combination of factor levels. In this case, the fractional factorial experiment can be implemented to run a subset of the complete runs.

Two-factor factorial design:

Using an example given by Montgomery and Runger (2018), a 2^2 two factor factorial design is explained as follows. Supposed that there are two factors A and B with a levels of factors A and b levels of factor B . For each of n experiment replications, there will be ab

treatment combinations. The effect of factor A is defined as the change in response produced by a change in the level of factor A . This is known as the main effect because it refers to the primary factors in the study.

Referring to Table 2.1, Factors A and B at two levels ($ALow$, $AHigh$, $BLow$, $BHigh$). The main effect of factor A is the difference between the average response at high level of A and the average response at the low level of A . From Equation 2.1, changing factor A from the low level to the high level causes an average response increase of 20 units. Similarly, the main effect of factor B is the difference between the average response at high level of B and the average response at the low level of B . From Equation 2.2, changing factor B from the low level to the high level causes an average response increase of 10 units.

Table 2.1: A Factorial Experiment with Two Factors

	Factor B	
Factor A	$BLow$	$BHigh$
$ALow$	10	20
$AHigh$	30	40

The main effect of Factor A

Equation 2.1

$$= \frac{(A_{high})(B_{low}) + (A_{high})(B_{high})}{2} + \frac{(A_{low})(B_{low}) + (A_{high})(B_{low})}{2}$$

$$A = \frac{30 + 40}{2} - \frac{10 + 20}{2} = 20$$

The main effect of Factor B

Equation 2.2

$$= \frac{(A_{low})(B_{high}) + (A_{high})(B_{high})}{2} - \frac{(A_{low})(B_{low}) + (A_{high})(B_{low})}{2}$$

$$B = \frac{20 + 40}{2} - \frac{10 + 30}{2} = 10$$

To determine the presence of interaction between factor A and B, further calculations are needed. The effect of A at low level of B and high level of B are given by Equation 2.3 and 2.4 respectively. Equations 2.3 and 2.4 show that the effect of A at both low & high level of B are the same, which is 20 units. Similarly, the effect of B at low level of A and high level of A respectively are given by Equations 2.5 and 2.6; these Equations show that the effects are the same that is 10 units. In this case, since the effects of A at both low & high B are the same and the effect of B at both low and high A are the same, then plotting these effects would produce parallel lines (Figure A2.2, Appendix A), which indicates that there is no interaction between factor A and B.

$$A = (A_{high}) - (A_{low}) \quad \text{Equation 2.3}$$

$$A = 30 - 10 = 20$$

$$A = (A_{high}) - (A_{low}) \quad \text{Equation 2.4}$$

$$A = 40 - 20 = 20$$

$$B = (B_{high}) - (B_{low}) \quad \text{Equation 2.5}$$

$$B = 20 - 10 = 10$$

$$B = (B_{high}) - (B_{low}) \quad \text{Equation 2.6}$$

$$B = 40 - 30 = 10$$

However, in some experiments, the difference in response between the levels of factor *A* is not the same at all levels of factor *B*, then in this case interaction occurs between factor *A* and *B*. Referring to the data shown in Table 2.2, the *A* effect at low level of *B* is given by Equation 2.7 (20 units), and the *A* effect at high level of *B* is given by Equation 2.8 (-20 units). The effect of *B* at low level of *A* is given by Equation 2.9 (10 units) and the effect of *B* at high level of *A* is given by Equation 2.10 (30 units). In this case, since the effects of *A* at both low and high *B* are not the same and the effects of *B* at both low and high *A* are also not the same, then plotting these effects would produce none parallel lines (Figure A2.3 Appendix A), which indicates that there is interaction between factor *A* and *B*.

Table 2.2: A Factorial Experiment with Interaction

	Factor B	
Factor A	<i>BLow</i>	<i>BHigh</i>
<i>Allow</i>	10	20
<i>Ahigh</i>	30	0

$$A = (A_{high}) - (A_{low}) \quad \text{Equation 2.7}$$

$$A = 30 - 10 = 20$$

$$A = (A_{high}) - (A_{low}) \quad \text{Equation 2.8}$$

$$A = 0 - 20 = -20$$

$$B = (B_{high}) - (B_{low}) \quad \text{Equation 2.9}$$

$$B = 20 - 10 = 10$$

$$B = (B_{high}) - (B_{low}) \quad \text{Equation 2.10}$$

$$B = 0 - 30 = -30$$

Two-Level Fractional Factorial Designs:

As stated earlier on if there are four, five or more factors, it is not necessary to execute the complete run, for example if there are 6 factors, then 64 runs need to be executed. In this case the fractional factorial design can be implemented. This fractional factorial design works on the assumption that certain high-order interactions are negligible, thus information

on the main effects and low-order interactions may be obtained by running only a fraction of the complete factorial experiment (Montgomery, 2020). The major application of fractional factorial design is in screening experiments, particularly when there are many factors to be considered.

The general, purpose of fractional factorial design is to determine the initial factors that have little or no effect on the response. There are several types of fractional factorial design, namely the one-half fraction of the 2^k design, the one-quarter fraction of the 2^k design and the general 2^{k-p} fractional factorial design. An important concept related to fractional factorial design is design resolutions. Montgomery (2020) stated that designs of resolution III, IV and V are particularly important and give the definitions as follows.

Fractional factorial with resolution III designs, has no main effects that are aliased with any other main effect, but the main effects are aliased with two factor-interactions and some two-factor interactions may be aliased with each other. For resolution IV designs, no main effect is aliased with any other main effect or with any two-factor interaction, but two-factor interactions are aliased with each other. Finally, the resolution V design, has no main effect or two-factor interaction that is aliased with any other main effect or two-factor interaction, but two-factor interactions are aliased with three-factors interactions.

The higher the resolution, the less restrictive the assumptions that are needed regarding which interactions that are negligible to obtain a unique interpretation of the results, thus the better option. Montgomery (2020), provide a Table (Table A3.3, Appendix A) with a selection of 2^{k-p} fractional factorial designs for ≤ 15 factors and up to $n \leq 128$ runs. This table can be used to design fractional factorial experiments with the highest possible resolution.

2.5.3 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a method used to compare means when there are more than two groups of means. Montgomery and Runger (2018) demonstrated that for factorial design, with two (2) factors, A (with a levels) and B (with b levels), the experiment is replicated n times, then ANOVA is used to test hypotheses for the main factor's effects of A and B and the AB interaction. The null hypotheses are there is no main effect of factor A , B and interaction between AB , which are shown respectively in Equation 2.11, 2.13, 2.15. Failure to reject the null hypotheses means that there is main effect of factor A , B and interaction between AB , as shown respectively in Equation 2.12, 2.14, 2.16.

Factor A

$$H_0: \tau_1 = \tau_2 = \dots = \tau_a = 0 \quad \text{Equation 2.11}$$

$$H_1: \text{at least one } \tau_i \neq 0 \quad \text{Equation 2.12}$$

Factor B

$$H_0: \beta_1 = \beta_2 = \dots = \beta_a = 0 \quad \text{Equation 2.13}$$

$$H_1: \text{at least one } \beta_i \neq 0 \quad \text{Equation 2.14}$$

AB Interaction

$$H_0: \tau\beta_{11} = \tau\beta_{12} = \dots = \tau\beta_{ab} = 0 \quad \text{Equation 2.15}$$

$$H_1: \text{at least one } \tau\beta_{ij} \neq 0 \quad \text{Equation 2.16}$$

Where,

τ_1 is the mean at level 1 of factor A

β_1 is the mean at level 1 of factor B

$\tau\beta_{11}$ is the mean at level 1 of factor A and B

The ANOVA table for a two-factor factorial is shown in Table A2.1 (Appendix). For factor A , the null hypothesis is rejected at the α level of significance if $f_0 > f_{\alpha, a-1, ab(n-1)}$. As for factor B , the null hypothesis is rejected at the α level of significance if $f_0 > f_{\alpha, b-1, ab(n-1)}$. Finally, for the interaction between A and B , the null hypothesis is rejected at the α level of significance if $f_0 > f_{\alpha, (a-1)(b-1), ab(n-1)}$. Test for interaction is performed first; if interaction is not significant, the interpretation of the tests on the main effects is straight forward. However, if interaction is significant, detail analysis of the main effects of the factors are needed.

2.6 Summary of Literature Review

This Chapter 2 has discussed the literature relevant to the research work. Specifically, section 2.2 presented research background on performance analysis and evaluation of manufacturing systems. Subsection 2.3.1 has discussed process factors that affect manufacturing/production lead-time and production throughput of manufacturing systems; these process factors are raw materials, workers, machines, production and assembly layout, workstations, scheduling rules and order release methods. Subsection 2.3.2 has discussed process factors that affect processing time and production throughput of crude palm oil production systems. These process factors are raw materials, workers, process, processing machines, and machine components and work method. Subsection 2.3.3 has identified the research gap as a study that models, experiments and analyse multiple process factors using the combination of discrete event simulation modelling with design of experiment (DOE) and analysis of variance (ANOVA). Section 2.4 has presented the fundamental concept of

discrete event simulation (DES) modelling which include pieces of simulation model, verification, validation, warmup period and number of replication and simulation project life cycle. Section 2.5 has presented statistical design of experiment (DOE), factorial experimental design, fractional factorial design and analysis of variance (ANOVA). Section 2.6 has illustrated the theoretical framework with all process factors that affect the manufacturing system and crude palm oil production system.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methodology for modelling and analysis of a crude palm oil production system considering input process factors. This chapter covers 6 sections. Section 3.2 discusses the simulation methodology. Section 3.3 discusses definition, validation, and architecture of the conceptual model for a crude palm oil production system. Section 3.4 discusses development of simulation model for the crude palm oil production system. Section 3.5 discusses the design and execution of the simulation experiments, which includes design of experiments for model validation, design of experiment and analysis of variance for factors screening and full factorial analysis. Finally, section 3.6, summarises the content for this chapter.

3.2 Simulation Methodology

The simulation methodology for this research work are shown in Figure 3.1 As shown in Figure 3.1 there were 6 phases involved. The first phase was formulating the problem statement, which involved observations at the case study company and reviewing related literatures. The performance metric of interest was selected to be the processing time (termed CPO processing time), which is defined as the total time taken to process one batch of fresh fruit bunch into the crude palm oil. In palm oil industry managing CPO processing time is important. Short processing time leads to high productivity and high-quality CPO with lower free fatty acids (FFAs) content. Then, the research objectives were set. Next, a research plan was prepared. Finally, a conceptual model for a CPO production system was developed and verified by an expert from the case study company.

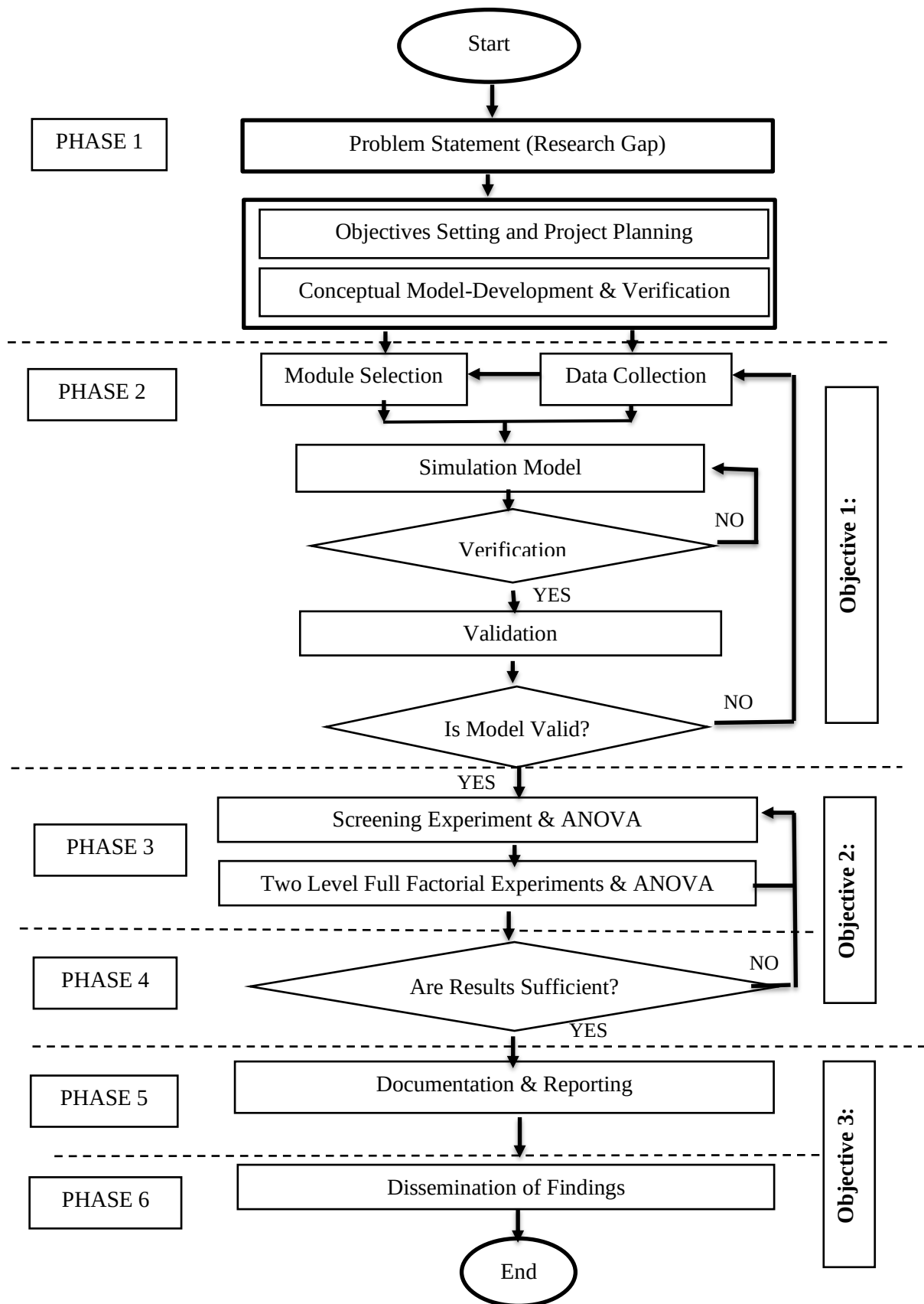


Figure 3.1: Simulation Methodology for Crude Palm Oil Processing System

The phase 2 consisted of 3 activities, simulation model development, verification, and validation. During the simulation model development, data collected (shown in Appendix B as Figures A3.1, A3.2, A3.3, A3.4 and Tables A3.1, A3.2 and A3.3) from the case study company (during phase 1) were used to code the simulation modules that represented each process in the conceptual model.

The second phase was carried out to develop, verified and validate the simulation model. The verified conceptual model from phase one was translated into the equivalent simulation model through coding of the simulation modules. During coding, data collected during the first phase were input into the simulation modules. The simulation model was then verified using the standard animation technique to ensure that the simulation logics were corrects. If the simulation logics were not correct, coding of the simulation modules were redo. The verification process was iterated until there were no errors in the simulation logics.

The simulation model was validated through the simulated CPO processing times. The CPO processing times obtained from the simulation model were validated in two ways. Firstly, the CPO processing times obtained from the simulation model were validated against the CPO processing times collected from the case study company. Secondly, the CPO processing times obtained from the simulation model were validated using sensitivity analysis to confirm that the trend exhibited by the simulated CPO processing times agrees with the trend of production time reported in standard production theory. For the sensitivity analysis, the process parameter that are varied are FFB Quantity, FFB Interarrivals time, weighbridge machine repair time and tipping machine repair time. Details of parameters and range of values are shown in Table 3.1 (subsection 3.5.1).

Design of experiment matrix was constructed to run the simulation experiment for the validation process. More data were gathered and input into the simulation model if the CPO processing times obtained from the simulation model did not match the trend stated in the production theory. The validation process was also iterated until the CPO processing times obtained from the simulation model tally with the CPO processing times collected from the case study company and the CPO processing times trend support the production theory.

In the third phase, factors screening was carried out first, in which experimental design matrix was constructed to run the simulation experiment for the screening process. CPO processing times from the simulation run were input into IBM Statistical Package for Social Science (SPSS) and analysis of variance (ANOVA) test was performed to identify factors that were significantly affecting the CPO processing time. Then, two-level full factorial design matrix was also constructed to run the simulation model with significant factors identified from the factors screening experiment. IBM SPSS was used to record the CPO processing times from the simulation run. An ANOVA test within the SPSS was then run to determine which factors and interactions between factors that significantly influencing the CPO processing times.

In the fourth phase, evaluation was carried out to check if more experiments were needed to achieve objective 2. In the fifth phase, findings were documented, and finally in the sixth phase research findings and proposals were reported to the case study company.

3.3 Definition, Validation and Architecture of Conceptual Model

Crude palm oil (CPO) production process consists of nine (9) processes; (i) arrival of fresh fruit bunches (FFBs), (ii) weighing process, (iii) grading, (iv) loading, (v)

sterilization, (vi) tipping and threshing, (vii) digestion, (viii) pressing, (ix) clarification. Figure 3.3 and Figure 3.4 show the conceptual model for CPO production system studied in this thesis. The basic for developing Figure 3.3 and 3.4 was the conceptual model proposed by Inyang et al., (2019), and latest observations from the case study company. Figure 3.3 and 3.4 was also validated by an expert from the case study company.

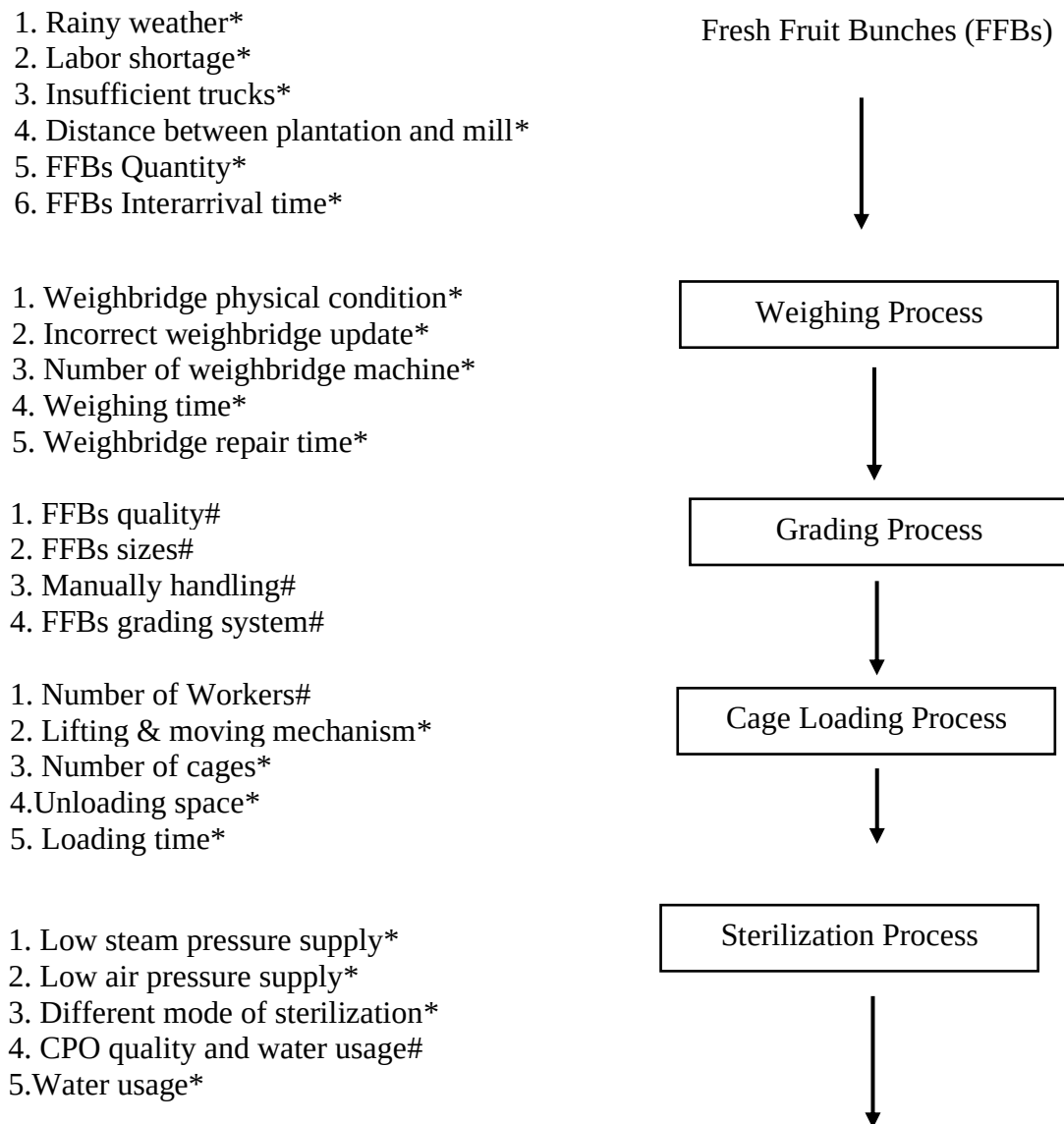


Figure 3.2: Generic conceptual model of crude palm oil production

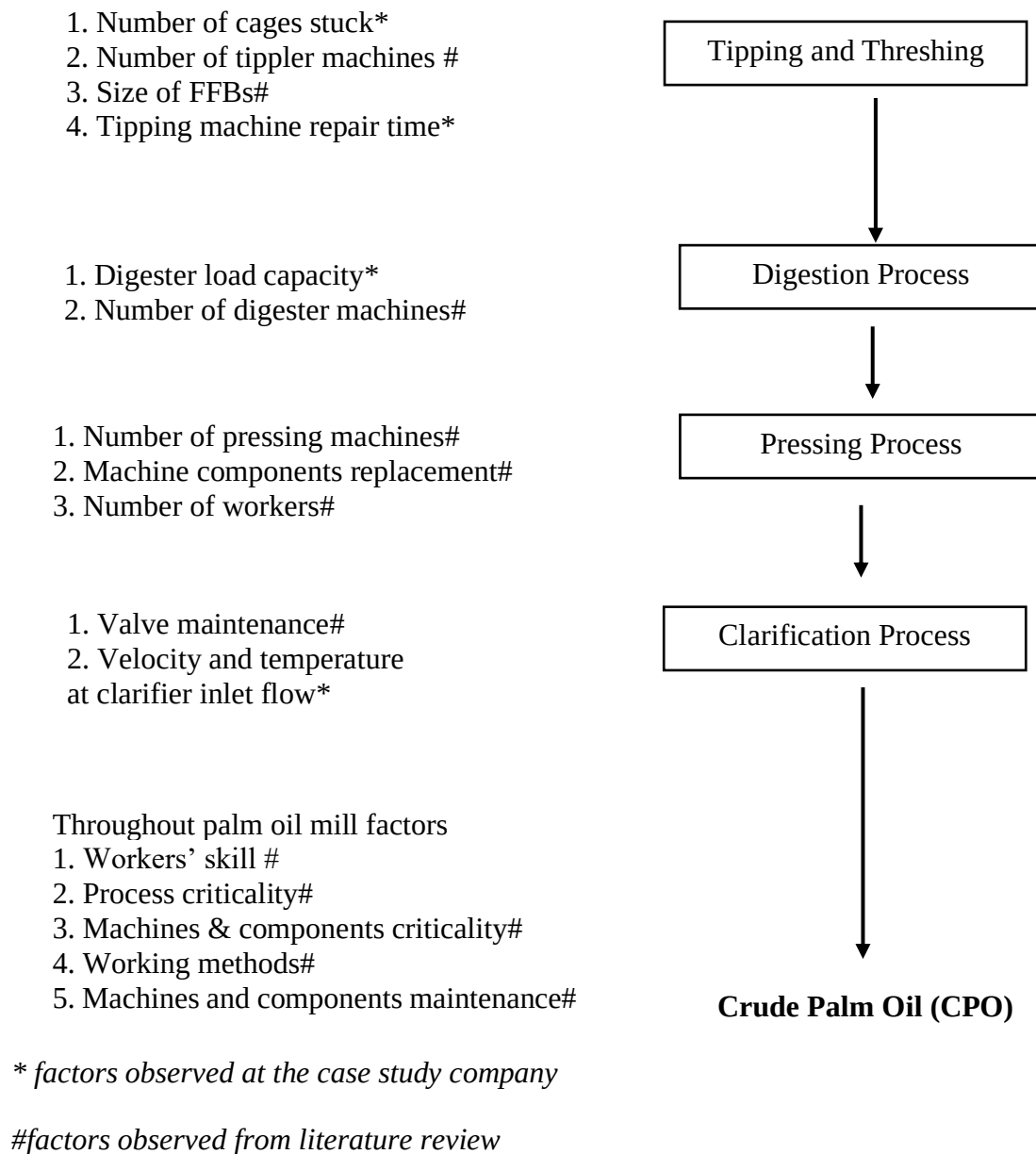


Figure 3.3: Generic conceptual model of crude palm oil production

Firstly, fresh fruit bunches (FFBs) are received from the estate. It is important that FFBs are delivered on time to the mill to maintain FFB's freshness. However, delivery of FFBs to the mill are affected by (i) rainy weather which causes delay of harvesting, (ii) labor shortages, which cause long harvesting time, (iii) insufficient number of trucks which causes delay delivery of FFB to the mill, and (iv) distance between plantation and mill, the longer the distance the longer time needed to deliver the FFB to the mill.

During the weighing process, FFBs estate of origin, actual weight and weight variance are recorded. The weighbridge maximum weight limit is 60 tonnes. The weighing process time is affected by the physical condition of the weighbridge, for example, misalignment of the weighbridge seal will affect the reading of FFBs crop weight. Also, the weighbridge system might not be updated correctly by the attendant during the FFBs weighing process.

During the grading process, FFBs are randomly graded at the grading ramp surface area. Based on guidelines given by Malaysian Palm Oil Board (MPOB, 2015), for any consignment (delivery) that is below 5 metric tonnes (MT), the minimum number of FFBs samples to be graded are 50, whereas for consignment that is above 5 metric tonnes, the minimum samples of FFBs to graded are 100. The FFBs are graded into three (3) classes, unripe, ripe, and overripe.

The following factors affect the FFBs grading process: (i) quality of incoming FFBs, which makes it difficult for the grader to determine the FFB's ripeness level; (ii) varying sizes of incoming FFBs, which makes it take longer to arrange the sample; (iii) manual handling of the sample, which results in fatigue and injury to the grader when they use a spear to remove the FFBs sample from the consignments; and (iv) the FFBs grading system,

which makes an advanced grading system more accurate for determining FFBs maturity level.

At the loading ramp, fresh fruit bunches (FFBs) are loaded into empty cages before being transport to the steam sterilization process. For one single cage, when fully loaded with FFBs, the load limit is 7.5 metric tonne. The cages are pulled up and transported to the sterilising process using wire rope and crane. The FFBs loading into the empty cages process is affected by the (i) number of workers stationed at the loading ramp, whereby worker is needed to operate the crane to lift up and delivers the cages to the sterilising station, (ii) mechanism for lifting and moving the cages, in which the wire rope could easily get cut during the lifting and moving process, life span of the wire rope becomes shorter when more cages are lifted and moved, (iii) number cages being lifted, in which a maximum of 5 cages could be lifted at a time for the wire rope.

Next FFBs are sterilised under high temperature and pressure steam. This high temperature and pressure steam must be allowed to penetrate the pericarp for a long period of time to ensure fruits separate easily from the bunch body. The sterilisation process is affected by (i) temperature and pressure of the steam, low temperature and pressure of steam will prevent fruits from detaching off the bunch, thus causing low oil extraction rate and kernel extraction rate, (ii) air pressure to the compressor, in which low air pressure supplied by the compressor affects the sterilising system, (iii) sterilising mode (time), in which unripe FFBs needed longer sterilising time compared to ripe FFBs.

After that cages loaded with FFBs are slowly tipped to unload the sterilised FFBs into the mechanical bunch feeder hydraulic door which is the entry for threshing process. The tipping process time is affected by the (i) number of cages that got stuck during tipping

operation, in which more cages got stuck would delay the tipping process time, and (ii) number of tipping machine, whereby more tipping machine would enable more cages to be tipped thus reducing the tipping process time, (iii) tipping machine repair time, in which longer repair time causes delay in tipping the cages.

The thresher is a rotating drum with large diameter use threshed the FFBs so that the stalk is separated from the fruit. The threshing operation is affected by the size of the FFBs, bigger size FFBs would get stuck inside the conveyor and cause the whole system to stop. Thus, maintain optimum tipping time is important to achieve high mill throughput.

The digester machine is used to rupture the oil-bearing cells and loosen the pericarp from the nuts. Also, during digesting process fibres are separated from the nut and oil are extracted from the fruit lets. Detached fruits are further softened with steam. This process is affected by the (i) steam supply to the digester machine; whereby low steam supply prevent high oil extraction rate from the fruit lets, and (ii) time taken to replace the digester blade; longer blade replacement time to replace the blade result in delay digestion process. The digester load capacity would affect the overall CPO processing time. For instance, for a digester with loading capacity of 30 metric tonne per hour if it is only loaded with sterilised FFBs with weight of 15 metric tonne, would lengthen the overall processing time for the whole batch. The number of digester machine in used also affect the overall CPO processing time; for example, if only one digester machine is used instead of three available machines, then the overall CPO processing time would be lengthened.

During the pressing process, screw press is used to press the digested fruit to extract the oil contained in the mesocarp. The pressing time are affected by the (i) number of pressing machines, in which more pressing machines would reduce the pressing process

time, (ii) maintenance activity to replace wear and tears machine components, in which longer maintenance time would delay the pressing process time, and (iii) number of workers, in which more workers dedicated to control each pressing machine, would yield shorter pressing process time.

Finally, during the clarification process, moisture, solids, and impurities are removed. Crude oil is stored in the vertical clarifier tank to allow sedimentation and to extract pure oil. Pure oil is stored and purified inside the pure oil tank. The skimmed, purified, and dried crude palm oil (low moisture content) is sold as CPO. The clarification process is affected by the valve maintenance activity at the clarifier storage tank. The velocity and temperature of CPO at the clarifier inlet flow should be maintained to reduce the percentage of oil clog at clarifier outlet.

The conceptual model is limited with respect to not representing the (i) physical condition of the weighbridge, (ii) updating process of weighbridge system, and (iii) physical condition of the wire rope for lifting and moving the cages.

3.4 Development of the Simulation Model

3.4.1 Basic Simulation Module of Arena Simulation Platform

The simulation model is developed based on the verified conceptual model of the crude palm oil (CPO) production system. The ARENA simulation platform student version 16 (Rockwell Automation, 2020) is used as the platform for developing the simulation model. Within the Arena simulation platform there are six simulation modules used to develop the simulation model. These six simulation modules are (i) Create module, (ii) Dispose module, (iii) Process module, (iv) Decide module, (v) Assign module and (vi) Record module.

The Create module shown in Figure 3.5 is used to create entities that circulate in the simulation model. For the CPO production system, the Create module is used to create the arrival of fresh fruit bunches (FFBs) to the system. The Disposed module shown in Figure 3.6 is the end point of the simulation model and used to disposed-off the circulating entities; for the CPO system, this module represents the processed crude palm oil.

The Process module depicted in Figure 3.7 is utilised to simulate any process and process time is allocated to the entity that seizes this module. For the CPO production system, the process module is used to simulate processes that include weighing, grading, loading, sterilising, tipping, digesting, pressing, vibrating screening, crude oil tank, clarifier, pure oil tank, oil purifier, and vacuum drying.

The Decide module illustrated in Figure 3.8 is used to simulate decision-making process in the simulation model. The decision is made based on conditions, which can be based on attribute value, variable value, entity type or an expression. There are two exit points out of the Decide module when the condition for decision is either 2-way by Chance or 2-way by Condition. There is one exit point for “true” and one for “false”, when the condition for decision is either N-way by Chance or by Condition and multiple exit points, for each condition or probability and a single “else” exit. For the CPO system, there are several Decide modules used to make decision on the number of weighbridge stations, grading stations, workers at loading ramp, sterilising stations, cages, digester stations and pressing stations.

The Assign module shown in Figure 3.9 is used for assigning new values to variables, entity attributes, entity types, entity pictures, or other system variables. Multiple assignments can be made with a single Assign module. For the CPO production system, the Assign

module is used to assign the arrival time of FFB in the system. The Record module shown in Figure 3.10 is used to collect statistics in the simulation model. Several types of statistics are available, including time between the entities pass through the module, entity statistics, general observations, and interval statistics. A count type of statistic is available as well. Tally and Counter sets can also be specified. For the CPO system, the Record module is used to record the processing time and quantity of CPO processed.



Figure 3.4: Create Module



Figure 3.5: Dispose Module

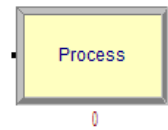


Figure 3.6: Process Module

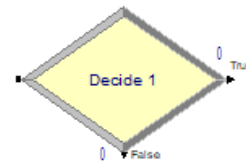


Figure 3.7: Decide Module



Figure 3.8: Assign Module



Figure 3.9: Record Module

3.4.2 Coding of the Simulation Module

The simulation model is developed within Arena simulation platform (Version 16.00.00002, 2019) using the six simulation modules described earlier. Each of the simulation module is coded using information collected from the literature and case study company. Correct coding of each simulation module is important to ensure there is no error in the simulation logic.

Fresh Fruit Bunch Fresh Fruit Bunch (FFB) Arrival

The Create module depicted in Figure 3.11 is used to create the arrival of fresh fruit bunches FFBs into the crude palm oil (CPO) production system. This Create module is labelled FFB Arrival, the entity type is set as Entity 1. The FFBs entities are specified to arrive according to Exponential distribution at every 1 day with 1 entity arriving at one time and maximum arrival of 25. 1 entity represents 50 metric tonne (MT) of FFBs, thus 25 entities represent 1250 MT of FFBs.

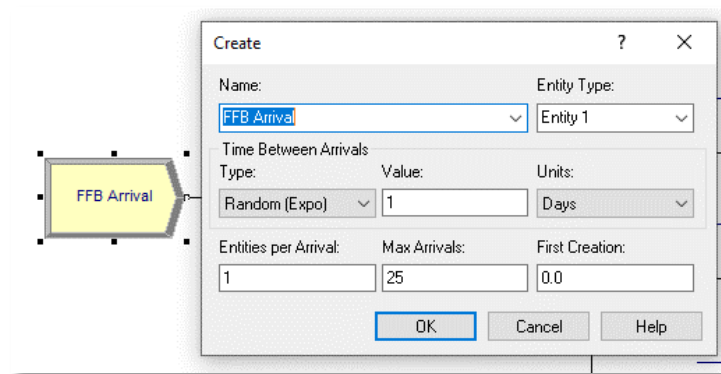


Figure 3.10: FFB Arrival Module Dialog Box

The Assign module named FFB Arrival Time illustrated in Figure 3.12 is used to assign an attribute (ArrivalTime) to all entities passing through it. This attribute ArrivalTime

is given the value TNOW, which represents the current simulation time. This attribute ArrivalTime is read by the Record module (Figure 3.31) and used to calculate time that elapsed (CPO processing time) since the FFB entity left the FFB Arrival Time module. The Assign module is also used to assign an attribute Entity Picture to the entity, which change the entity picture to Truck.

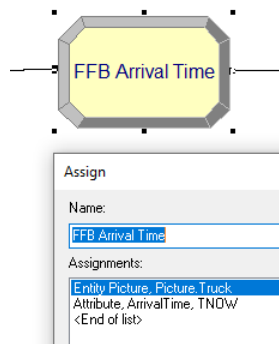


Figure 3.11: Dialog Box for FFB Arrival Time Module

Weighbridge Stations

The first Decide module shown in Figure 3.13 is used to specify the number of weighbridge station in operation (1, 2 or 3); this specification is based on N-way by Chance, according to the Arena rule. The N-way by Chance percentage that is coded into this Decide module must ensure equal usage of weighbridge stations when there are 2 or 3 weighbridge stations. When 2 weighbridge stations are in operation as shown in Figure 3.13, the Percentage coded are 50%, 50% (according to Arena rule). This 50%, 50% rule direct half of the FFBs entities to take the first right exit to the Weighbridge Station WB1 module and the rest to take the second right exit to the Weighbridge Station W2 module. When there are 3 weighbridge stations are in operation the Percentage coded are 33%, 33% and 34%

(according to Arena rule). This 33%, 33%, 34% rule directs an equal number of FFBs entities to each of the weighbridge stations. When there is only one weighbridge station is in operation, the Percentage coded is 100%, which direct all FFBs entities to take the first right exit to the Weighbridge Station W1 module.

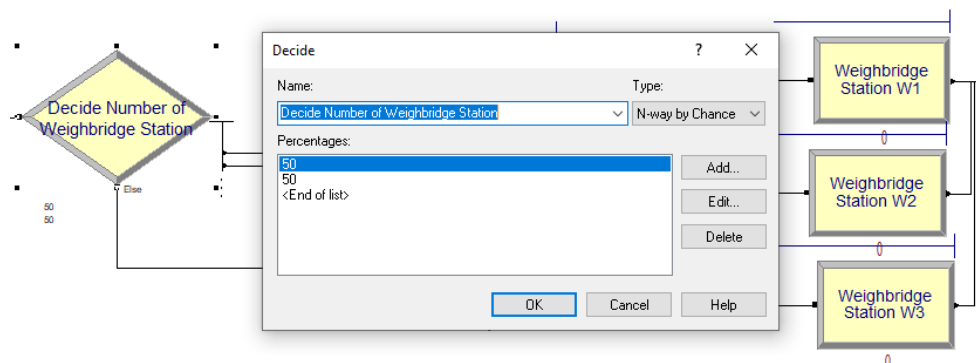


Figure 3.12: Dialog Box for Decide Number of Weighbridge Station Module

The Weighbridge Station WB1, WB2, WB3 modules shown in Figure 3.14 represent the FFBs weighing process at Weighing Station 1, 2 and 3 respectively. The logic specified for these modules is Seize, Delay, Release, which represents the step of booking, weighing the FFBs and releasing the weighing station. For Weighbridge Station WB1, the resource for weighing (station) is labelled WB1 and assigned one machine. Time taken to weigh the FFBs is coded to follow the Triangular distribution, with minimum, average and maximum time coded as 5 minutes, 10 minutes and 15 minutes respectively. Similar settings are specified for Weighbridge 2 and Weighbridge 3.

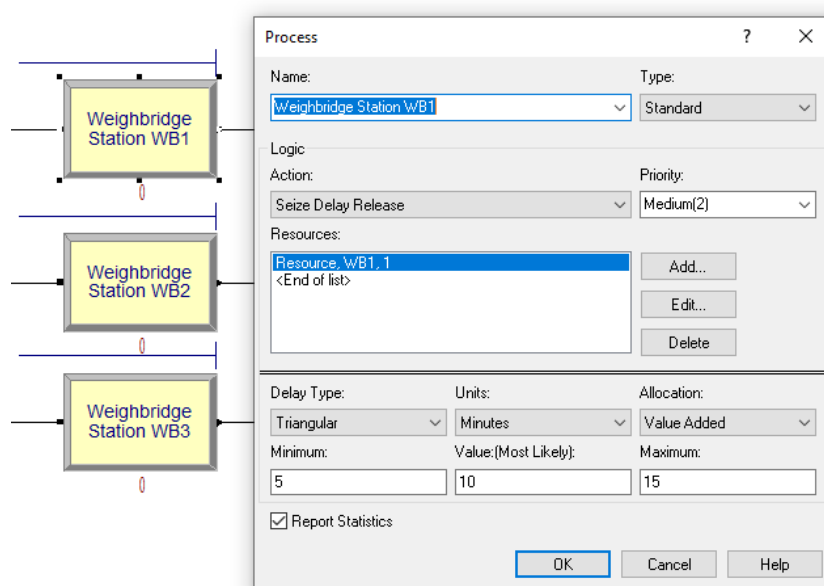


Figure 3.13: Dialog Box for Weighbridge Staion WB1 Module

The WB 1 Repair, WB 2 Repair, and WB 3 Repair modules shown in Figure 3.15 represent the repair process for Weighbridge station 1, 2, and 3 respectively. The logic specified for these modules is Seize, Delay, Release, which simulate the step of repair worker booking the weighbridge for repair, repairing, and releasing the weighbridge after repair. For WB 1 Repair, the resource for repair (repair worker) is labelled WBRep1 and coded one worker. Time taken for the repair process is coded to follow the Constant distribution with repair time specified as 3 hours. Similar settings are coded for WB 2 Repair and WB 3 Repair.

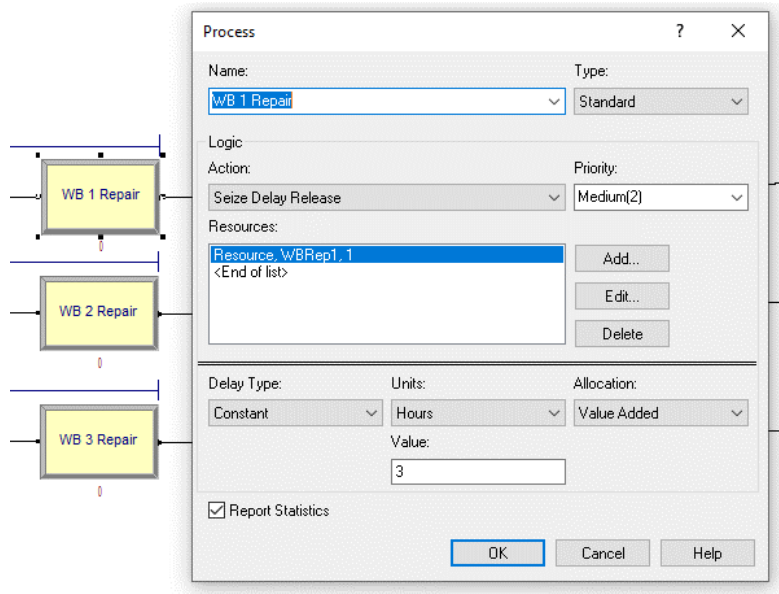


Figure 3.14: Dialog Box for WB 1 Repair Module

Grading Stations

The Decide module shown in Figure 3.16 is used to specify the number of grading stations in operation (1, 2, or 3); this specification is based on N-way by Chance. The N-way by Chance percentage that is coded must ensure equal usage of grading machines when there are 2 or 3 machines. When there are 3 grading stations in operation, as shown in Figure 3.16 the Percentage coded are 33%, 33% and 34%, (according to Arena rule). This 33%, 33% and 34% rule direct an equal number of FFBs entities to each of the grading stations module. When there is only 1 grading station in operation, the Percentage coded is 100% (according to Arena rule). This 100% rule directs all FFBs entities to take the first right exit to the Grading Station 1 module. Finally, when there are 2 grading stations in operation, the Percentage is coded as 50%, 50% (according to Arena rule). This 50%, 50% rule directs half of the FFBs entities to take the first right exit and the rest to take the second right exit to the Grading station 2 module.

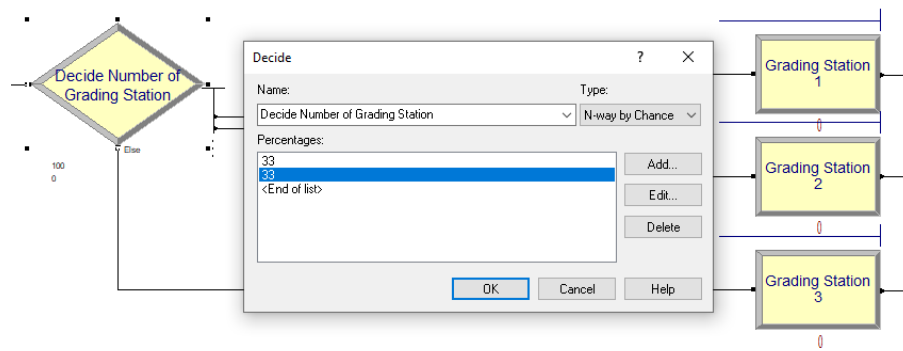


Figure 3.15: Dialog Box for Decide Number of Grading Station Module

The Grading Station 1, 2, 3 modules shown in Figure 3.17 represent the FFBs grading process at station 1, 2, and 3 respectively. The logic coded for these modules are Seize, Delay, Release, which represent the step of booking the grading station, grading the FFBs and releasing the grading station after the grading process. For Grading Station 1, the resource for grading (worker) is labelled GS1 and allocated one worker. Time taken to grade the FFBs is coded to follow Triangular distribution with minimum, average and maximum time, 21 minutes, 26 minutes, and 31 minutes respectively. Similar settings are coded for Grading Station 2 and Grading Station 3.

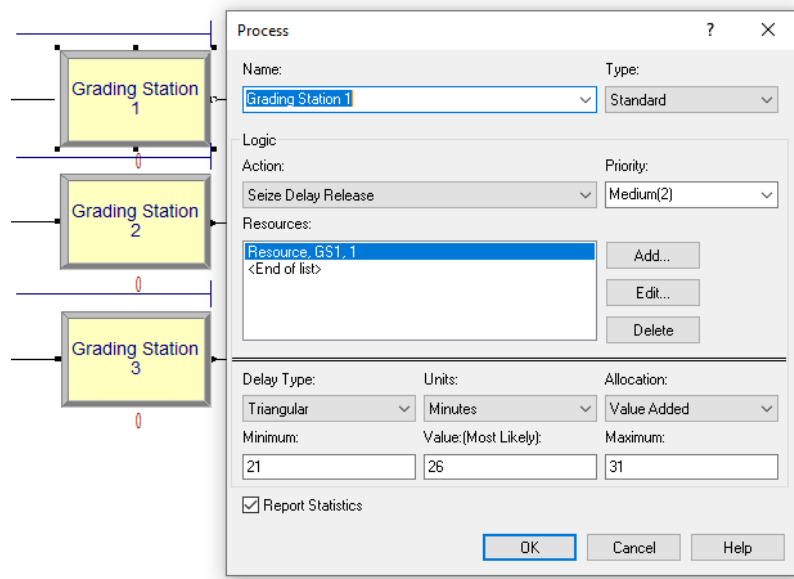


Figure 3.16: Dialog Box for Grading Station 1 Module

Loading Ramp

The Decide module shown in Figure 3.18 is used to allocate the number of workers at the loading ramp (1, 2, 3, 4 or 5); which is based on N-way by Chance according to the Arena rule. The N-way by Chance percentage coded must ensure equal usage of workers at the loading ramp when there are 2, 3, 4 or 5 workers. When five workers are allocated at the loading ramp as shown in Figure 3.18, the percentage coded are 20%, 20%, 20%, 20% and 20% (according to Arena rule). This 20%, 20%, 20%, 20% and 20% rule direct equal number of FFBs entities to all five exits from the Decide module. When 4 workers are allocated at the loading ramp, the percentage coded are 25%, 25%, 25% and 25% (according to arena rule). This 25%, 25%, 25% and 25% rule direct equal number of FFBs entities to the first four exits at the right branch of the decide module. When 3 workers are allocated at the loading ramp, the coded percentages are 33%, 33%, and 34% (according to arena rule). This 33%, 33%, and 34% rule directs an equal number of FFBs entities to the first three exits at

the right branch of the decide module. When 2 workers are allocated at the loading ramp, the Percentage is coded are 50%, 50% (according to arena rule). This 50%, 50% rule directs half of the FFBs entities to take the first and second exits at the right branch of the decide module. When there is only 1 worker at the loading ramp, the Percentage coded is 100% (according to arena rule). This 100% rule directs all FFBs entities to take the first right exit from the Decide module.

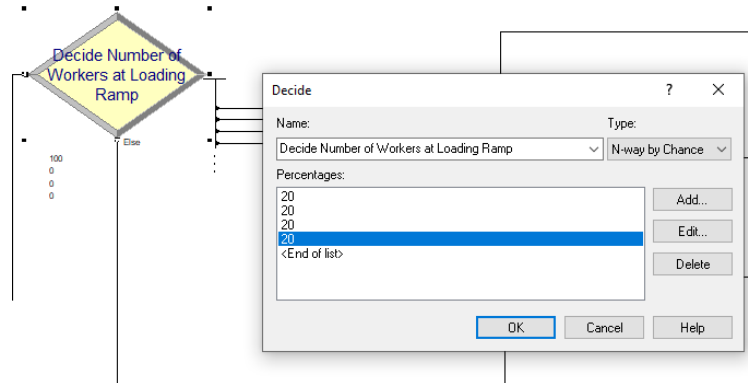


Figure 3.17: Dialog Box for Decide Number of Workers at Loading Ramp Modules

The Worker Loading Ramp 1, 2, 3 4, 5 modules shown in Figure 3.19 represent the FFBs loading into the cages by 1, 2, 3, 4 and 5 workers respectively. The logic coded for these modules are Seize, Delay, Release, which represent the process of allocating worker, loading FFBs into the cages by worker(s), and freeing worker(s) after the loading process. For Worker Loading Ramp 1, the resource for FFBs loading (worker) is labelled LR1 and allocated one worker. Time taken to book the worker, loading FFBs and free the worker is coded to follow Triangular distribution with minimum, average and maximum time, 25 minutes, 30 minutes and 35 minutes respectively. Similar settings are specified for worker Loading Ramp 2, 3, 4 and 5.

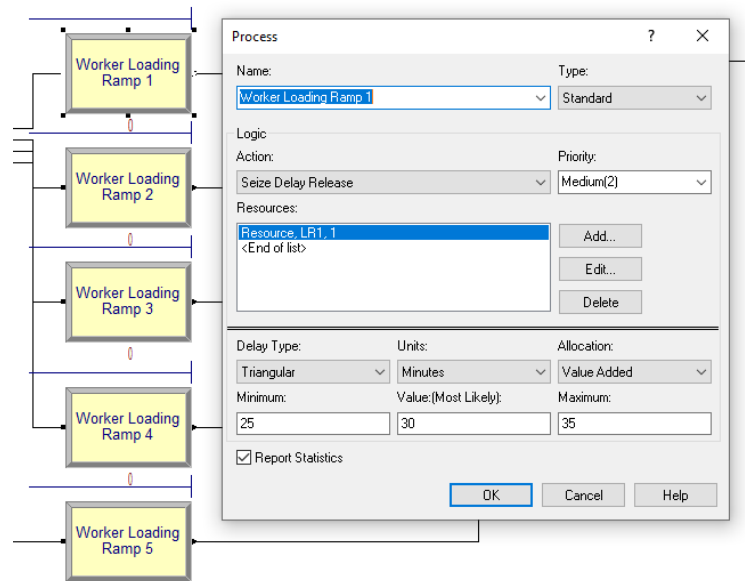


Figure 3.18: Dialog Box for Worker Loading Ramp 1 Module

Sterilising Station

The Decide module shown in Figure 3.20 is used to specify the number of sterilizers in operation (1, 2, or 3); this specification is based on N-way by Chance according to the Arena rule. The N-way by Chance percentage that is coded must ensure equal usage of sterilisation stations in the case of 2 or 3 stations. When 2 sterilisers are in operation as shown in Figure 3.20, the Percentage is coded are 50%, 50% (according to arena rule). This 50%, 50% rule directs half of the FFBs entities to take the first and second right exits from the Decide module. When 3 sterilisers are in operation, the Percentage is coded are 33%, 33% and 34% (according to arena rule). This 33%, 33% and 34% rule direct an equal number of FFBs entities to each exit from the Decide module. When only 1 sterilizer is in operation, the Percentage code is 100% (according to arena rule). This 100% rule directs all FFBs entities to take the first right exit from the Decide module.

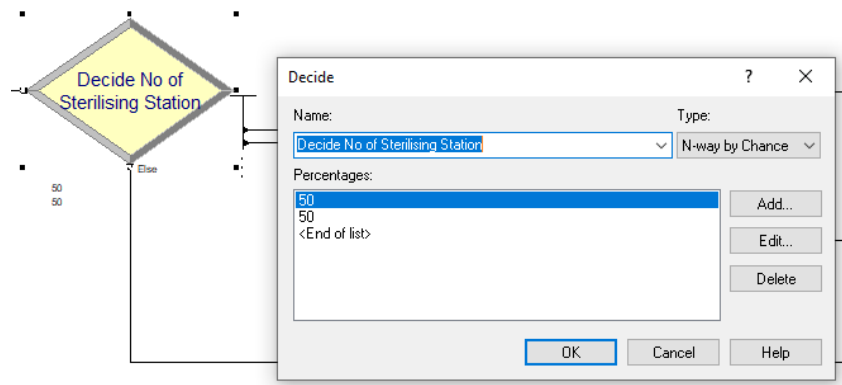


Figure 3.19: Dialog Box for Decide Number of Sterilizing Station Module

The Steriliser Station 1, 2, 3 modules shown in Figure 3.21 represent the sterilisation process at station 1, 2, and 3 respectively. The logic coded for these modules are Seize, Delay, Release, which represent the process of booking the steriliser station, sterilising the FFBs, and releasing the steriliser station after the sterilisation process. For Steriliser Station 1, the resource for sterilisation (machine) is labelled ST1 and allocated one machine. Time taken to book the station, sterilise the FFB and release the station is coded to follow Triangular distribution with minimum, average and maximum time, 130 minutes, 140 minutes and 150 minutes respectively. Similar settings are specified for Steriliser Station 2, and 3.

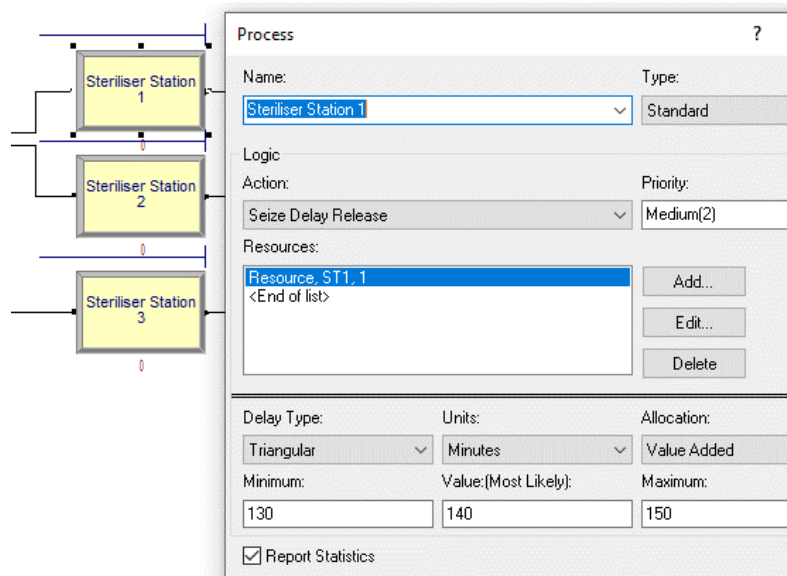


Figure 3.20: Process Module Dialog Box for Sterilizer Station 1, 2 and 3

Cages

The Decide module shown in Figure 3.22 is used to specify the number of cages containing sterilized FBBs to be transported to the next process (1, 2, 3, 4 or 5); this specification is based on N-way by Chance according to the Arena rule. The N-way by Chance percentage that is coded must ensure equal usage of cages in the case of 2, 3, 4 or 5 cages. When only 1 cage is to be transported, the Percentage coded is 100% (according to Arena rule). This 100% rule directs all FFBs entities to take the first right exit from the Decide. When 2 cages are to be transported as shown in Figure 3.22, the Percentage coded are 50%, 50% (according to Arena rule). This 50%, 50% rule directs half of the FFB sentities to take the first and second right exits respectively. When 3 cages are to be transported, the Percentage coded are be 33%, 33% and 34% (according to arena rule). This 33%, 33% and 34% rule direct an equal number of FFBs entities to the first three exits from the Decide module. When 4 cages are to be transported, the Percentage coded are 25%, 25%, 25% and 25% (according to arena rule). The 25%, 25%, 25% and 25% rule directs equal number of

FFBs entities to the first four exits from the Decide module. Finally, when 5 cages are to be transported, the Percentage coded are 20%, 20%, 20%, 20% and 20% (according to arena rule). The 20%, 20%, 20%, 20% and 20% rule directs equal number of FFBs entities to all five exits from the Decide module.

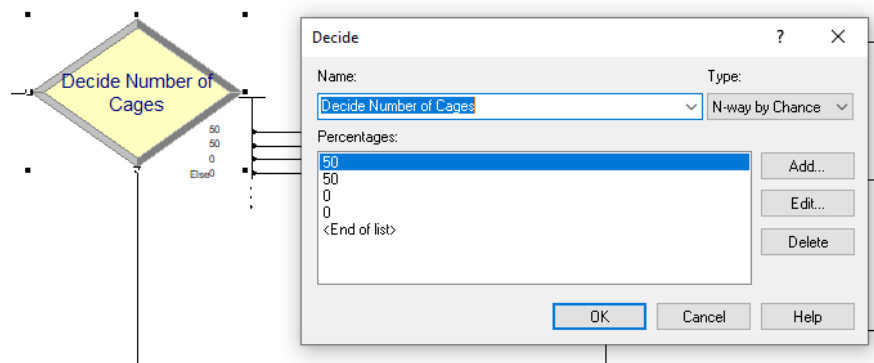


Figure 3.21: Dialog Box for Decide Number of Cages Module

The Cage 1, 2, 3, 4, 5 modules shown in Figure 3.23 represent the process of transporting FFBs to the next process. The logic coded for these modules are Seize, Delay, Release, which represent the process of booking the cage, transporting the cage, and releasing the cage. For Cage 1, the resource (cage) is labelled TS1 c1 and allocated one cage. Time taken for booking, transporting and releasing is coded to follow Triangular distribution with minimum, average and maximum time, 20 minutes, 25 minutes and 30 minutes respectively. Similar settings are specified for Cage 2, 3, 4 and 5.

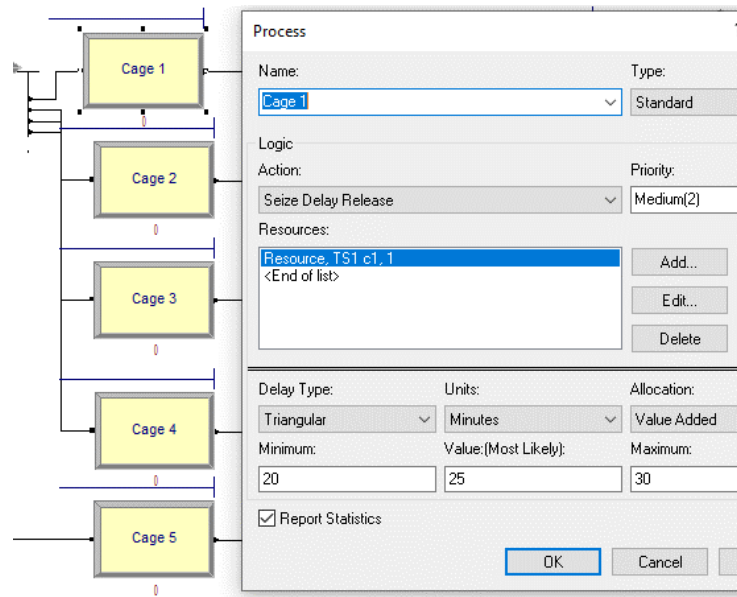


Figure 3.22: Dialog Box for Cage 1 Module.

Tipping Machine

The Tipping Machine Repair module shown in Figure 3.24 represent the repair process of tipping machine. The logic coded for this module is Seize, Delay, Release, which represent the process of booking the tipping machine, repairing and releasing after repair process. The resource (Tipping machine) is labelled Tipp and allocated one machine. The time taken for booking, repairing and releasing the Tipping machine follows a Constant distribution.

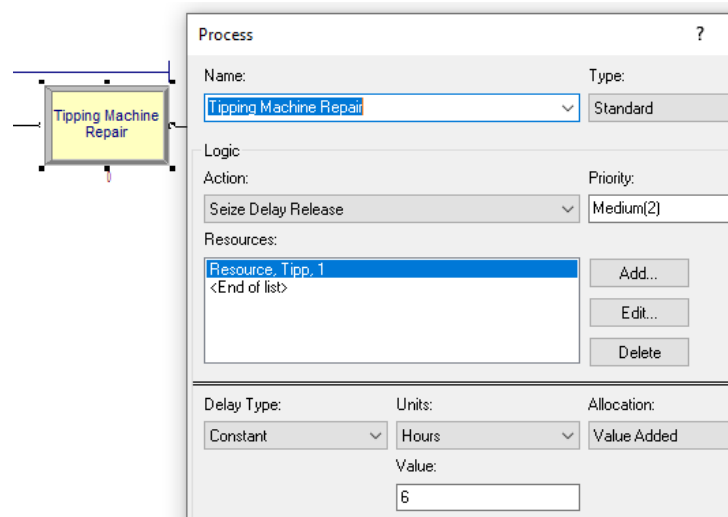


Figure 3.23: Dialog Box for Tipping Machine Repair Module

Digester Stations

The Decide module shown in Figure 3.25 is used to specify the number of digester stations in operation (1, 2, or 3); this specification is based on N-way by Chance according to the Arena rule. The N-way by Chance percentage that is coded must ensure equal usage of digester stations when there are 2 or 3 digesters. When 3 digester stations are operation as shown in Figure 3.25, the Percentage coded are 33%, 33% and 34% (according to arena rule). The 33%, 33% and 34% rule directs an equal number of FFBs entities to take each of the three exits from the Decide module. When 2 digester stations are operation, the Percentage coded are 50%, 50% (according to arena rule). This 50%, 50% rule directs an equal amount FFBs entities to the first and second exits respectively from the from the Decide module. When only 1 digester station in operation, the Percentage coded is 100% (according to arena rule). This 100% rule directs all FFBs entities to take the first right exit from the Decide module.

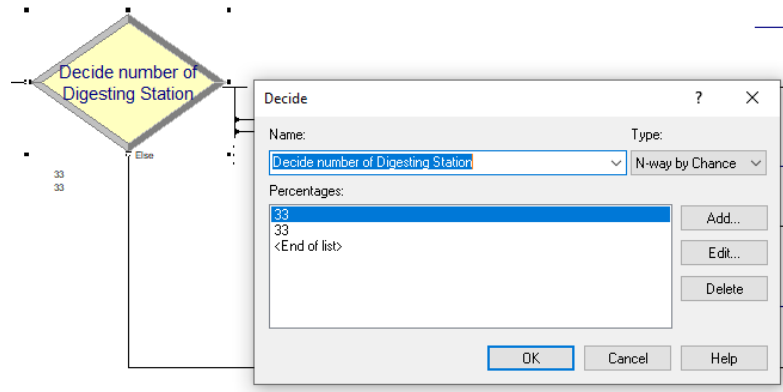


Figure 3.24: Decide Module Dialog Box for Number of Digester Stations

The Digester Station 1, 2, 3 modules shown in Figure 3.26 represent the digesting process of FFBs. The logic coded for these modules are Seize, Delay, Release, which represent the process of booking the digester station, digesting the FFBs and releasing the digester station. For Digester Station1 module, the resource (machine) is labelled DS1 and allocated one digester. Time taken for booking, digesting and releasing is specified to follow Triangular distribution with minimum, average and maximum time, 90 minutes, 100 minutes and 110 minutes respectively. Similar settings are specified for Digester Station 2 and 3.

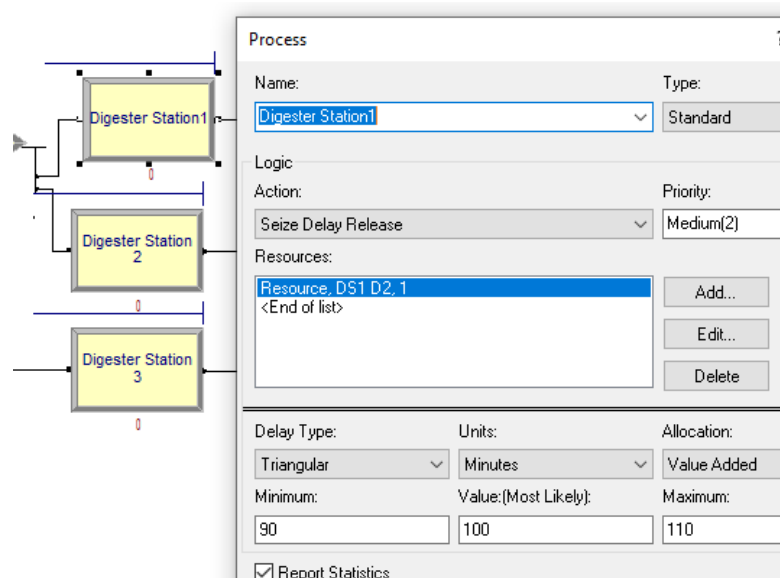


Figure 3.25: Dialog Box for Digester Station 1 Module

Pressing Stations

The Decide module shown in Figure 3.27 is used to specify the number of pressing stations in operation (1, 2, or 3); this specification is based on N-way by Chance according to the Arena rule. The N-way by Chance percentage coded must ensure equal usage of machines when there are 2 or 3 pressing stations. When only 1 pressing station is in operation, the Percentage coded is 100% (according to arena rule). The 100% rule directs all FFBs entities to take the first right exit from the Decide module. When 2 pressing stations are operation as shown in Figure 3.27, the Percentage coded are 50%, 50% (according to arena rule). The 50%, 50% rule directs an equal amount of FFBs entities to take the first and second exits from the Decide module. When 3 pressing stations are operation, the Percentage coded are 33%, 33% and 34% (according to arena rule). The 33%, 33% and 34% rule directs an equal number of FFBs entities to all three exits from the Decide module.

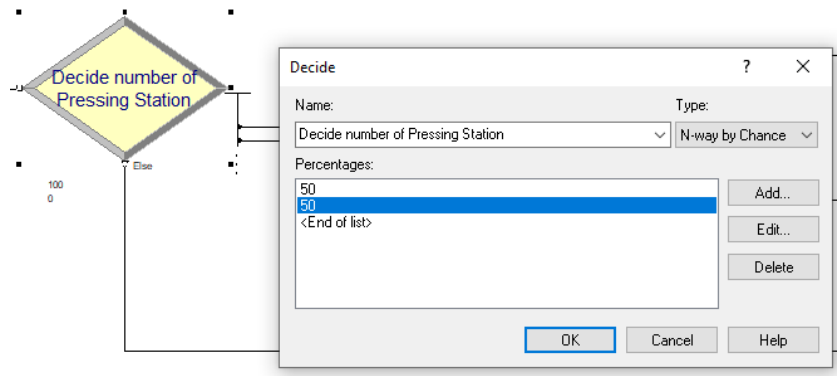


Figure 3.26: Dialog Box for Decide Number of Pressing Station Module

The Presser Station 1, 2, 3 modules shown in Figure 3.28 represent the pressing process. The logic coded for these modules are Seize, Delay, Release, which represent the process of booking the pressing station, pressing the FFBs and releasing the pressing station. For Pressing Station 1 module, the resource (machine) is labelled PS1P1 and allocated one Presser. Time taken for booking, pressing and releasing is coded to follow Triangular distribution with minimum, average and maximum time, 90 minutes, 100 minutes and 110 minutes respectively. Similar settings are specified for Pressing Station 2 and 3.

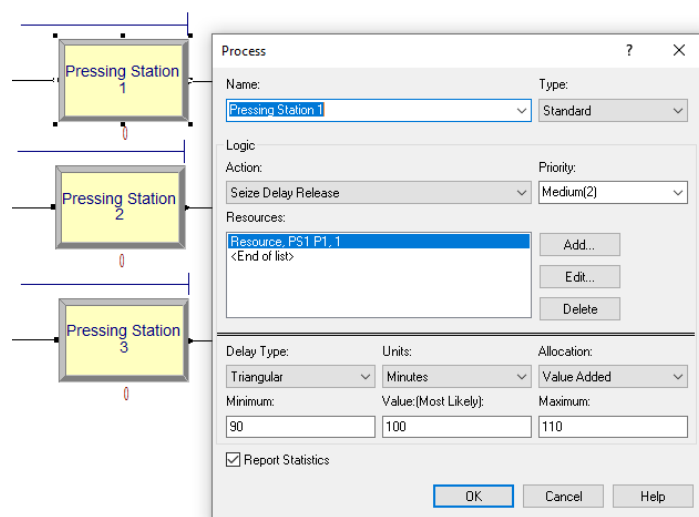


Figure 3.27: Dialog Box for Pressing Station 1 Module

Clarification Station

The Vibrating Screen, Crude Oil Tank, Clarifier, Pure Oil Tank, Oil Purifier and Vacuum Drier modules shown in Figure 3.29 represent the downstream process after the pressing station. The logic coded for these modules are Seize, Delay, Release, which represent booking the downstream process, processing and releasing the downstream process. Time taken to carry out each downstream process is coded to follow Constant distribution with values of 5 minutes for Vibrating Screen, Crude Oil Tank, Clarifier, Pure Oil Tank and Vacuum Drier, and 10 minutes for Oil Purifier.

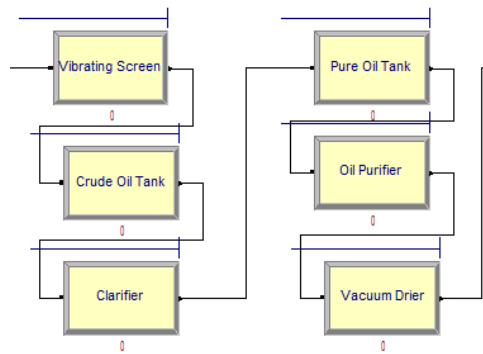


Figure 3.28: Downstream Process Modules

Record

The Record Module shown in Figure 3.30 labelled Production Quantity is used to record the quantity of processed crude palm oil and uses 'Count' as the coded statistical logic. Record Module shown in Figure 3.31 labelled Processing time is used to record the time elapsed since the FFB entities left the Assign Module; the statistics logic coded is Time Interval. Finally, the Dispose Module shown in Figure 3.31 labelled as Crude Palm Oil is used to simulate the disposal of FFB entities at the end of the simulation.

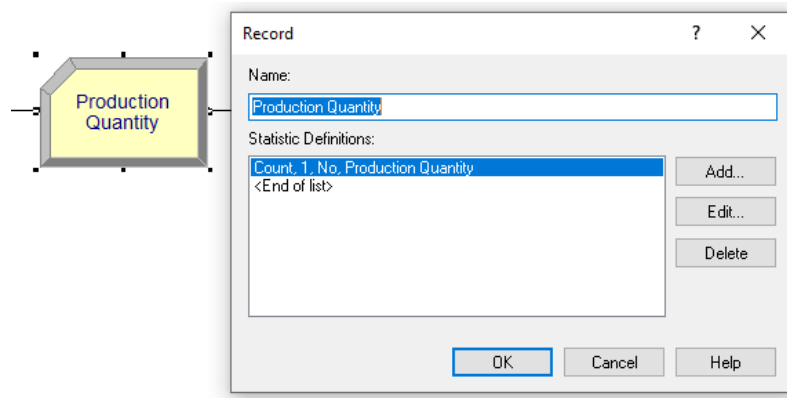


Figure 3. 29: Dialog Box for Record Production Quantity Module

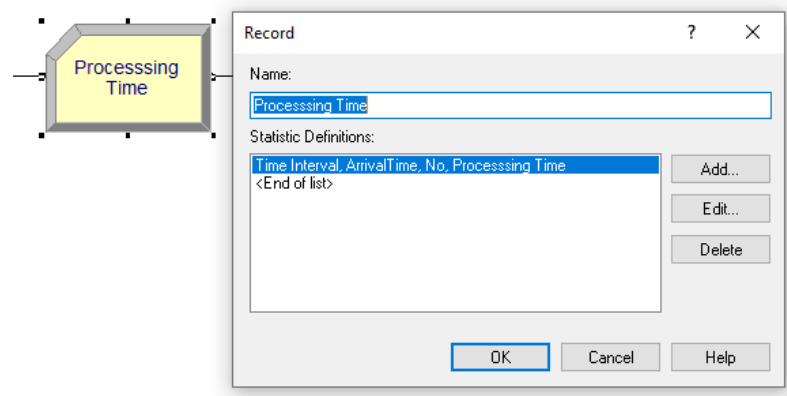


Figure 3.30: Dialog Box for Record Processing Time Module

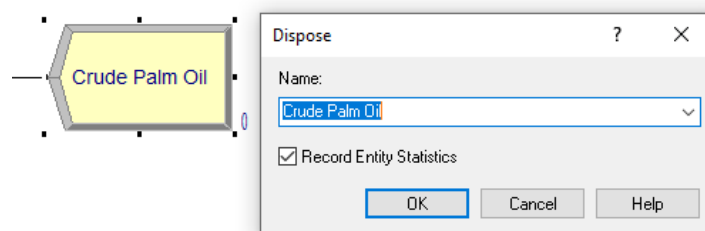


Figure 3.31: Dialog Box for Dispose Crude Palm Oil Module

Simulation Run Setup

Figure 3.32 shows the default setting for Replication Parameters Tab which is used to code and controls several aspects of the simulation run. Number of replications is used to code how many times the experiment is replicated for every single run. The appropriate number of replications is simultaneously determined with the warm-up period and replication length. Warm-up period is used to code period of time in which the observed output is unstable. Replication length is used to code how long the simulation run is carried out. Hours per day is used to code the operating time of the system per day. Time units is used to code the unit for each operating time (seconds, minutes, hours, or days). Base time units is used to code the unit for time in the final simulation output. Terminating condition is used to code how the simulation run is ended; this is applicable for terminating type of system.

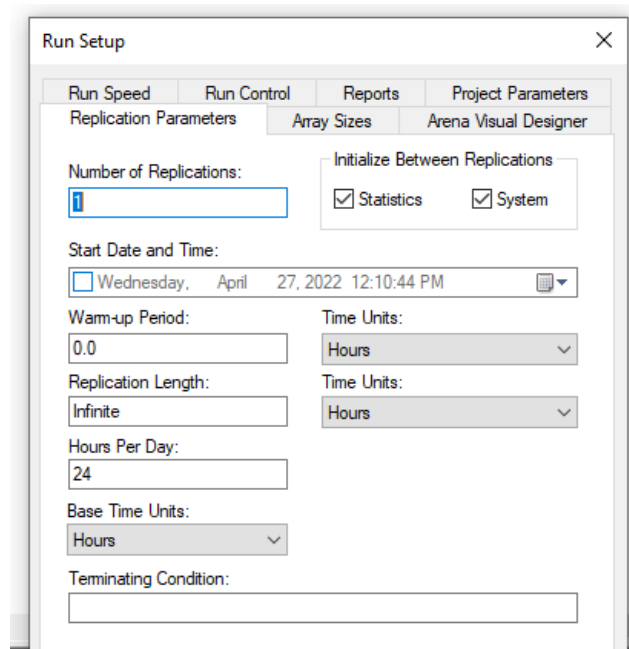


Figure 3.32: Dialog Box Replication Parameters Tab

3.4.3 Verification of the Simulation Logic

The simulation logic is verified using standard animation technique in which visual observation and checking is carried out to ensure that the conceptual model's assumptions have been correctly coded and thus the simulation model behave and performed as intended. In other words, the simulation logic is correct for the overall model. The crude palm oil production system is divided into eight segments and verification process is carried out for each of the segment. The run control parameter that allows an entity to be animated (seen visually) is enabled and the simulation speed factor is specified to be low.

Segment 1 (FFB arrival, weighbridge repair and weighing process)

As shown in Figure 3.34, FFBs entity exiting from the Assign module the picture type is represented by truck. In Figure 3.35, all FFBs entities take the first right exit to the WB 1 Repair module and several FFBs entities queue up at the WB 1 Repair module. The scenario (Figure 3.35) verify that the simulation logic for segment 1 is correct. The Create module is used to generate the arrival of the FFBs entities.

The Assign module is used to specify the FFBs entity picture type truck. The decision logic for the Decide module is coded to be 100%, which directs all FFBs entities to take the first right exit to the WB1 Repair module. The WB 1 Repair module is used to represent the repair process for the weighbridge, causing FFBs entities to wait in queue while waiting for the repair process. And the Weighbridge machine W1 process module is used to represent the weighing process of FFBs entities.



Figure 3.33: Verification of FFBs exiting from the Assign Module

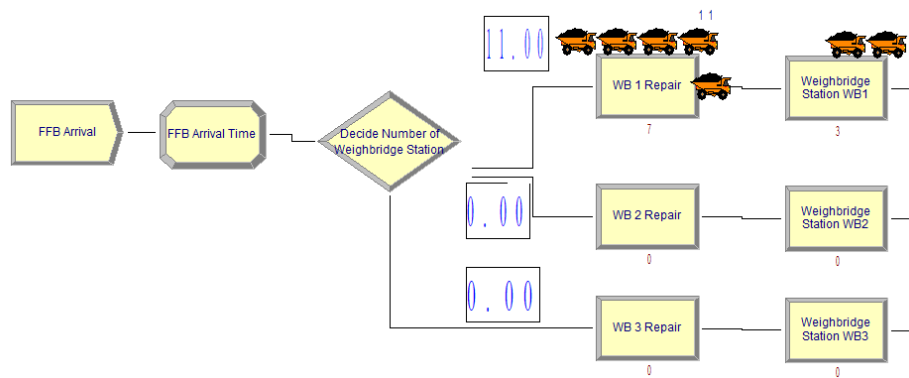


Figure 3.34: Verification of Weighbridge Repair and Weighing Process

Segment 2 (Grading Process)

As shown in Figure 3.36 FFBs entities exit from the Decide module and take the first and second right exits, to the Grading Station 1 and Grading Station 2 process modules. The FFBs entities are then place in a queue at these two process modules. This scenario verifies that the simulation logic for segment 2 is correct. The Decide module is used to direct 50% of the entities to the first right exit to and the rest 50% to the second right exit. And the Grading Station 1 and 2 process modules are used to represent the grading process of FFBs.

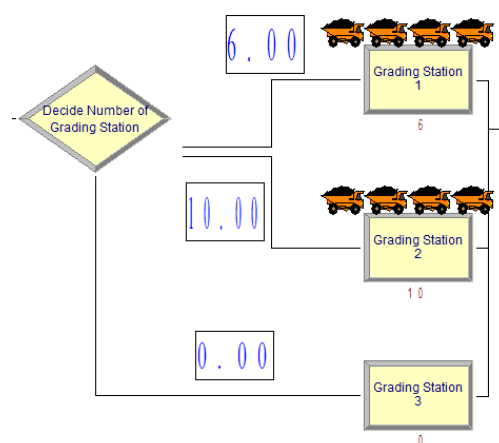


Figure 3.35: Verification of Grading Process

Segment 3 (Loading process)

As shown in Figure 3.37, FFBs entities exit from the Decide module and take any of the five exits, to Worker Loading Ramp 1, 2, 3, 4 and 5 process modules. The FFBs entities then queue up at these five process modules. The scenario shown in this Figure 3.37 verifies that the simulation logic for segment 3 is correct. The Decide module is used to FFBs entities to any of the five exits. The Worker Loading Ramp 1, 2, 3, 4 and 5 process modules are used to represent the loading process of FFBs by the workers.

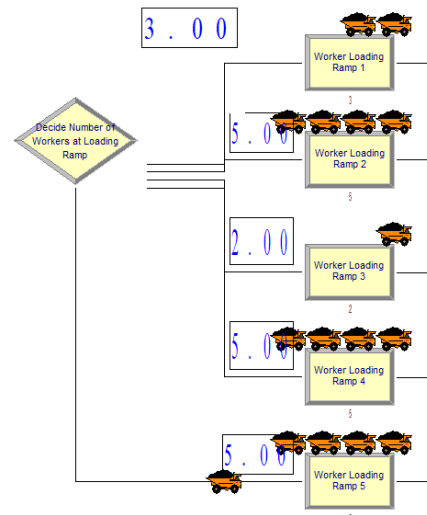


Figure 3.36: Verification of Workers for Loading Process

Segment 4 (Sterilisation Process)

As shown in Figure 3.38, FFBs entities exiting from the Decide module takes the first exit, to Steriliser Station 1 module. The FFBs entities then queue up at this process module. The scenario shown in this Figure 3.38 verifies that the simulation logic for segment 4 is correct. The Decide module is used to direct all (100%) of the entities to the first exit, and the Steriliser Station 1 module is used to represent the sterilising process of the FFBs.

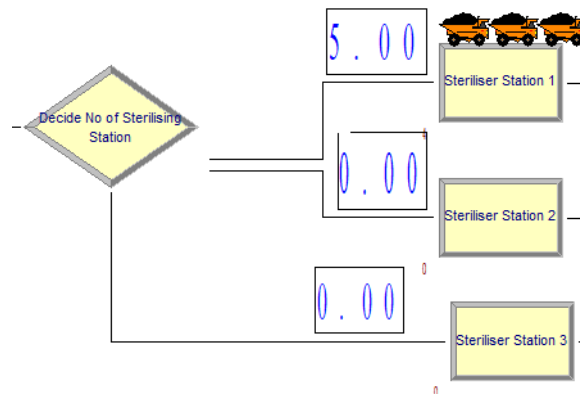


Figure 3.37: Verification of Sterilisation Process

Segment 5 (Cages and Tipping Machine)

As shown in Figure 3.39, FFBs entities exit from the Decide module and take the first three exits to the Tipping Machine Repair module. The FFBs entities then queue up at this Tipping Machine Repair module. This scenario in Figure 3.39 verifies that the simulation logic for segment 5 is correct. The Decide module is used to direct FFBs entities to the first three exits. The Tipping Machine Repair module is used to represent the process of repairing the tipping machine.

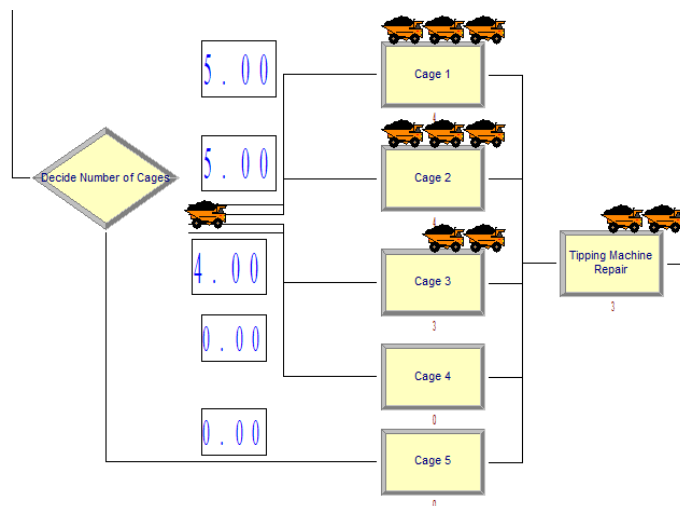


Figure 3.38: Verification of Cages and Tipping Machine Repair Process

Segment 6 (Digestion process)

As shown in Figure 3.40, FFBs entities exits from the Decide module and take the first and second right exits, to the Digester Station 1 and Digester Station 2 process modules. The FFBs entities then queue up at these two process modules. The scenario shown in this Figure 3.40 verifies that the simulation logic for segment 6 is correct. The Decide module is used to direct 50% of the entities to the first right exit and the rest 50% to the second right exit. And the Digester Station 1 and 2 process modules are used to represent the digesting process of FFBs.

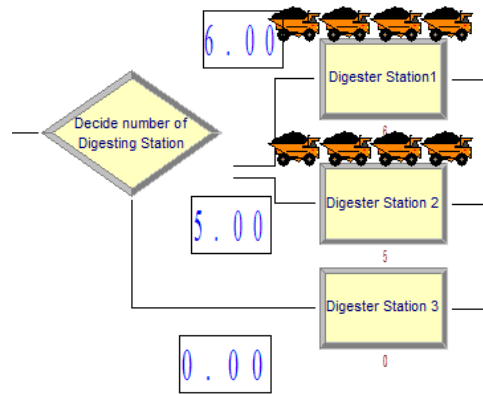


Figure 3.39: Verification of digestion process

Segment 7 (Pressing Process)

As shown in Figure 3.41, FFBs entities exit from the Decide module and take any of the three exits, to the Presser Station 1, 2, 3 modules. The FFBs entities then queue up at these Presser Station 1, 2, 3 modules. The scenario depicted in Figure 3.41 verifies that the simulation logic for segment 7 is correct. The Decide module is used to direct the entities to any of the three exits. The Presser Station 1, 2, and 3 modules represent the pressing process of FFB.

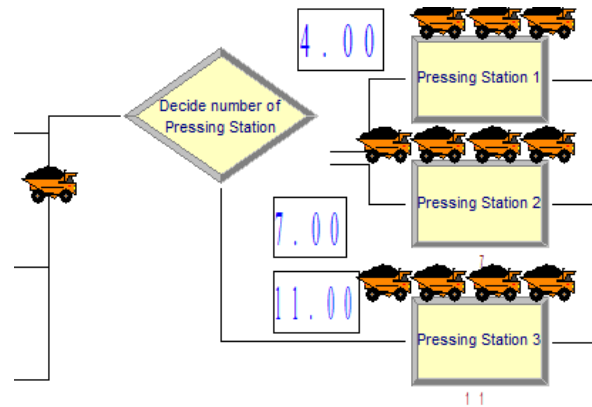


Figure 3.40: Verification of pressing process

Segment 8 (Downstream Process, Record and Dispose)

As shown in Figure 3.42, FFBs entities pass through six process modules that include Vibrating Screen, Crude Oil Tank, Clarifier, Pure Oil Tank, Oil Purifier and Vacuum. The FFBs entities queue up at these six process modules. Finally, as shown in Figure 3.43 all FFBs entities pass through two Record modules and are disposed-off. The scenario depicted in these Figures 3.42 verifies that the simulation logic for segment 8 is correct. All process modules are used to represent the downstream processing of FFBs, the record modules are used to record the statistics and the disposed module are used to remove the CPO entities from the system.

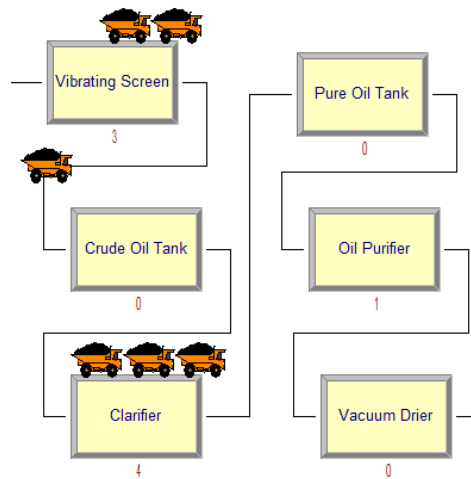


Figure 3.41:Verification of Downstream Process Modules

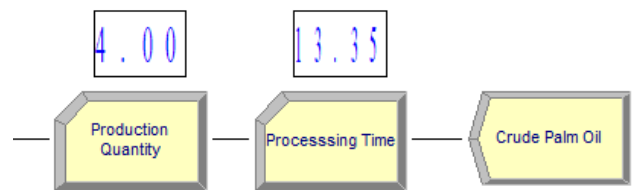


Figure 3.42:Verification of Record and Dispose Modules

In summary, verification of simulation logic for each segment confirms that these segments have been correctly coded and thus the simulation model behave and performed as intended. Overall results of simulation model development are discussed in Chapter 2, subsection 4.2.1.

3.5 Design and Execution of the Simulation Experiments

3.5.1 Design of Simulation Experiment for Simulation Model Validation

Two methods were adopted to validate the simulation model. For the first approach the simulation output (CPO processing time) was compared against the real industry CPO processing time; detailed discussions are provided in Chapter 4. For the second method, four

process factors (FFBs quantity, FFBs interarrival time, Weighbridge machine repair and tipping machine repair time) were used to run the simulation model. For each of the process factor five levels were selected (Table 3.1), which this resulted in 180 simulation runs (Table A3.4, Appendix B).

Referring to Table 3.1, the minimum and maximum FFBs quantity received at the mill are 250 metric tonne and 1250 metric tonne respectively. For plotting the validation graphs, five levels of FFBs quantity simulated are 250MT, 500MT, 750MT, 1000MT and 1250MT. For the FFBs inter-arrival time the most frequent and least frequent inter-arrival time to the mill are 1 day and 5 days respectively. Similarly, for plotting the validation graphs, five levels of inter-arrival times simulated are 1 day, 2 days, 3 days, 4 days, and 5 days. The shortest and longest weighbridge machine downtime for repair activity experienced are 3 hours and 7 hours respectively. Thus, for plotting the validation graphs, the weighbridge machine repair times simulated are 3 hours, 4 hours, 5 hours, 6 hours and 7 hours.

Finally, for tipping machine repair time, the minimum and maximum downtime repair activity experienced are 6 hours and 10 hours respectively. Hence, for plotting the validation graphs, five levels of repair times simulated are 6 hours, 7 hours, 8 hours, 9 hours and 10 hours. Outputs from the simulation model (CPO processing time) were then plotted. As emphasized by Sargent (2020) the direction behaviour of the processing time was analysed against the trends of production theory. Detailed discussions of the validation results are also provided in Chapter 4.

Table 3.1: Process Factors and Levels for Validation of Simulation Model

Levels	Factors			
	FFBs Quantity (MT)	FFBs InterArrival Time (days)	Weighbridge Machine Repair Time (hours)	Tipping Machine Repair Time (hours)
1	250	1	3	6
2	500	2	4	7
3	750	3	5	8
4	1000	4	6	9
5	1250	5	7	10

3.5.2 Design of Simulation Experiment and Analysis of Variance (ANOVA) for Factors Screening

Factor screening was carried out to identify process factors that were significantly affecting the crude palm oil (CPO) processing time. Four cases were considered in this study; in case A and B it was assumed that operation of CPO production system was 8 hours and 12 hours respectively. Meanwhile in case C and D, it was assumed that the FFBs quantity processed by the CPO production system was 250 metric tonne (MT) and 1150 MT respectively.

For both cases A and B, fourteen (14) process factors (FFBs quantity, FFBs inter-arrival time, number of weighing machines, weighing time, weighbridge repair time, number of grading machines, grading time, number of workers at loading station, loading time, number of sterilisers, sterilising time, tipping machine repair time, number of digesters and number of pressers) were identified through the literature review and observations at the case study company (Table A3.5 in Appendix B). The two-level fractional factorial design 2_{III}^{14-10} outlined by Montgomery (2020, Table 8.14) and reproduced as Table A3.6 (Appendix B), was used to design the factor screening simulation experiment. Table A3.7 (Appendix

B) shows the design of experiment matrix used to run the simulation model for factor screening. Table A3.7 also tabulates the CPO processing time obtained from running the simulation model for factor screening for case A and B. Analysis of variance (ANOVA) was carried out for the CPO processing time; detailed discussions are provided in Chapter 4.

In cases C and D, FFBs quantity is chosen as a criterion to give different cases. For cases C and D, the arriving FFBs quantity was assumed to be 250 MT and 1150 MT respectively arriving at every day. As such, for both cases C and D, from the fourteen factors, after excluding the FFBs quantity and FFBs inter-arrival time, there were twelve (12) process factors (number of weighing machines, weighing time, weighbridge repair time, number of grading machines, grading time, number of workers at loading station, loading time, number of sterilisers, sterilising time, tipping machine repair time, number of digesters and number of pressers) also listed in Table A3.8 (in Appendix B). The two-level fractional factorial design 2_{III}^{12-8} outlined by Montgomery (2020) and reproduced as Table A3.6, was used to design the factor screening simulation experiment.

Table A3.9 (Appendix B) show the design of experiment matrix used to run the simulation model for factor screening for cases C and D. Table A3.9 also tabulates the CPO processing time obtained from running the simulation model for factor screening. Analysis of variance (ANOVA) was carried out for the CPO processing time; detailed discussions are provided in Chapter 4.

3.5.3 Design of Simulation Experiment and Analysis of Variance for Full Factorial Analysis

A full factorial experiment was conducted for process factors identified to be significant from the screening experiment. The two-level full factorial design was selected to design the simulation experiment.

For Case A. from the factors screening experiment, nine (9) process factors (Table A3.10 in Appendix B) were identified to be significant; thus 512 simulation runs ($2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2$) were carried out (Table A3.11). Table A3.11 also shows the CPO processing time obtained from running the simulation model. The minimum and maximum values of process factors were coded before conducting ANOVA for the CPO processing time; detailed discussions are provided in Chapter 4.

For Case B. from the factors screening experiment, five (5) process factors were identified to be significant; thus 32 simulation runs ($2 \times 2 \times 2 \times 2 \times 2$) were carried out (Table A3.12). Table A3.12 also shows the CPO processing time obtained from running the simulation model. The minimum and maximum values of process factors were coded before conducting ANOVA for the CPO processing time; detailed discussions are provided in Chapter 4.

For Case C. from the factors screening experiment, three (3) process factors were identified to be significant; thus 8 simulation runs ($2 \times 2 \times 2$) were carried out (Table A3.13). Table A3.13 also shows the CPO processing time obtained from running the simulation model. The minimum and maximum values of process factors were coded before conducting ANOVA for the CPO processing time; detailed discussions are provided in Chapter 4.

Finally, for Case D from the factors screening experiment, four (4) process factors were identified to be significant; 16 simulation runs ($2 \times 2 \times 2 \times 2$) were carried out (Table A3.14). Table A3.14 also shows the output (CPO processing time) obtained from running the simulation model. The minimum and maximum values of factors were coded before conducting ANOVA for the CPO processing time; detailed discussions are provided in Chapter 4.

3.5.4 Determination of Number of Replications

The simulation run of CPO production system was specified as terminating, whereby a maximum of 5 arrivals that represent FFBs arrivals for 5 days was set in the FFB Arrival module. The simulation run terminates once these five arrivals are completely simulated. The appropriate number of replications was determined by observing the half-width value for the CPO processing time in the simulation output report. Trial-and-error number of replications were used to run the simulation and the appropriate number of replications was found when the half-width value has a less than symbol. The suitable number of replications for running the validation, factor screening and full-factorial experiments were found to be 300.

3.6 Summary

This chapter has presented the methodology for research work on modelling and analysis of a crude palm oil production system with input process factors. This chapter has covered five (5) sections. Section 3.1 introduces the chapter content. Section 3.2 has discussed the simulation methodology that consists of six (6) phases. Section 3.3 has presented the definition, validation, and architecture of the conceptual model for a crude palm oil production system. Section 3.4 has covered the development of a simulation model

for the crude palm oil production system, which included simulation modules required, coding the simulation modules and verifying the simulation segments. Section 3.5 has discussed the design and execution of the simulation experiments, which included design of experiments for model validation, design of experiment and analysis of variance for factors screening and full factorial analysis. The research methodology is limited with respect to the (i) data collection on processing time for each process that was based on estimated minimum, average and a maximum, (ii) findings and insights generated from the simulation model may be specific to the context of the case study company and may not directly applicable to other CPO productions systems or industrial processes without further validation and (iii) methodology primarily focuses on modelling CPO processing time as the performance metric of interest. It may not capture other important aspect of the production system, such as resources utilization which could limit the comprehensiveness of the analysis.

CHAPTER 4

DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the research findings related to objectives 1, 2 and 3. Section 4.1 introduces the chapter content. Section 4.2 is divided into three subsections (4.2.1, 4.2.2 and 4.2.3). Subsection (4.2.1) discusses results of simulation model development; subsection (4.2.2) presents results of simulation model output validation against data obtained from the case study company. Subsection (4.2.3) presents the results simulation model output validation against production theory. Section 4.3 discusses results of process factors analysis with respect to processing time under the assumed four industrial settings, subsection (4.3.1) for Case A, subsection (4.3.2) for Case B, subsection (4.3.3) for Case C and subsection (4.3.4) for Case D. Subsection 4.3.1, 4.3.2, 4.3.3 and 4.3.4. also provide discussions on relevance of the simulation results to previous studies. Subsection 4.3.5 discusses results of combined process factors analysis under the assumed two industrial settings. Section 4.4 discusses proposals for managerial strategies and actions to reduce the processing time. Finally, section (4.5) provides the chapter summary.

4.2 Development and Validation of the Simulation Model of Crude Palm Oil Production System

4.2.1 Development of the Simulation Model

Architecture of the Simulation Model

As mentioned in subsection 3.4.3, the simulation models consist of eight (8) segments: (i) fresh fruit bunches (FFBs) arrival, weighbridge repair and weighing process, (ii) grading process, (iii) loading process, (iv) sterilisation process, (v) cages and tipping

machine repair, (vi) digestion process, (vii) pressing process, (viii) downstream, record and disposed process. The architecture of these major segments is discussed below. The complete architecture of the CPO production system simulation model is shown in Figure 4.1 and Figure 4.2.

Segment 1 (FFB Arrival, Weighbridge Repair and Weighing Process)

The first process starts with the arrival of fresh fruit bunches (FFBs). After arrival, FFBs are send to the weighing station to record the weight; the weighing process takes 5 minutes at the minimum, 10 minutes on average and 15 minutes at the maximum. There is a possibility of operating one (1), two (2) or three (3) weighbridge stations. If the weighbridge station breaks down, then repair process takes place. The repair process takes 1 hour at the minimum, 3 hours on average and 6 hours at the maximum.

Segment 2 (Grading Process)

Then fresh fruit bunches (FFBs) are send to the grading station where FFBs are graded to ensure the FFBs quality comply with the regulation set by the Malaysian Palm Oil Board (MPOB) Standard. The quantity of ripe and fresh FFBs are also recorded. The grading process takes 21 minutes at the minimum, 26 minutes on average and 31 minutes at the maximum. There is a possibility of operating one (1), two (2) or three (3) grading stations.

Segment 3 (Loading Process)

Next workers load the fresh fruit bunches (FFBs) into empty cages at the loading ramp station. The loading process of FFBs into the empty cages takes 5 minutes at the minimum, 10 minutes on average and 15 minutes at the maximum. There is a possibility of allocating one (1), two (2), three (3), four (4) or five (5) workers for the loading process.

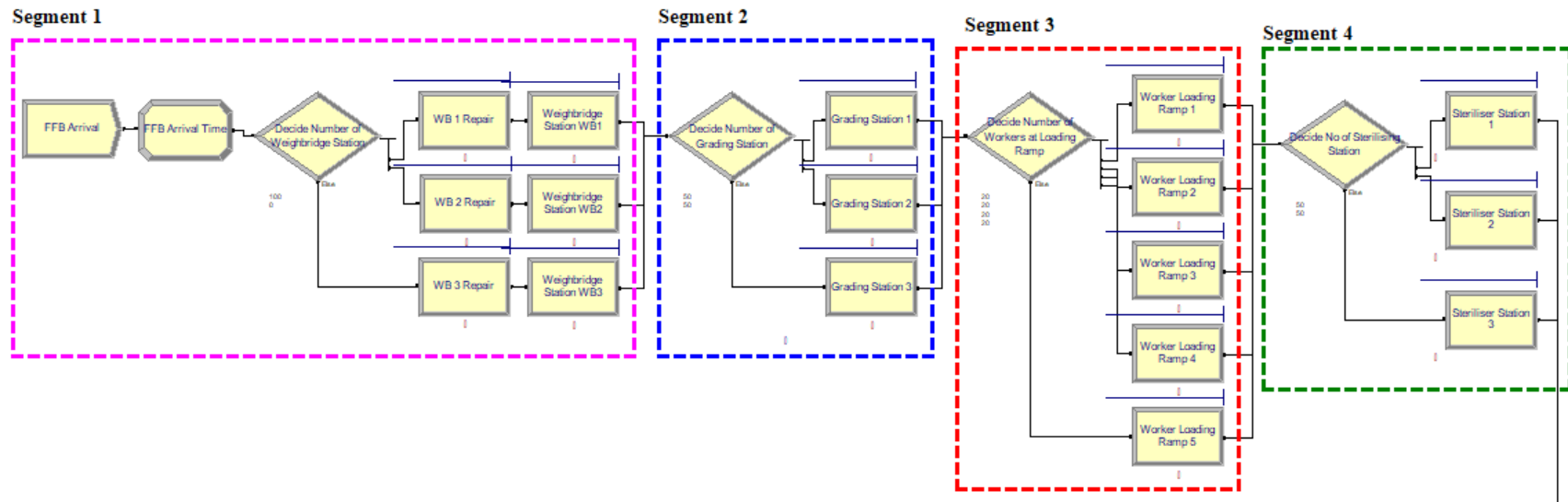


Figure 4.1: Simulation model of crude palm oil production system

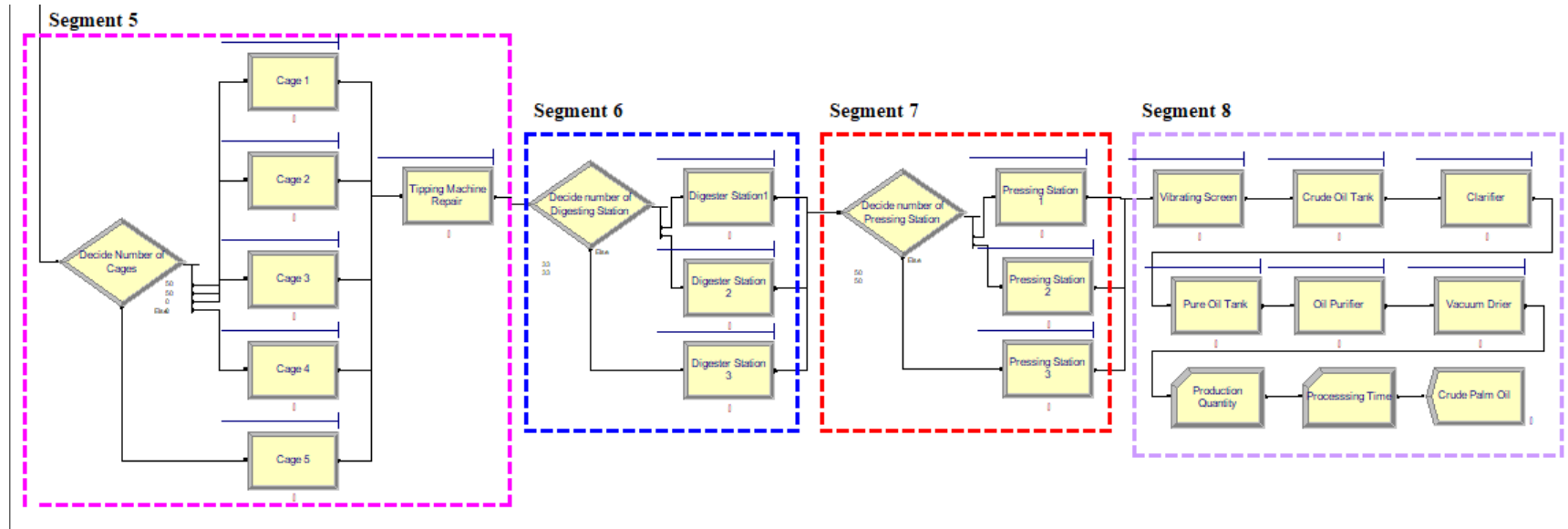


Figure 4.2: Simulation model of crude palm oil production system (continued)

Segment 4 (Sterilisation process)

The cages filled with fresh fruit bunches (FFBs) are sent to the sterilisation process. This process takes 130 minutes at the minimum, 140 minutes on average and 150 minutes at the maximum. There is a possibility of one (1), two (2), or three (3) units of sterilisers available for usage.

Segment 5 (Cages and Tipping Machine Repair)

Then cages are tipped to unload sterilised fresh fruit bunches (FFBs) into the threshing station. If the tipping machine breaks down, then repair process takes place. The repair process takes 3 hours at the minimum, 6 hours on average and 12 hours at the minimum.

Segment 6 (Digestion Process)

Fresh fruit bunches (FFBs) are sent to digestion process to separate the mesocarp, crude palm oil, water, sludge and other impurities. This process takes 90 minutes at the minimum, 100 minutes on average and 110 minutes at the maximum. This segment allows the possibility of using one (1), two (2), or three (3) units of digesters.

Segment 7 (Pressing Process)

After digestion process, fresh fruit bunches (FFBs) are sent to pressing process to separate the palm kernel, shell and crude palm oil. The pressing process takes 90 minutes at the minimum, 100 minutes on average and 110 minutes at the maximum. This segment allows the possibility of using one (1), two (2), or three (3) units of pressers.

Segment 8 (Clarification and Downstream Process)

After pressing process, FFBs are sent for screening at the vibrating screen process. Then after clarification process, pure oil is obtained and send for purification at the oil purifier process. Next, the pure oil is sent to the vacuum drier process for drying. Finally, the pure palm oil is sent to the CPO storage tank before being dispatched to the refinery. All these downstream processes take 5 minutes on average.

Racedo-Gutiérrez et al. (2020) only focus on the first three processes (FFBs reception, weighing and unloading) of CPO production. The authors examined several unloading strategies to reduce average and maximum waiting time for the trucks in the mill. Compared to the study by Racedo-Gutierrez et al. (2012), the simulation model shown in Figure 4.1 and 4.2 is more comprehensive because all processes are represented. This is in line with the suggestion from Racedo-Gutiérrez et al. (2020) that future studies need to include downstream processing as these processes are important and could causes delays in the overall production of CPO.

4.2.2 Validation of the Simulation Model Output Against Data from Case Study Company

Figure A4.1 (Appendix C) show the CPO processing time obtained from running the simulation model with basic process parameters collected from the case study company. This CPO processing time of 43.5 hours is obtained from simulating 1250MT of FFBs being process, thus yielding a CPO processing time of 0.035hours per one metric tonne. Data collected from the case study company (Figure A4.2, Appendix C) show that the average monthly CPO processing time was 19.50 hours for 601 metric tonne (MT) of FFBs, which gives a CPO processing time of 0.032 hours per metric tonne. Given that the percentage

difference between the simulated and actual CPO processing time is consider small, 9.4% $[(0.035-0.032)/0.032]$, this indicates the simulation model is valid and could be used to conduct the simulation experiments to achieve objective number 2. From this point onwards, “processing time” will be used to indicate “CPO processing time”.

4.2.3 Validation of the Simulation Model Output Against Production Theory

a) Validation of the Simulation Model Output with Respect to Fresh Fruit Bunch (FFB) Quantity

Figure 4.3 shows results for simulating the effect of increasing fresh fruit bunches (FFBs) quantity on the simulated processing time at three simulated values of FFBs inter-arrival time. As shown in Figure 4.3, for all three simulated values of FFBs inter-arrival times, the simulated processing time increases as the simulated FFBs quantity to be processed increases (from 250 MT to 1150 MT). For all three FFBs inter-arrival times, when FFBs quantity is simulated to be low (250 MT), the simulated processing time is short (60.4 hrs, 74.4 hrs and 100.4 hours, when FFBs inter-arrival time are 1 day, 3 days and 5 days, respectively) because less FFBs quantity compete for the resource. On the other hand, when FFBs quantity is simulated to be high (1250 MT), the simulated processing time is long (500.3 hrs, 468.5 hrs and 436.6 hrs when the FFBs inter-arrival time are 1 day, 3 days and 5 days, respectively) because more FFBs quantity compete for the resource.

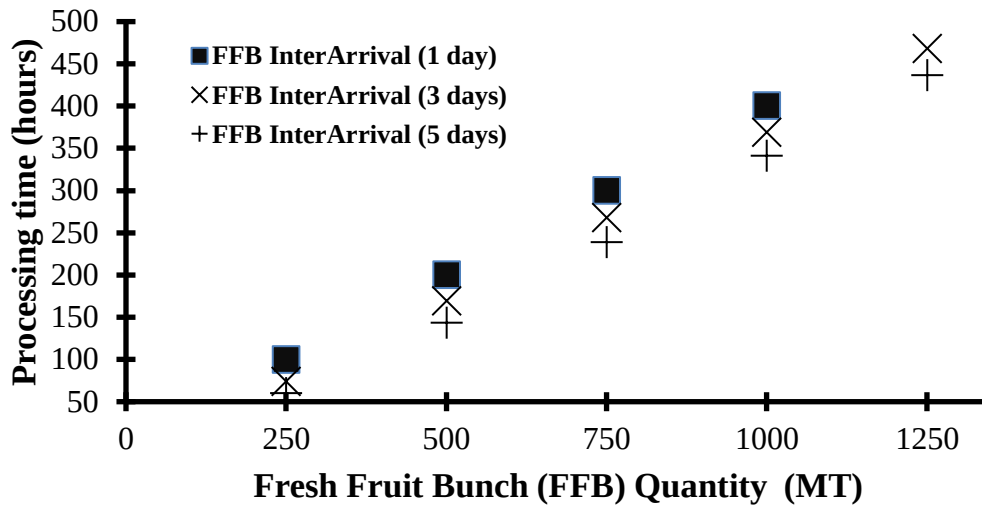


Figure 4.3: Simulated fresh fruit bunches (FFBs) quantity against simulated processing time at different value of simulated FFBs inter-arrival times

As expected in the palm oil industry, the FFBs quantity to be processed is one of the factors affecting the processing time; higher quantities naturally require longer process time. However, it is also worth noting that FFBs inter-arrival time do influence the processing time. Specifically, an inter-arrival of every 1 day, results in the longest processing time compared to other inter-arrival times. This is likely because the more FFBs arriving, more competition for resource, thus delay in processing.

Figure 4.4 shows results for simulating the effect of increasing fresh fruit bunches (FFBs) quantity on the simulated processing time at three simulated values of weighbridge (WB) machine repair times. As shown in Figure 4.4 for all three simulated values of weighbridge machine repair times, simulated processing time increases as the simulated FFBs quantity to be processed increases (from 250 MT to 1150 MT). For all three weighbridge machine repair times, when FFBs quantity is simulated to be low (250 MT), the simulated processing time is short (72 hrs, 74 hrs and 76 hrs, when weighbridge repair

time are 3 hrs, 5 hrs and 7 hrs respectively) because less FFBs quantity compete for the resource. However, when FFBs quantity is simulated to be high (1250 MT), the simulated processing time is long (469 hrs, 471 hrs and 473 hrs, when weighbridge repair time are 3 hrs, 5 hrs and 7 hrs respectively)) because more FFBs quantity compete for the resource.

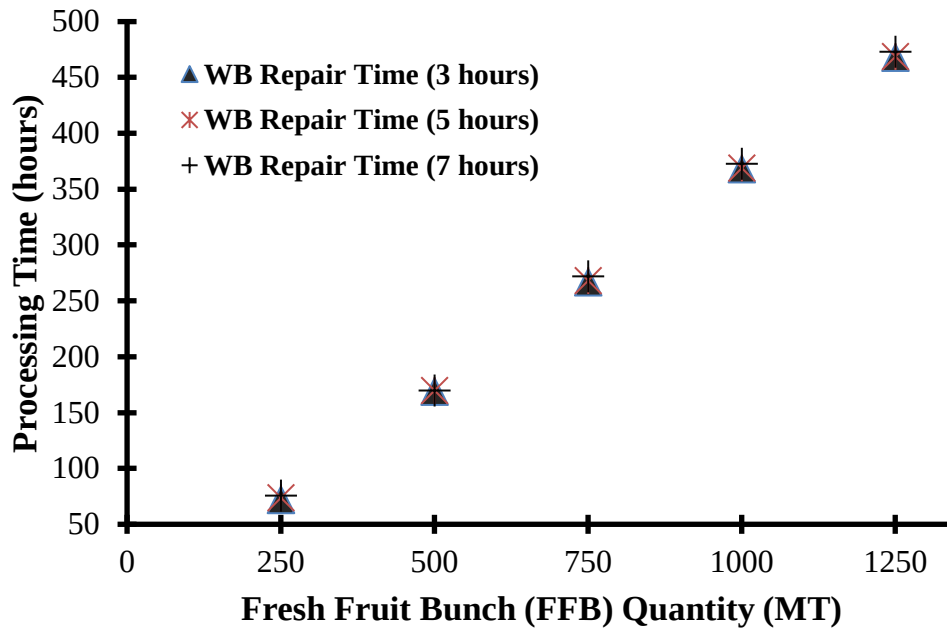


Figure 4.4: Simulated Fresh fruit bunches (FFBs) quantity against simulated processing time at different value of simulated weighbridge machine repair time

As anticipated in the palm oil industry, the quantity of FFBs to be processed is one of factors influencing the processing time; higher quantities naturally require longer processing times. However, it's also worth noting that weighbridge machine repair times do influence the processing time. Specifically, a repair time of 7 hours results in the longest processing time compared to other repair durations. This is likely because the longer repair time leads to delays, as more FFBs queue up waiting for the weighbridge machine to be functional again.

Figure 4.5 shows results for simulating the effect of increasing fresh fruit bunches (FFBs) on the simulated processing time at three different simulated tipping machine repair time. As shown in Figure 4.5, for all three simulated value of different tipping machine repair times, simulated processing time increases as the simulated FFBs quantity to be processed increases (from 250 MT to 1150 MT). For all three tipping machine repair times, when FFBs quantity is simulated to be low (250 MT), the simulated processing time is short (52 hrs, 74.4 hrs and 98.4 hrs, when the tipping repair time are 6 hrs, 8 hrs and 10 hrs respectively) because less FFBs quantity compete for the resource. However, when FFBs quantity is simulated to be high (1250 MT), the simulated processing time is long (342 hrs, 468.5 hrs and 594.6 hrs, when the tipping repair time are 6 hrs, 8 hrs and 10 hrs respectively) because more FFBs quantity compete for the resource.

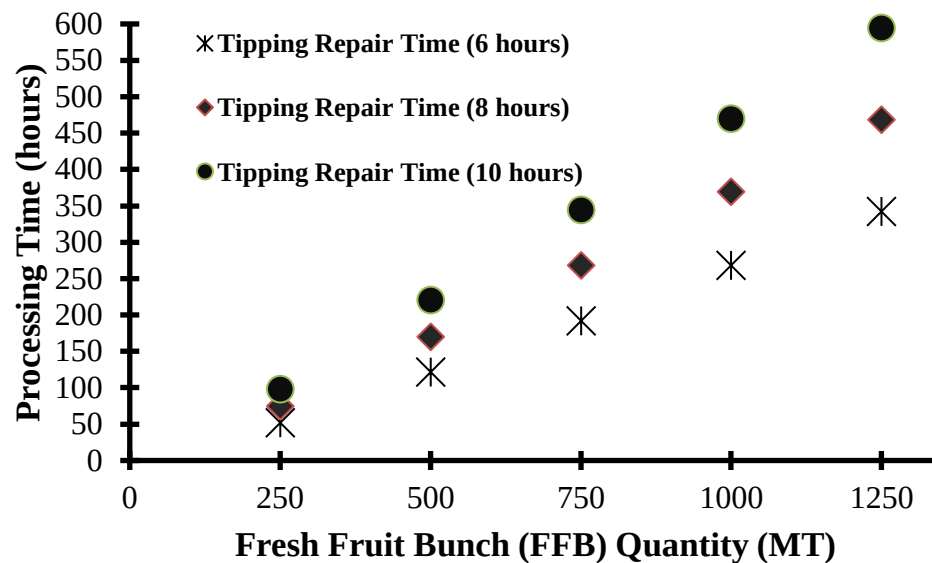


Figure 4.5: Simulated fresh fruit bunches (FFBs) quantity against simulated processing time at different value of simulated tipping repair time

As anticipated in palm oil industry, the FFBs quantity to be processed is one of factors influencing the processing time, higher quantities of FFBs to be processed would require longer processing time. It is also worth noting that tipping machine repair time do influence the processing time. Specifically, tipping machine repair time of 10 hours result in the longest processing time compared to the other tipping machine repair times. This is likely because the longer repair time leads to delays, as more FFBs quantity queue up waiting for the tipping machine to be functional again. Figure 4.5 also shows that the difference in processing time (between tipping repair time of 6 hours and 10 hours) is large (252 hours) when FFBs quantity is 1250 MT, as compare to when FFBs quantity is 250 MT (a difference of 46.4 hours). As expected, when maintenance time for tipping machine is the longest, more FFBs quantity queue up while repair work is carried out, this quantity would be even more when the arriving FFBs quantity is high, thus resulting in extremely long processing time (595 hours, when FFB quantity is 1250 MT).

As illustrated in Figures 4.3, 4.4 and 4.5, the linear relationship between fresh fruit bunches (FFBs) quantity and simulated processing time suggest that the graphical method would be suitable for predicting simulated processing time for a given FFBs quantity. Furthermore, the findings that more FFBs quantity to be processed resulted in longer simulated processing time, agrees with the general production theories that, given the same production resource, high input (raw materials) into the production system would result in longer production time compared to low input. This suggest that the output (simulated processing time) from the simulation model is valid, which also indicates that the simulation model is valid.

b) Validation of the Simulation Model Output with Respect to Fresh Fruit Bunch (FFB) Inter-Arrival Time

Figure 4.6 shows results for simulating the effect of increasing fresh fruit bunches (FFBs) inter-arrival time on the simulated processing time at three simulated values of different FFBs quantity. As seen in Figure 4.6, for all three simulated values FFBs quantity, simulated processing time decreases as the FFBs inter-arrival time becomes long (from every 1 day to every 5 days). For all three FFBs quantity, when FFBs inter-arrival time is simulated to be frequent (every 1 day), the simulated processing time is long (100.4 hrs, 300.3 hrs and 500.3 hrs when FFB quantity are 250 MT, 750 MT and 1250 MT respectively) because more FFBs quantity compete for the resource. However, when FFBs inter-arrival time is simulated to be infrequent (every 5 days), the simulated processing time is short (60.4 hrs, 239.3 hrs and 436.6 hrs when FFB quantity 250 MT, 750 MT and 1250 MT respectively) because less FFBs quantity compete for the resource.

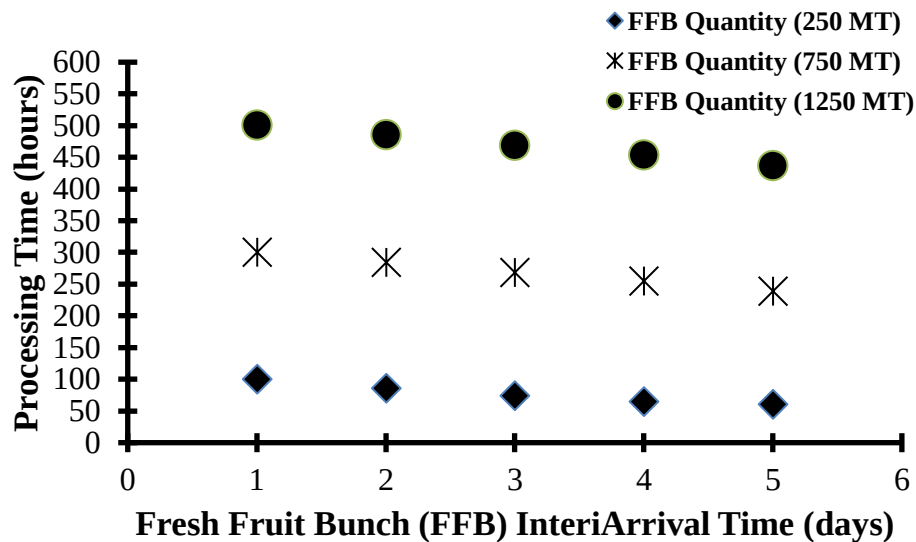


Figure 4.6: Simulated fresh fruit bunches (FFBs) inter-arrival time against simulated processing time at different value of simulated FFBs quantity

As expected in palm oil industry, the FFBs inter-arrival time is one of the factors affecting the processing time; infrequent FFBs inter-arrival time (hence less FFBs quantity) would require shorter time to process these FFBs. It is also worth noting that FFBs quantity do affect the processing time. Specifically, FFBs quantity of 1250 MT results in the longest processing time compared to the other FFBs quantity. This is likely because the more FFBs quantity to be processed is high, more competition for resource, thus delay in processing.

Figure 4.7 shows results for simulating the effect of increasing fresh fruit bunches (FFBs) inter-arrival time on the simulated processing time at different simulated valued of weighbridge machine repair times. As shown in Figure 4.7, for all different simulated values of weighbridge machine repair times, simulated processing time decreases as the FFBs inter-arrival time becomes longer (from every 1 day to every 5 days). Referring to Table A4.1 (Appendix C), for all three weighbridge machine repair times, when FFBs inter-arrival time is simulated to be frequent (every 1 day), the simulated processing time is long (298.3 hrs, 300.3 hrs and 302.3 hrs when weighbridge repair time are 3 hrs, 5 hrs and 7 hrs respectively) because more FFBs quantity compete for the resource. However, when FFBs inter-arrival time is simulated to be infrequent (every 5 days) the simulated processing time is short (253.3 hrs, 239.3 hrs and 240.3 hrs when weighbridge repair time are 3 hrs, 5 hrs and 7 hrs respectively) because less FFBs quantity compete for the resource.

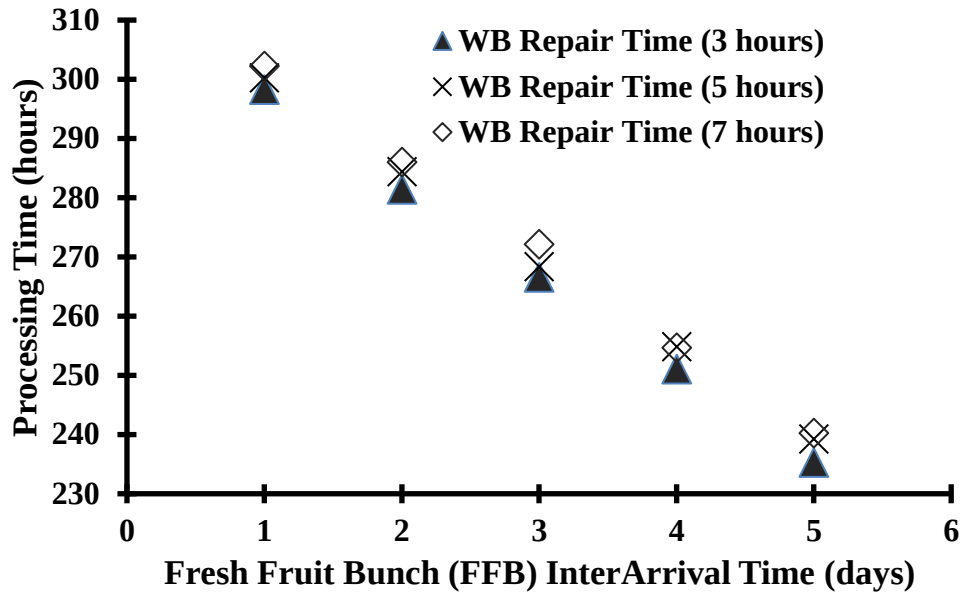


Figure 4.7: Simulated fresh fruit bunches (FFBs) inter-arrival time against simulated processing time at different value of simulated weighbridge repair time

As observed in palm oil industry, FFBs inter-arrival time is one of the factors affecting the processing time; frequent arrival of FFB resulted in more FFBs to be processed hence naturally require longer processing time. It is worth noting that the weighbridge machine repair time is also one of the factors impacting the processing time. Specifically, a repair time of 7 hours results in the longest processing time compared to other repair times. This is likely because the longer repair time leads to delays, as more FFBs queue up waiting for the weighbridge machine to be in operation again. However, detail analysis (Table A4.1 in Appendix) show that the processing time differs by 2 hours between all three weighbridge machines repair time.

Figure 4.8 shows results for simulating the effect of increasing fresh fruit bunches (FFBs) on the simulated processing time at different simulated values of tipping machine repair times. As shown in Figure 4.8, for all three different simulated values of tipping

machine repair times, the simulated processing time decreases as the simulated FFBs inter-arrival time becomes longer (from every 1 day to every 5 days). For all three tipping machine repair times, when FFBs inter-arrival time is simulated to be frequent (every 1 day), the simulated processing time is longer (224.1 hrs, 300.3 hrs and 376.9 hrs when tipping repair time are 6 hrs, 8 hrs and 10 hrs respectively) because more FFBs quantity compete for the resource. However, when FFBs inter-arrival time is simulated to be infrequent (every 5 days), the simulated processing time is short (164.1 hrs, 239.3 hrs and 314.6 hrs when tipping repair time are 6 hrs, 8 hrs and 10 hrs respectively) because less FFBs quantity compete for the resource.

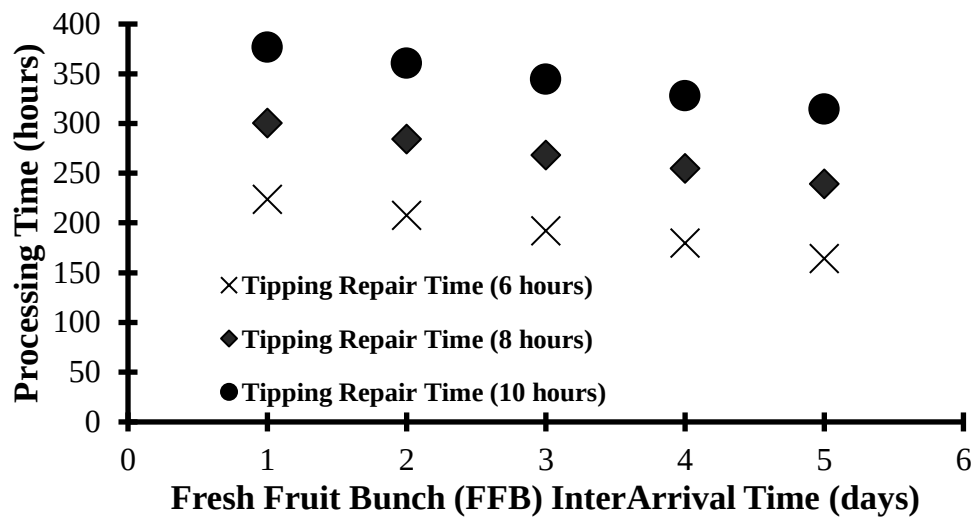


Figure 4.8: Simulated fresh fruit bunches (FFBs) inter-arrival time against simulated processing time at different value of simulated tipping repair time

As expected in palm oil industry, FFBs inter-arrival time is one of the factors affecting the processing time, infrequent FFBs inter-arrival time (hence less FFBs quantity) require shorter processing time. It is also worth noting that tipping machine repair time do influence processing time. Specifically, tipping machine repair time of 10 hours result in the longest processing time compared to the other tipping machine repair times. This is likely

because the longer tipping machine repair time leads to delays, as more FFBs quantity queue up waiting for the tipping machine to be functional again. Figure 4.8 also shows that the difference in processing time (between tipping repair time of 6 hours and 10 hours) is small (150.5 hrs) when FFB interarrival time is every 5 days as compared to when FFB interarrival time is every 1 days (a difference of 152.8 hours). As expected, when maintenance time for tipping machine is the longest, more FFB interarrival time queue up while repair work is carried out, this quantity would be even more when the FFB interarrival time is high, thus resulting in extremely long processing time (314.6 hours, when FFB interarrival time is every 5 days).

As depicted in Figures 4.6, 4.7 and 4.8, the linear relationship between fresh fruit bunches (FFBs) inter-arrival time and simulated processing time suggest that the graphical method would be suitable for predicting the simulated processing time for a given FFBs inter-arrival time. In addition, the finding that infrequent arrival of FFBs, hence less FFBs quantity to be processed resulted in shorter simulated processing time, agrees with the general production theories that, given the same production resource, low input (raw materials) into the production system would resulted in shorter production time compared to high input. This suggest that the simulated processing time obtained from the simulation model is valid, which also advocate that the simulation model is valid.

c) Validation of the Simulation Model Output with Respect to Weighbridge Repair Time

Figure 4.9 shows results for simulating the effect of increasing weighbridge machine repair time on the simulated processing time at three simulated values of FFBs quantity.-As shown in Figure 4.9, for all three simulated value of FFBs quantity, simulated processing time increases very minimal as the weighbridge machine repair time (hours) become longer

(from 3 hours to 7 hours). Specifically, an increase of 3.8 hours, 5.6 hours and 4.4 hours, respectively for 250 MT, 550 MT and 1150 MT of FFBs quantity. For all three FFBs quantity, when weighbridge machine repair time is simulated to be short (3 hours), the simulated processing time is short (72.2 hrs, 266.6 hrs and 468.1 hrs, when FFB quantity are 250 MT, 750 MT and 1250 MT, respectively) because more less FFBs quantity queue up while repair work is carried out. However, when the weighbridge machine repair time is simulated to be longer (7 hours), more FFBs quantity queue up while repair work is carried out, causing delay in processing and, hence a slightly longer processing time (76 hrs, 272.2 hrs and 472.5 hrs when FFBs quantity are 250 MT, 750 MT and 1250 MT).

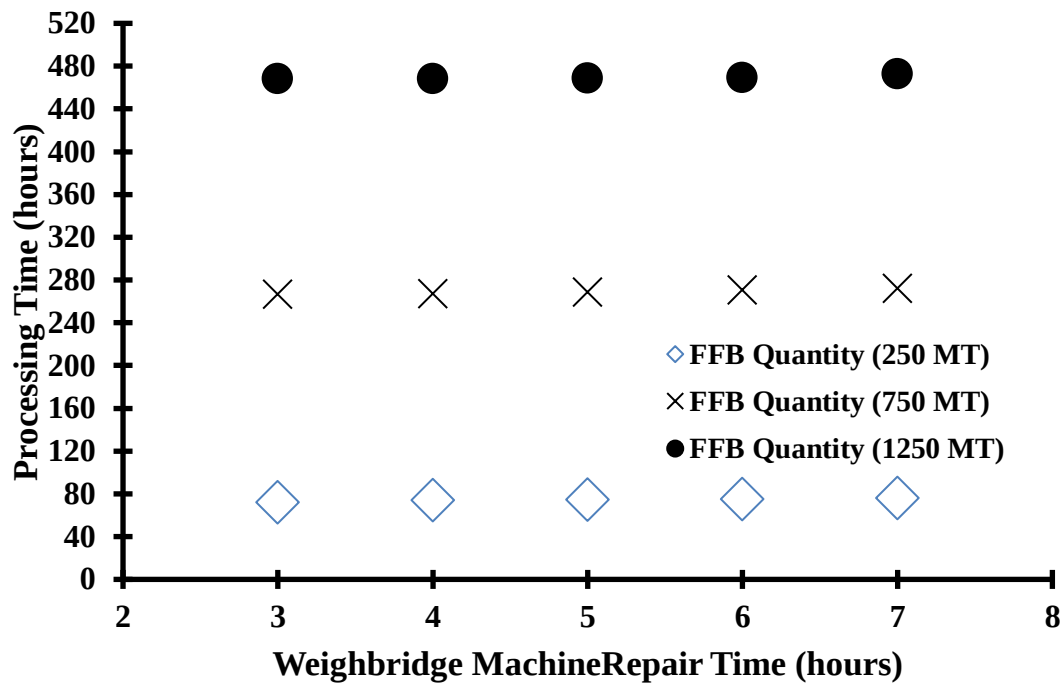


Figure 4.9: Simulated weighbridge machine repair time against simulated processing time at different value of simulated fresh fruit bunches (FFBs) quantity

As anticipated in palm oil industry, the FFBs quantity to be processed is one of factors influencing the processing time; higher quantities naturally require longer processing time. Specifically, a FFBs quantity of 1250 MT resulted in the longest processing time compared to the other FFBs quantity. This is likely because the higher FFBs quantity to be processed, more competition for resource occurs, causing delay in processing and hence longer processing time.

Figure 4.10 shows results for simulating the effect of increasing weighbridge machine repair time—on the simulated processing time at three different simulated inter-arrival times. As shown in Figure 4.10, for all three simulated value of different inter-arrival times, simulated processing time increases slightly as the weighbridge machine repair time becomes longer (from 3 hours to 7 hours). Specifically, an increase of 4 hours, 5 hours and 5 hours, respectively for 1 day, 3 days and 5 days of FFBs inter-arrival time. For all three FFBs interarrival times, when weighbridge machine repair time simulated to be short (3 hours), the simulated processing time is short (298.3 hrs, 266.6 hrs and 235.3 hrs, when the FFBs interarrival time are 1 days, 3 days and 5 days, respectively) because less FFBs quantity queue up while repair work is carried out. On the other hand, when weighbridge machine repair time is simulated to be longer, (7 hours), more FFBs quantity queue up while repair work is carried out, causing delay in processing, hence longer processing time (302.3 hrs, 272.2 hrs and 240.3 hrs, when the FFB interarrival time are 1 days, 3 days, and 5 days, respectively).

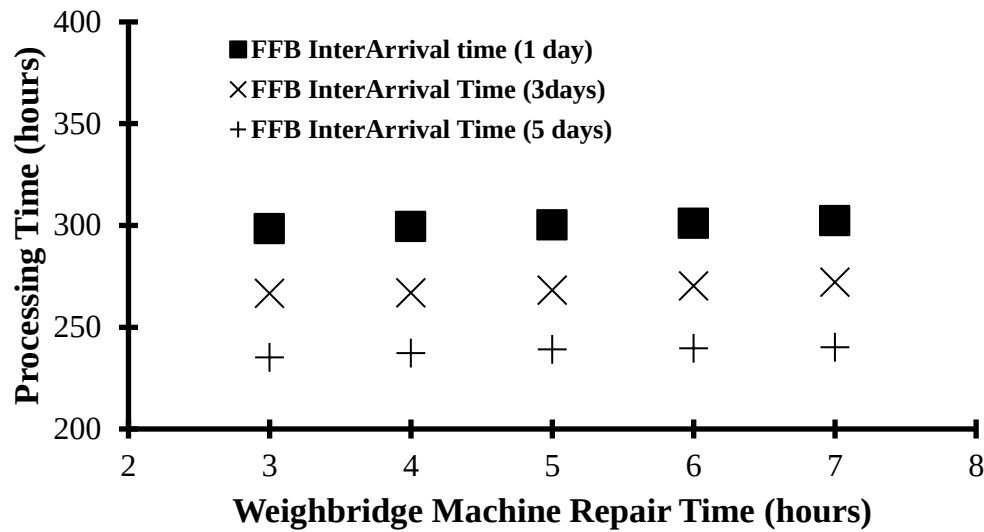


Figure 4.10: Simulated weighbridge machine repair time against simulated processing time at different value of simulated fresh fruit bunches (FFBs) inter-arrival time

As observed in palm oil industry, the FFBs inter-arrival time is one of factors influencing the processing time; frequent FFBs inter-arrival time (hence more FFBs) naturally require longer process time. Specifically, FFBs interarrival time of every 1 day resulted in the longest processing time compared to the other FFBs interarrival times. This is likely because, the higher FFBs quantity to be processed, more competition for resources, hence delay in processing and longer processing time.

Figure 4.11 shows results for simulating the effect of increasing weighbridge machine repair time on the simulated processing time at different simulated tipping repair times. As shown in Figure 4.11, for tipping machine repair time of 8 hours and 10 hours, the simulated processing time increase very minimally as the weighbridge machine repair becomes longer (from 3 hours to 7 hours). For tipping machine repair time of 6 hours, the simulated processing time increase very minimally when the weighbridge machine repair time increases from 3 hours to 6 hours. However, the simulated processing time increases

significantly (40 hours) when the weighbridge repair time is 7 hours. This significant increase is due to FFBs queuing up longer time before the weighbridge can be operational when the weighbridge repair time is 7 hours compared to being repaired for 6 hours. For all three tipping machine repair times, when weighbridge machine repair time is simulated to be short (3 hours), the simulated processing time is short (191.3 hrs, 266.6 hrs and 342.7 hrs, when tipping repair time are 6 hrs, 8 hrs and 10 hrs, respectively) because less FFBs quantity queue up while repair work is carried out. However, when weighbridge machine repair time is simulated to be long (7 hours), more FFBs quantity queue up while repair work is carried, causing high competition for resources, and hence longer processing time (231.4 hrs, 272.2 hrs, 346.7 hrs, when tipping repair time are 6 hrs, 8 hrs and 10 hrs, respectively).

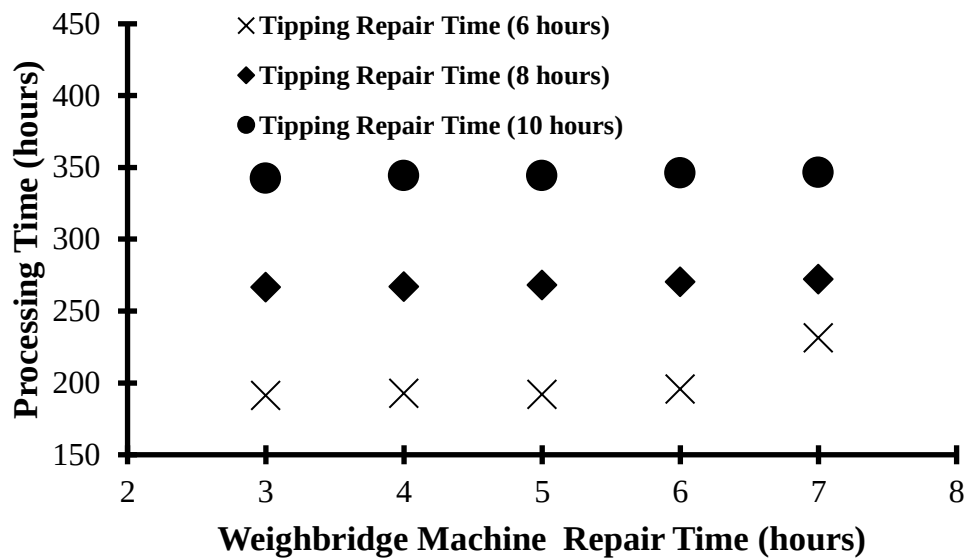


Figure 4.11: Simulated weighbridge machine repair time against simulated processing time at different value of simulated tipping machine repair time

As expected in palm oil industry, the tipping machine repair times is one of the factors affecting the processing time; longer tipping machine repair time causes more FFB quantity to queue up while repair work is carried out, resulting in longer processing time.

Specifically, tipping machine repair time of 10 hours resulted in the longest processing time compared to the other tipping machine repair times. This is likely because longer tipping machine repair time leads to delays, as more FFBs quantity queue up waiting for the tipping machine to be functional again.

As shown in Figures 4.9, 4.10 and 4.11, the small linear relationship between weighbridge repair time and simulated processing time suggest that the graphical method would be suitable for predicting the simulated processing time for a given weighbridge repair time. In addition, the findings that long weighbridge machine repair times, resulted in longer simulated processing time, agrees with the general production theories that, given the same raw materials to be processed, long repair time of any machines in the production system would result in longer production time compared to short repair time. This suggest that the simulated processing time obtained from the simulation model is valid, which also indicates that the simulation model is valid.

d) Validation of the Simulation Model Output with Respect to Tipping Repair Time

Figure 4.12 shows results for simulating the effect of increasing tipping repair time on simulated processing time at three simulated values of FFB quantity. As shown in Figure 4.12, for all three simulated values of FFBs quantity, the simulated processing time increases as the simulated tipping machine repair time becomes longer (from 6 hours to 10 hours). For all three FFBs quantity, when tipping repair time is simulated to be short (6 hours), the simulated processing time is short (52 hrs, 192.3 hrs, 342 hrs when FFBs quantity are 250MT, 750 MT and 1250MT, respectively) because less FFBs quantity queue up while repair work is carried out. However, when tipping machine repair time is simulated to be long (10 hours), more FFBs quantity queue up while repair work is carried out, causing delay

in processing, and hence longer processing time (98.4 hrs, 344.3 hrs and 594.6 hrs, when FFB quantity are 250MT, 750MT and 1250 MT, respectively).

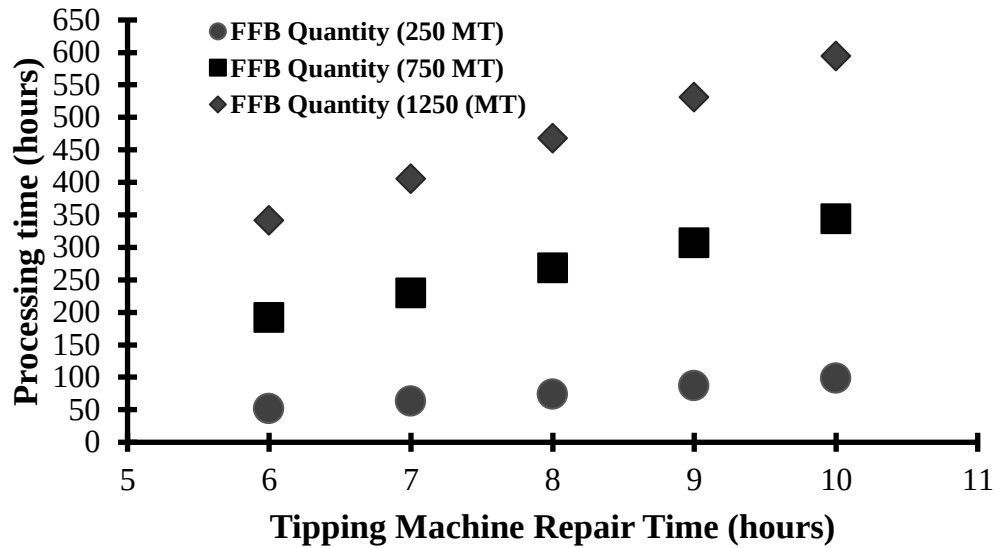


Figure 4.12: Simulated tipping repair time against simulated processing time at different value of simulated fresh fruit bunches (FFBs) quantity

As observed in palm oil industry, tipping machine repair time is one of the factors affecting the processing time; longer tipping machine repair time requires, yields longer processing time. Specifically, It is also worth noting that FFBs quantity do influence the processing time. Specifically, FFBs quantity of 1250 MT resulted in the longest processing time compared to the other FFBs quantity. This is likely because the more FFBs quantity to be processed is high, more competition for resources, thus delay in processing.

Figure 4.13 shows results for simulating the effect of increasing tipping repair time on the simulated processing time at three simulated different FFB inter-arrival times. As shows in Figure 4.13, for all three simulated values of FFB inter-arrival times, the simulated

processing time increases as the tipping machine repair time becomes longer (6 hours to 10 hours). For all three FFBs inter-arrival time, when tipping machine repair time is simulated to be short (6 hours), the simulated processing time is short (224.1 hrs, 192 hrs and 164.1 hrs, when FFBs interarrival time are 1 days, 3 days and 5 days respectively) because less FFBs quantity queue up while repair work is carried out. However, when tipping machine repair time simulated to be long (10 hours), more FFBs quantity queue up while repair work is carried out, causing delay in processing, hence longer simulated processing time (375.9 hrs, 344.3 hrs and 314 hrs, when FFBs inter-arrival time are 1 days, 3 days and 5 days respectively).

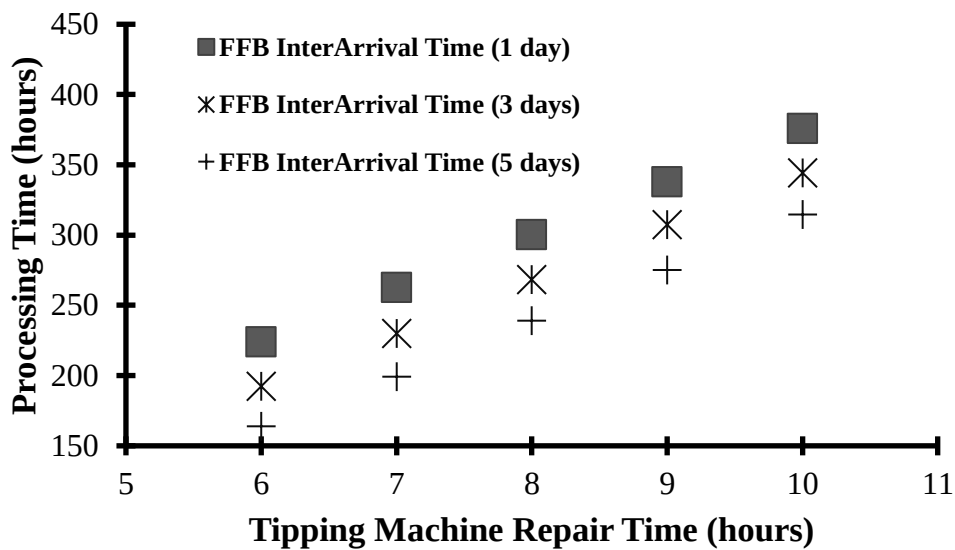


Figure 4.13: Simulated tipping repair time against simulated processing time at different value of simulated fresh fruit bunches (FFBs) inter-arrival time

As observed in palm oil industry, tipping repair time is one of the factors affecting the processing time, longer tipping repair time naturally yield longer processing time. It is also worth noticing that FFBs inter-arrival time do influence processing time. Specifically, FFBs inter-arrival time of every 1 day, resulted in the longest processing time compared to the other FFBs inter-arrival times. This is likely because when FFBs arrival is frequent, more FFB quantity to be processed, more competition for resource, thus delay in processing.

Figure 4.14 shows results for simulating the effect of increasing tipping repair time on simulated processing time at three simulated values of different weighbridge machine repair time. As shown in Figure 4.14, for all three simulated values of weighbridge machine repair times, the simulated processing time increases as tipping machine repair time becomes longer from every (6 hours to 10 hours). For all three weighbridge machine repair times, when tipping machine repair time is simulated to be short (6 hours), the simulated processing time is short (191.3 hrs, 192.3 hrs and 231.4 hrs, when weighbridge repair time are 3 hrs, 5 hrs and 7 hrs) because less FFBs quantity queue up while repair work is carried out. However, when tipping machine repair time simulated to be long (10 hours), more FFBs quantity queue up while repair work is carried out, causing delay in processing, hence longer processing time (342.7 hrs, 344.3 hrs and 346.7 hrs, when weighbridge repair time are 3 hrs, 5 hrs and 7 hrs respectively).

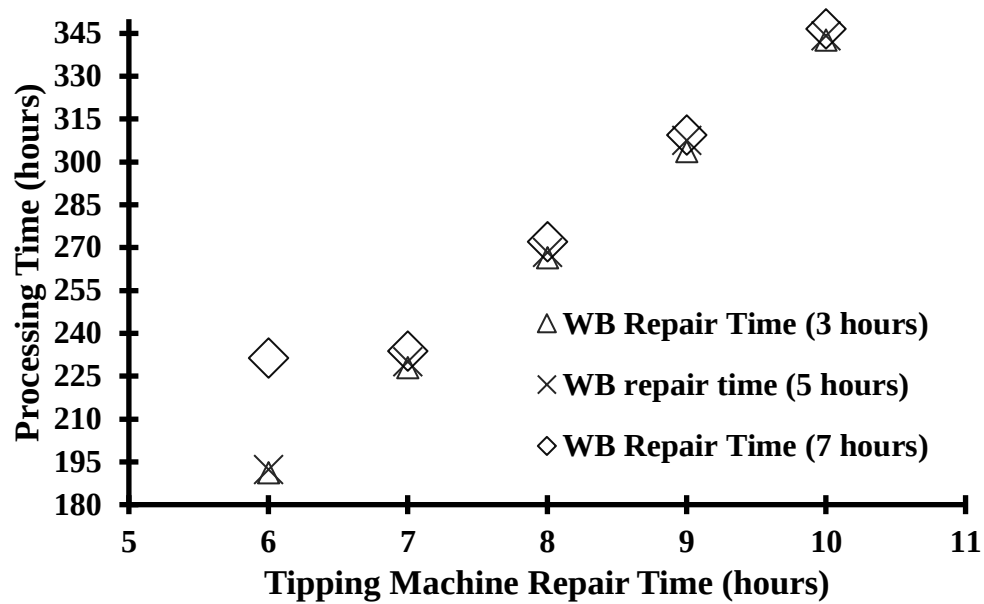


Figure 4.14: Simulated tipping repair time against simulated processing time at different value of simulated weighbridge repair time

As reported in palm oil industry, tipping repair time is one of the factors influencing processing time, longer repair time naturally yield longer processing time. It is worth observing that weighbridge machine repair time do influence the processing time. Specifically, weighbridge machine repair time of (7 hours), resulted in slightly longer processing time compared to the other weighbridge repair times. However, detail analysis (Table A4.2 in Appendix) show that when tipping machine repair time is 10 hours, the simulated processing time differs by only 2 hours for all three weighbridge machine repair times. Given 10 hours is the longest simulated tipping machine repair time, a lot of FFBs queue up before the tipping machine, thus, simulating different values of weighbridge repair time would not affect the simulated processing time significantly.

As shown in Figures 4.12, 4.13 and 4.14, the linear relationship between tipping repair time and simulated processing time indicates that the graphical method would be

suitable for predicting the simulated processing time for a given tipping repair time. In addition, the findings that long tipping repair time, resulted in longer simulated processing time, agrees with the general production theories that, given the same raw materials to be processed, long repair time of any machines in the production system would result in longer production time compared to short repair time. This suggest that the output (simulated processing time) from the simulation model is valid, which also indicated that the simulation model is valid.

4.3 Analysis of Process Factors Affecting the Processing Time under Four Industrial settings

4.3.1 Case A: Crude Palm Oil Production System Operation Time-8 Hours per Day

In Case A, the crude palm oil (CPO) mill is assumed to be operating for 8 hours per day. There are fourteen (14) process factors identified for the screening experiment; these are FFBs quantity, FFBs inter-arrival time, number of weighing machines, weighing time, weighbridge repair time, number of grading machines, grading time, number of workers at loading station, loading time, number of sterilisers, sterilising time, tipping machine repair time, number of digesters and number of pressers. The ANOVA utility within the IBM SPSS version 28 software was used to analyses the main effects of these fourteen (14) process factors on the simulated processing time. The ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence); a p-value of less than 0.05 indicates that a factor was significant.

Case A: Main Effect Analysis of Process Factors Screening Experiment

Referring to Table A4.3 (Appendix C) amongst the fourteen (14) process factors, there are nine (9) process factors which main effects on the simulated processing time are

statistically significant. For these nine (9) process factors (FFBs quantity, tipping machine repair time, weighing time, FFBs interarrival time, number of sterilisers, number of grading machines, number of pressers, weighbridge repair time and sterilizing time), the main and interactions effects need to be further explore using two-level full factorial experiment.

Case A - Main and Interactions Effects Analysis of Full Factorial Experiment for Nine (9) Process Factors

The ANOVA utility within the IBM SPSS version 28 software was used to analyse the main and interactions effects of nine (9) process factors on the simulated processing time. The ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence); a p -value of less than 0.05 indicates that a factor was significant.

Main effect analysis

The ANOVA results (Table A4.4, Appendix C) show that amongst the nine (9) process factors mentioned previously, there are five (5) process factors, (FFBs quantity, FFBs interarrival time, weighbridge repair time, sterilising time and tipping machine repair time) which main effects on the simulated processing time are statistically significant. In descending order of F-value (highest F-value indicates highly significant), these factors are (i) FFBs quantity, (ii) tipping machine repair time, (iii) FFBs interarrival time, and (iv) weighbridge repair time, (v) sterilising time. Previous studies have also found important factors related to FFBs quantity, FFBs inter-arrival time, machineries and sterilising time. Sembiring et al. (2018) found that implementing engine maintenance schedule for machineries and components do affect machine downtime, which consequently influence overall CPO processing time. Susilawati et al. (2019) found that replacement of worn-out machine components is important for improving overall equipment effectiveness (OEE),

hence production throughput. Ishak et al. (2020) found that duration of repair process influence production yield and suggest continuous maintenance as a good practice. Marimin and Zavira (2020) found that machineries such as thresher, digester and boiler are critical to achieve high production throughput of palm oil mill and must be maintained properly. Pakdeechot et al. (2021), found that longer sterilisation time resulted in increased percentage of fruit-bunch separation, increased crude palm oil yield and CPO with acceptable commercial quality.

Figure A4.3 (Appendix C) shows the main effect plots for all five (5) process factors. As expected increasing the quantity of FFBs to be processed would result in longer simulated processing time as more FFBs compete for the same resources. Longer time taken to repair malfunction tipping machine would also result in longer simulated processing time, as the sterilised FFBs cannot be processed in the next process (digestion). Infrequent arrival of FFBs to be processed would also result in shorter simulated processing time, as less quantity of FFBs compete for the same resources. Longer time taken to repair malfunction weighbridge would also result in longer simulated processing time, as the weighbridge machine is not in operation and trucks loaded with FFBs needs to queue up while repair work is carried out. Finally, longer time to sterilise the FFB would result in longer simulated processing time.

The main effects plots also reveals that for significant process factors, the minimum simulated processing time is obtained when the FFB quantity are 250 MT as shown in Figure A4.3(a), FFB inter-arrival time is every 5 days as shown in Figure A4.3(c), weighbridge repair time is 3 hours as shown in Figure A4.3(d), tipping repair time is 6 hours as shown in Figure A4.3(b), and sterilising time is TRIA (90, 100, 110) as shown in Figure A4.3(e). As

for the none-significant process factors, naturally to save cost, the weighing time implemented is TRIA (5, 19, 15), grading machine used is 1 unit, steriliser used is 1 unit and presser used is 1 unit.

Interaction Effects Analysis

The ANOVA results (Table A4.4, in Appendix C) also shows that there are four (4) two-way interactions which effects on the simulated processing time are statistically significant. In descending order of F-value (highest F-value indicates highly significant) these are (i) FFBs quantity*tipping machine repair time, (ii) FFBs quantity*FFBs interarrival time, (iii) FFBs interarrival time*tipping machine repair time and (iv) weighbridge repair time*tipping machine repair time.

The significant interaction between FFBs quantity and FFBs inter-arrival time is shown in Figure A4.4(b) Appendix C. This figure shows that the main effect of FFBs quantity on simulated processing time was different for FFBs interarrival time of every 1 day than it was for FFBs interarrival time of every 5 days. Referring to Figure A4.4(b), closer inspection of the graph showed that, the main effect of FFBs quantity on simulated processing time at FFBs inter-arrival time of every 1 day is slightly steeper than the effect at FFBs inter-arrival time of every 5 days (solid line). It can be observed that the simulated processing time at FFBs inter-arrival time of every 1 day is always higher than the simulated processing time at FFBs inter-arrival time of every 5 days. In addition, detailed analysis shows that when FFBs is 250 MT, difference in the simulated processing time (between inter-arrival of 1 day and inter-arrival of 5 days) is 41 hours. The difference in simulated processing time is 62 hours when FFBs is 1150 MT. This suggest that at high quantity of FFBs, switching to daily arrival of FFBs leads to a much longer simulated processing time due to more FFBs to be processed. Finally, it can be observed that the simulated processing

time is minimum when FFBs Quantity is kept at low level (250 MT) and FFBs inter-arrival is kept at low level (every 5 days). Maximum simulated processing time is obtained when FFBs Quantity is kept at high level (1150 MT) and low FFBs Interarrival time (every 1 day).

From industrial perspective, in order to utilize the maximum capacity of CPO mill receiving and processing high quantity of FFBs is a good practice. However, this would lead to longer processing time, especially when the arrival of FFBs is daily. When mill is operating for only one shift, then over time would be needed to completely process the FFBs; this over time would incur extra cost for the mill. Thus, to reduce and hence maintain optimum processing time (and avoid over time cost), mill could be planned to operate continuously for 2 shifts. In sum, for mill managers, decision making on quantity of FFBs to be processed must consider the frequency of FFBs arrival into the mill.

The significant interaction between FFBs quantity and tipping machine repair time is shown in Figure A4.4(a) Appendix C. This figure indicates that the main effect of FFBs quantity on simulated processing time was different for tipping machine repair time of 6 hours than it was for tipping machine repair time of 12 hours. Referring to Figure A4.4 (a), closer inspection of the graph shows that, the main effect of FFBs quantity on simulated processing time at tipping machine repair time of 12 hours is more significant (steeper slope) than the effect at tipping machine repair time of 6 hours (dotted line). It can also be observed that the simulated processing time at tipping machine repair time of 12 hours is always higher than the simulated processing time at tipping machine repair time of 6 hours. Also detailed analysis show that when FFB is 250 MT, difference in simulated processing time (between repair time of 12 and 6 hours) is 67 hours, while it is 348 hours when FFB is 1150 MT. This suggest that at high quantity of FFBs, very long repair time for tipping machine leads to a

much longer simulated processing time; this is due to more FFBs queue up while repair work is carried out. Finally, it can be observed that simulated processing time is minimum when FFB Quantity is kept at low level (250 MT) and tipping machine repair time is kept at low level (6 hours). Maximum simulated processing time is obtained when FFB Quantity is kept at high level (1150 MT) and high level of tipping machine repair time (12 hours).

From industrial perspective, in order to utilize the maximum capacity of CPO mill receiving and processing high quantity of FFBs is a good practice. However, in the presence of tipping machine downtime and needing repair, FFBs would queue up waiting to be processed, this waiting time would be much longer when repair time is very long. When mill is just operating for only one shift, it would be impossible to process all FFBs within one shift, and over time would be needed, which incur extra cost for the mill. In order to maintain optimum processing time and reduce cost, it is important to carryout daily and preventive maintenance for the tipping machine parts (boogie wheel, the program logic control joystick controller, and tippler chain mechanism operation) in order to avoid breakdown. Management need to keep track of maintenance report, follow maintenance schedule. The workers must be properly train to operate the tipping machine; for example, not to lift up overloaded cage with sterilized FFBs which cause the tipper chain to slip from the bearing. In short, for mill managers, decision making on quantity of FFBs to be processed must consider the working conditions of tipping machines.

The significant interaction between FFBs inter-arrival time and tipping machine repair time, is shown in Figure A4.4(c) Appendix C. This figure shows that the main effect of FFBs inter-arrival time on simulated processing time was different for machine repair time of 6 hours than it was for machine repair time of 12 hours. Referring to Figure A4.4

(c), closer inspection of the graph shows that, the effect of FFBs Inter-arrival on processing time at machine repair time of 12 hours is more significant (steeper slope) than the effect at machine repair time of 6 hours (dotted line). It can also be observed that the simulated processing time at machine repair time of 12 hours is always higher than simulated processing time at machine repair time of 6 hours. Also, detail analysis show that when FFBs Inter-arrival time is every 1 day, difference in simulated processing time (between repair time of 12 and 6 hours) is 213 hours, while it is 202 hours when FFBs Inter-arrival time is every 5 days. This suggest that at frequent arrival of FFBs, very long repair time for tipping machine leads to more FFBs queueing up while repair work is carried out, thus simulated longer processing time. Finally, it can be observed that simulated processing time is minimum when FFBs inter-arrival time is kept at high level (every 5 days) and machine repair time is kept at low level (6 hours). Maximum simulated processing time is obtained when FFBs Inter-arrival time is kept at low level (every 1 day) and high level of machine repair time (12 hours).

From industrial perspective, in order to utilize the maximum capacity of CPO mill daily arrival and continuous processing of FFBs is a good practice. However, in the presence of Tipping Machine downtime and needing repair, FFBs would queue up while repair work is carried and wait to be processed, this waiting time would be much longer when repair time is very long. When mill is just operating for only one shift, it would be impossible to process all FFBs within one shift, and over time would be needed, which incur extra cost for the mill. In order to maintain optimum processing time and reduce cost, it is important to carryout daily and preventive maintenance for the tipping machine parts (boogie wheel, the program logic control joystick controller, and tippler chain mechanism operation) in order to avoid breakdown. Management need to keep track of maintenance report, follow maintenance

schedule. The workers must be properly train to operate the Tipping Machine; for example, not to lift up overloaded cage with sterilized FFBs which cause the tipper chain to slip from the bearing. In short, for mill managers, decision making on arrival of FFBs to be processed must consider the working conditions of tipping machine to ensure maintaining optimum processing time.

Finally, the significant interaction between weighbridge repair time and tipping machine repair time, is shown in Figure A4.4(d) Appendix C. This figure shows that the main effect of weighbridge repair time on simulated processing time was different for tipping machine repair time of 6 hours than it was for tipping machine repair time of 12 hours. Referring to Figure A4.4 (d), closer inspection of the graph shows that, the effect of weighbridge repair time on simulated processing time at machine repair time of 12 hours is slightly significant than the effect at machine repair time of 6 hours (dotted line). It can also be observed that the simulated processing time at tipping machine repair time of 12 hours is always higher than simulated processing time at tipping machine repair time of 6 hours. In addition, detailed analysis show that when weighbridge repair time is 3 hours, difference in simulated processing time (between repair time of 12 and 6 hours) is 208 hours, while it is 207 hours when weighbridge repair time is 6 hours. Finally, it can be observed that simulated processing time is minimum when is weighbridge repair time kept at low level (3 hours) and machine repair time is kept at low level (6 hours). Maximum simulated processing time is obtained when weighbridge repair time is kept at high level (6 hours).

From industrial perspective, in order to utilise the maximum capacity of CPO mill, maintaining good working conditions of machines to avoid breakdown and stoppage is a good practice. When mill is just operating for only one shift, good working conditions of all

machines is very important to ensure all FFBs are processed within the operating hours to avoid over time for the workers. In order to maintain optimum processing time and reduce cost, it is important to make sure that weighbridge and tipping machines are not overloaded with FFBs, carryout daily and preventive maintenance for the weighbridge (checking physical condition) and tipping machine parts (boogie wheel, the program logic control joystick controller, and tippler chain mechanism operation) in order to avoid breakdown. Management need to keep track of maintenance report, follow maintenance schedule, train and remind workers of safety when operating the weighing and tipping machine; for example, not to lift up overloaded cage with sterilized FFBs which cause the tipper chain to slip from the bearing. In short, for mill managers, decision making on arrival of FFBs to be processed must consider the working conditions of machines to ensure maintaining optimum processing time.

Thus, in summary for Case A, there are five process factors (FFBs quantity, tipping machine repair time, FFBs interarrival time, weighbridge repair time, sterilising time) which main effect on the simulated processing time are statistically significant. As for the interaction effects, there are four interactions between factors (FFBs quantity*tipping machine repair Time; FFBs quantity*FFBs interarrival time; FFBs interarrival time*tipping machine repair time; weighbridge repair time*tipping machine repair time) which effects on the simulated processing are significant.

4.3.2 Case B: Crude Palm Oil Production System Operation Time - 12 Hours per Day

In Case B, the mill is assumed to be operating for 12 hours per day. Similar to Case A, there are fourteen (14) process factors (FFBs quantity, FFBs inter-arrival time, number of weighing machines, weighing time, weighbridge repair time, number of grading

machines, grading time, number of workers at loading station, loading time, number of sterilisers, sterilising time, tipping machine repair time, number of digesters and number of pressers) identified for the analysis. IBM Statistical Package for Social Sciences (SPSS) version 28 is used to perform analysis of variance (ANOVA) on the simulated processing time obtained from the simulation runs. The ANOVA was conducted to compare the main effects of these fourteen (14) process factors on the processing time; the ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence). A P-value of less than 0.05 indicates that a factor was significant.

Case B: Main Effect Analysis of Process Factors Screening Experiment

Referring to Table A4.5 (Appendix C) amongst the fourteen (14) process factors, there are five (5) process factors which main effects on the simulated processing time are statistically significant. For these five (5) process factors the main and interaction effects need to be further explore using the two-level full factorial experiment.

Case B - Main and Interactions Effects Analysis of Full Factorial Experiment for Five Process Factors

The ANOVA utility within the IBM SPSS version 23 software was used to analyses the main and interactions effects of five (5) process factors on the simulated processing time. The ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence); a P-value of less than 0.05 indicates that a factor was significant.

Main effects Analysis

The ANOVA results Table A4.6 in Appendix C) showed that amongst the five (5) process factors mentioned above, there are three (3) process factors (FFBs quantity, tipping

machine repair time and FFBs interarrival time) which main effects on the simulated processing time are statistically significant. In descending order of F-value (highest F-value indicates highly significant), these are FFB quantity, tipping machine repair time and FFB inter-arrival time. Similar to Case A, previous studies have also found important factors related to FFBs quantity, FFBs inter-arrival time and machineries. Sembiring et al. (2018) found that implementing engine maintenance schedule for machineries and components do affect machine downtime, which consequently influence overall CPO processing time. Susilawati et al. (2019) found that replacement of worn-out machine components is important for improving overall equipment effectiveness (OEE), hence production throughput. Ishak et al. (2020) found that duration of repair process influence production yield and suggest continuous maintenance as a good practice. Marimin and Zavira (2020) found that machineries such as thresher, digester and boiler are critical to achieve high production throughput of palm oil mill and must be maintained properly.

Figure A4.5 (Appendix C) shows the main effect plots for all three (3) process factors. As shown in Figure A4.5(a), expectedly, increasing the quantity of FFBs to be processed would result in longer simulated processing time as more FFBs compete for the same resources. From Figure A4.5(b) longer time taken to repair malfunction tipping machine would also result in longer simulated processing time, as the tipping machine is not in operation and sterilised FFBs need to queue up to be tipped while repair work is carried out. Finally, as seen in Figure A4.5(c), the FFBs Inter-arrival time also significantly affect the simulated processing time, whereby longer time spent on FFBs delivery from the estate resulted in longer simulated processing.

The main effect plots also reveal that for significant process factors, the minimum simulated processing time is obtained when the FFBs quantity are 250 MT as shown in Figure A4.5 (a), FFBs inter-arrival time is every 5 days as shown in Figure A4.5 (c), and tipping repair time is 6 hours as shown in Figure A4.5(b). As for none-significant factors, naturally to save cost, the weighing time implemented is TRIA (5, 19, 15) and steriliser of 1 unit.

Interaction Effects Analysis

The ANOVA results Table A4.6 in Appendix C) also shows that there are three (3) two-way interactions which effects on the simulated processing time are statistically significant. In descending order of F-value (highest F-value indicates highly significant) these are (i) FFBs quantity and tipping machine repair time, (ii) FFBs quantity and FFBs inter-arrival time, (iii) FFBs inter-arrival time and tipping machine repair time.

The significant interaction between FFBs quantity and FFBs inter-arrival time is shown in Figure 4.6 (a). This figure indicates that the main effect of FFBs quantity on simulated processing time was different for FFBs inter-arrival time of every 1 day than it was for FFBs inter-arrival time of every 5 days. Referring to Figure A4.6(a), closer inspection of the graph shows that, the main effect of FFBs quantity on simulated processing time at FFBs inter-arrival time of every 1 day is more significant than the effect at FFBs inter-arrival time of every 5 days (solid line). It can also be observed that the simulated processing time at FFBs inter-arrival time of every 1 day is always higher than the simulated processing time at FFBs inter-arrival time of every 5 days. In addition, detailed analysis shows that when FFBs is 250 MT, difference in simulated processing time (between inter-arrival of 1 day and inter-arrival of 5 days) is 45 hours. The differences in simulated processing time while it is 94 hours when FFB is 1150 MT. This suggest that at high quantity

of FFBs, switching to daily arrival of FFBs leads to a much longer simulated processing time due to more FFBs to be processed. Finally, it can be observed that the simulated processing time is minimum when FFBs quantity is kept at low level (250 MT) and FFBs inter-arrival is kept at low level (every 5 days). Maximum simulated processing time is obtained when FFBs quantity is kept at high level (1150 MT) and low FFB Interarrival time (every 1 day).

From industrial perspective, in order to utilize the maximum capacity of CPO mill receiving and processing high quantity of FFBs is a good practice. When mill is operating for only one shift, then over time would be needed to completely process the FFBs; this over time would incur extra cost for the mill. Thus, to reduce and hence maintain optimum processing time (and avoid over time cost), mill could be planned to operate continuously for 2 shifts. Similar to Case A, for mill managers, decision making on quantity of FFBs to be processed must consider the frequency of FFBs arrival into the mill.

The significant interaction between FFBs inter-arrival time and tipping machine repair time is shown in Figure A4.6 (b). This figure indicates that the main effect of FFBs inter-arrival time on simulated processing time was different for tipping machine repair time of 6 hours than it was for tipping machine repair time of 12 hours. Referring to Figure A4.6 (b), closer inspection of the graph shows that, the main effect of FFBs inter-arrival on the simulated processing time at tipping machine repair time of 12 hours is more significant than the effect at tipping machine repair time of 6 hours (dotted line). It can also be observed that the simulated processing time at tipping machine repair time of 12 hours is always higher than simulated processing time at tipping machine repair time of 6 hours. In addition, detailed analysis shows that when FFBs inter-arrival time is every 1 day, difference in simulated processing time (between repair time of 12 and 6 hours) is 228 hours, while it is

210 hours when FFBs inter-arrival time is every 5 days. This suggest that at frequent arrival of FFBs, very long repair time for tipping machine leads to more FFBs queueing up while repair work is carried out, thus longer simulated processing time. Finally, it can be observed the simulated processing time is minimum when FFBs inter-arrival time is kept at high level (every 5 days) and tipping machine repair time is kept at low level (6 hours). Maximum simulated processing time is obtained when FFBs inter-arrivals time is kept at low level (every 1 day) and high level of tipping machine repair time (12 hours).

Similar to Case A, from industrial perspective, in order to utilize the maximum capacity of CPO mill, daily arrival and continuous processing of FFBs is a good practice. However, in the presence of tipping machine downtime and needing repair, FFBs would queue up while repair work is carried and wait to be processed, this waiting time would be much longer when repair time is very long. When mill is just operating for only one shift, it would be impossible to process all FFB within one shift, and over time would be needed, which incur extra cost for the mill. Thus, in order to maintain optimum processing time and reduce cost, it is important to carryout daily and preventive maintenance for the tipping machine parts (boogie wheel, the program logic control joystick controller, and tippler chain mechanism operation) in order to avoid breakdown. Management need to keep track of maintenance report, follow maintenance schedule. The workers must be properly train to operate the tipping machine; for example, not to lift up overloaded cage with sterilized FFBs which cause the tippler chain to slip from the bearing. In short, for mill managers, decision making on arrival of FFBs to be processed must consider the working conditions of machines to ensure maintaining optimum processing time.

The significant interaction between FFBs quantity and tipping machine repair time is shown in Figure A4.6 (c). This figure indicates that the main effect of FFBs quantity on simulated processing time was different for tipping machine repair time of 6 hours than it was for tipping machine repair time of 12 hours. Referring to Figure A4.6 (c), closer inspection of the graph shows that, the main effect of FFBs quantity on simulated processing time at tipping machine repair time of 12 hours is more significant than the effect at tipping machine repair time of 6 hours (dotted line). It can also be observed that the simulated processing time at tipping machine repair time of 12 hours is always higher than simulated processing time at tipping machine repair time of 6 hours. Also, detailed analysis shows that when FFBs is 250 MT, difference in simulated processing time (between repair time of 12 and 6 hours) is 61 hours, while it is 376 hours when FFBs is 1150 MT. This suggests that at high quantity of FFBs, very long repair time for tipping machine leads to a much longer simulated processing time; this is due to more FFBs queue up while repair work is carried out. Finally, it can be observed that simulated processing time is minimum when FFB Quantity is kept at low level (250 MT) and tipping machine repair time is kept at low level (6 hours). Maximum simulated processing time is obtained when FFB Quantity is kept at high level (1150 MT) and high level of tipping machine repair time (12 hours).

From industrial perspective, in order to utilize the maximum capacity of CPO mill receiving and processing high quantity of FFBs is a good practice. However, in the presence of tipping machine downtime and needing repair, the FFBs would queue up waiting to be processed, this waiting time would be much longer when repair time is very long. When mill is just operating for only one shift, it would be impossible to process all FFBs within one shift, and over time would be needed, which incur extra cost for the mill. In order to maintain optimum processing time and reduce cost, it is important to carry out daily and preventive

maintenance for the tipping machine parts (boogie wheel, the program logic control joystick controller, and tippler chain mechanism operation) in order to avoid breakdown. Management need to keep track of maintenance report, follow maintenance schedule. The workers must be properly train to operate the Tipping Machine; for example, not to lift up overloaded cage with sterilized FFBs which cause the tipper chain to slip from the bearing. In short, for mill managers, decision making on quantity of FFBs to be processed must consider the working conditions of machines.

Thus, in summary, for case B, there are three process factors (FFBs quantity, tipping machine repair time, and FFBs interarrival time) which main effect on the processing time are statistically significant. As for the interaction effects, there are three (3) two-way interactions (FFBs quantity*tipping machine repair time, FFBs quantity*FFBs inter-arrival time, FFB inter-arrival time*tipping machine repair time) which effects on the processing time are statistically significant.

4.3.3 Case C FFB Quantities at 250 Metric Tonne

In Case C, the Crude Palm Oil (CPO) mill is assumed to be operating for 8 hours per day and 250 metric tonne (MT) of FFBs arrive in one batch at every 1 day. There are twelve (12) process factors identified for the screening experiment; these are number of weighing machines, weighing time, weighbridge repair time, number of grading machines, grading time, number of workers at loading station, loading time, number of sterilisers, sterilising time, tipping machine repair time, number of digesters and number of pressers. The ANOVA utility within the IBM SPSS version 28 software was used to analyses the main and interactions effects of these twelve (12) process factors on the simulated processing time.

The ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence); a P-value of less than 0.05 indicates that a factor was significant.

Case C: Main Effect Analysis of Process Factors Screening Experiment for FFB at 250 Metric Tonne

Referring to Table A4.7 (Appendix C) amongst the twelve (12) process factors, there are three (3) process factors which main effects on the simulated processing time are statistically significant. Thus, for these three (3) process factors the main and interaction effects need to be further explore using the two-level full factorial experiment.

Case C: Main and Interactions Effects Analysis of Full Factorial Experiment for Three Process Factors for FFB at 250 Metric Tonne

The ANOVA utility within the IBM SPSS version 28 software was used to analyses the main and interactions effects of three (3) factors on the simulated processing time. The ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence); a *p*-value of less than 0.05 indicates that a factor was significant.

Main effects Analysis

The ANOVA results (Table A4.8 in Appendix C) showed that amongst the three (3) process factors mentioned above, there are two (2) process factors (weighbridge repair time and tipping machine repair time) which main effects on the simulated processing statistically significant. In descending order of F-value (highest F-value indicates highly significant), these are tipping machine repair time and weighbridge repair time. Previous studies have also found important factors to be related to machineries. Sembiring et al. (2018) found that implementing engine maintenance schedule for machineries and components do affect

machine downtime, which consequently influence overall CPO processing time. Susilawati et al. (2019) found that replacement of worn-out machine components is important for improving overall equipment effectiveness (OEE), hence production throughput. Ishak et al. (2020) found that duration of repair process influence production yield and suggest continuous maintenance as a good practice. Marimin and Zavira (2020) found that machineries such as thresher, digester and boiler are critical to achieve high production throughput of palm oil mill and must be maintained properly.

Figure A4.7 (Appendix C) shows the main effect plots for all two (2) process factors. Referring to Figure A4.7(a), as expected, longer tipping machine repair time, would result in longer simulated processing time; when the tipping machine is not in operation, the sterilized FFBs need to queue up to be tipped while repair work is carried out. Also, as shown in Figure A4.7(b), longer weighbridge repair time would result in longer simulated processing time because FFBs need to queue up while repair work is carried out.

The main effect plots also revealed that for significant process factors, the minimum simulated processing time is obtained when the tipping machine repair time are 6 hours as shown in Figure A4.7 (a), and weighbridge repair is 3 hours as shown in Figure A4.7 (b). As for the none significant process factor, naturally to save cost, the sterilising implemented is TRIA (90, 100, 110) minutes.

Interaction Effects Analysis

The ANOVA results (Table A4.8 in Appendix C) also shows that there are no significant two-way interactions amongst the three factors. The nonsignificant interaction between weighbridge repair time and tipping machine repair time indicates that weighbridge repair time significantly affected the simulated processing at all levels of tipping machine

repair time. Also, the nonsignificant interactions between tipping machine repair time and weighbridge repair time suggest that tipping machine repair time significantly affected the simulated processing time at all levels of weighbridge machine as shown in Figure A4.8. In other words, the main effect of weighbridge repair time on processing time was the same for tipping machine repair time of 12 hours as it was for tipping machine repair time of 6 hours.

It can be observed that the simulated processing time at tipping machine repair time of 12 hours is always higher than as the simulated processing time at tipping machine repair of 6 hours. In addition, detailed analysis shows that when weighbridge repair time is 3 hours difference in simulated processing time (between tipping machine repair time of 6 and 12 hours) is 78 hours. The difference in simulated processing time is 78 hours when weighbridge repair time is 6 hours. Finally, it can be observed that the simulated processing time is minimum when weighbridge repair time is kept at low level, 3 hours and tipping machine repair time is kept at low level, 6 hours. Maximum simulated processing time is obtained when weighbridge repair time is 6 hours and sterilising time is kept at high level, 12 hours.

From industrial perspective, short weighbridge repair and tipping machine repair time is good for attaining short simulated processing time. Weighbridge must be always in good working condition to avoid any delay in processing the FFB; thus daily and preventive maintenance is important. Management need to keep track of maintenance report, follow maintenance schedule, train and remind workers of safety when operating the weighbridge. Also, it is important to carryout daily and preventive maintenance for the tipping machine parts (boogie wheel, the program logic control joystick controller, and tippler chain mechanism operation) in order to avoid breakdown. Management need to keep track of

maintenance report, follow maintenance schedule. The workers must be properly train to operate the Tipping machine; for example, not to lift up overloaded cage with sterilised FFBs which cause the tipper chain to slip from the bearing. In short, sustaining tipping machine in good working condition is critical to avoid long simulated processing time regardless of the sterilising time being short or long.

Thus, in summary for case C, there are two factors (tipping machine repair time, weighbridge repair time) which main effects on the simulated processing time are statistically significant. As for the interaction effects, there are no interactions between factors which effects on the simulated processing time are statistically significant.

4.3.4 Case D FFB Quantities at 1150 Metric Tonne

In Case D, the Crude Palm Oil (CPO) mill is assumed to be operating for 8 hours per day, however the quantity of FFBs that arrived every day at the CPO mill is assumed to be 1150 metric tonne (MT). Also similar to Case C, there are twelve (12) process factors (number of weighing machines, weighing time, weighbridge repair time, number of grading machines, grading time, number of workers at loading station, loading time, number of sterilisers, sterilising time, tipping machine repair time, number of digesters and number of pressers) are identified for the screening experiment.

IBM Statistical Package for Social Sciences (SPSS) version 28 is used to perform analysis of variance (ANOVA) on the simulated processing time obtained from the simulation runs. The ANOVA was conducted to compare the main effects of these twelve (12) process factors on the simulated processing time; the ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence). A P-value of less than 0.05 indicates that a factor was significant.

Case D- Main Effect Analysis of Process Factors Screening Experiment for FFB at 1150 Metric Tonne

The ANOVA results (Table A4.9 in Appendix C) showed that amongst the twelve (12) process factors, there are four (4) process factors which main effects on the simulated processing time are statistically significant. Thus, for these four (4) processes factors (tipping machine repair time, weighbridge repair time, weighing time and sterilising time) the main and interactions effects need to be further explore using the two-level full factorial experiment.

Case D: Main and Interactions Effects Analysis of Full Factorial Experiment for Four Process Factors for FFB at 1150 Metric Tonne

The ANOVA utility within the IBM SPSS version 28 software was used to analyse the main and interactions effects of four (4) process factors on the simulated processing time. The ANOVA was conducted at a significant level alpha (α) of 0.05 (95% confidence); a p -value of less than 0.05 indicates that a factor was significant.

Main effect analysis

The ANOVA results (Table A4.10, in Appendix C) showed that for all four (4) process factors mentioned above, the main effects on simulated processing time are statistically significant. In descending order of F-value (highest F-value indicates highly these four factors are tipping machine repair time, weighbridge repair time, sterilising time and weighing Time.

Previous studies have also found important factors related to machineries, working method and sterilising time. Sembiring et al. (2018) found that implementing engine maintenance schedule for machineries and components do affect machine downtime, which consequently influence overall CPO processing time. Susilawati et al. (2019) found that replacement of worn-out machine components is important for improving overall equipment effectiveness (OEE), hence production throughput. Ishak et al. (2020) found that duration of repair process influence production yield and suggest continuous maintenance as a good practice. Marimin and Zavira (2020) found that machineries such as thresher, digester and boiler are critical to achieve high production throughput of palm oil mill and must be maintained properly.

For factors related to working method, Ishak et al. (2019) found that FFBs sorting time, stacking and weighing time and unloading time were factors that affect the CPO processing time. Ishak et al. (2020) also found that working method that involves sorting and receiving of FFBs affect the production yield (or throughput) of palm oil mill. Racedo-Gutierrez et al. (2020), found that working method that consider different unloading strategies do influence the waiting time for a vehicle in the mill, subsequently affect the CPO processing time. Pratma and Susilawati (2021) also found that good working method at several stations (sorting, loading, sterilising, purification and storage) is critical for improving productivity.

Figure A4.9 (Appendix C) shows the main effect plots for all four (4) process factors. As expected, shown in Figure 4.9(a), longer time taken to repair malfunction tipping machine would also result in longer simulated processing time, as the tipping machine is not in operation and sterilized FFBs need to queue up to be tipped while repair work is carried

out. Referring to Figure 4.9(b), longer weighbridge repair time would also result in longer simulated processing time as FFBs queue up to be weighed while repair work is carried out. Increasing the sterilizing time (as shown in Figure A4.9(c)) would also result in longer simulated processing time as sterilized FFBs are delayed for the next process. Finally, as seen from Figure A4.9(d) increasing the weighing time at weighing station would result in longer simulate processing time because FFBs would be delayed for the next process.

The main effects plots also reveals that for significant process factors, the minimum simulated processing time are tipping machine repair time are 6 hours as shown in Figure A4.9 (a), weighbridge repair time is 3 hours as shown in Figure A4.9 (b), sterilising time is TRIA (90, 100, 110) as shown in Figure A4.9 (c) and weighing time is TRIA (5, 10, 15) as shown in Figure A4.9 (d).

Interaction effects analysis

The ANOVA results (Table A4.10, in Appendix C) also shows that there are two (2) two-way interactions which effects on the simulated processing time are statistically significant. In descending order of F-value (highest F-value indicates highly significant) these are weighing time*weighbridge repair time and weighbridge repair time*sterilising time.

The significant interaction between weighbridge repair time and sterilising time is shown in Figure A4.10 (b). This figure indicates that the significant main effect of weighbridge repair time on simulated processing time was different at sterilising time of TRIA (90, 100, 110) minutes than it was at sterilising time of TRIA (130, 140, 150) minutes. Detailed analysis show that the main effect of weighbridge repair time on simulated processing time is more significant at sterilising time of TRIA (130, 140, 150). It can also

be observed that the simulated processing time at sterilising time of TRIA (130, 140, 150) minutes is always higher than the simulated processing time at sterilising time of TRIA (90, 100, 110) minutes. In addition, detailed analysis shows that when weighbridge repair time is 3 hours, the difference in simulated processing time (between sterilising time of TRIA (90, 100, 110) and TRIA (130, 140, 150) minutes) is 1 hour. The differences in simulated processing time is also 1 hour when weighbridge repair time is 6 hours. Finally, it can be observed that the simulated processing time is minimum when weighbridge repair time is kept at low level (3 Hours) and sterilising time is kept at low level (TRIA 90, 100, 110 minutes). Maximum simulated processing time is obtained when weighbridge repair time is kept at high level (6 Hours) and high sterilising time (TRIA 130, 140, 150 minutes).

From industry perspective, short weighbridge repair and sterilising time is good for accomplishing short processing time. Weighbridge must be always in working condition to avoid any delay in processing the FFBs; thus, daily and preventive maintenance is important. Management need to keep track of maintenance report, follow maintenance schedule, train and remind workers of safety when operating the weighbridge. It is also critical to grade the incoming FFBs properly into the relevant category and setting the correct time to sterilize the different category of FFBs. In sum, maintaining weighbridge in good working condition is critical to avoid long processing time regardless of the sterilising time being short or long.

The significant interaction between weighing time and weighbridge repair time is shown in Figure A4.10 (a). This figure shows that the main effect of weighing time on simulated processing time was different at weighbridge repair time of 3 hours than it was for weighbridge repair time of 6 hours. Referring to Figure A4.10 (a), closer inspection shows that, the main effect of weighing time on simulated processing time at weighbridge repair

time of 6 hours is more significant than the main effect at weighbridge repair time of 3 hours. It can also be observed that the simulated processing time at weighbridge repair time of 6 hours is always higher than simulated processing time at weighbridge of 3 hours. Also, detailed analysis shows that when weighing time is TRIA (5, 10, 15) minutes, the difference in simulated processing time (between weighbridge repair time of 3 and 6 hours) is 3 hours, while it is 4 hours when weighbridge repair time is TRIA (25, 30, 35). This suggest that at long weighing time, very long weighbridge repair time leads to longer simulated processing time, which is due to more FFBs queuing up prior to weighing and waiting for repair work. Finally, it can be observed that simulated processing time is minimum when weighing time is kept at low level (TRIA 5, 10, 15 mins) and weighbridge repair time is kept at low level (3 Hours). Maximum simulated processing time is obtained when weighing time is kept at high level (TRIA 25, 30, 35 mins) and high level of weighbridge repair time (6 Hours).

From industry perspective, short weighing and weighbridge repair time is good for realizing short processing time. Weighbridge must be always in working condition to avoid any delay in processing the FFBs; thus, daily and preventive maintenance is important. Management need to keep track of maintenance report, follow maintenance schedule, train and remind workers of safety when operating the weighbridge. Thus, maintaining weighbridge in good working condition is critical to avoid long processing time.

In summary, for case D, there are four process factors (tipping machine repair time, weighbridge repair time, sterilising time and weighing time) which main effects on the processing time are statistically significant. As for the interaction effects, there are two two-way interactions (weighing Time*weighbridge repair time and weighbridge repair time*sterilising time) which effects on the processing time are statistically significant.

4.3.5 Combined Process Factor Analysis Under Assumed Four Industrial Settings

Results showed that for case A, the combinations of process factors and corresponding values that resulted the shortest simulated CPO processing time (approximately 42 hours) correspond to FFBs quantity of 250 metric tonnes (MT), FFBs arrival at every 5 days, weighbridge repair time of 3 hours, tipping machine repair time of 6 hours, sterilisation time of TRIA (90,100,110), and one pressing machine, regardless of a short or long weighing time, one or three gradings, and sterilisation machines. In other words, when 250 MT (FFBs quantity) arrive at every 5 days and the sterilisation time is short, despite a long weighing time, one grading, sterilisation, and pressing machine each, as long as the weighbridge and tipping machine repair times are short, the simulated CPO processing time is still the shortest.

Results also showed that for case A, the combination of process factors and corresponding values that resulted the longest simulated CPO processing time (approximately 696 hours) corresponds to FFBs quantity of 1150 MT, FFBs arrival at every 1 day, weighing time of TRIA (25,30,35), weighbridge repair time of 6 hours, and tipping machine repair times of 12 hours, three grading, sterilising, and pressing machines each; and sterilisation time of TRIA(90,100,110). In other words, when 1150 MT of FFBs arrive at every 1 day, despite the short sterilisation time, three grading, sterilisation, and pressing machines each, if the weighing, weighbridge, and tipping repair times are longer, the simulated CPO processing time is still the longest.

As for case B, results showed that the combination of process factors and corresponding values that yielded the shortest simulated CPO processing time (33 hours) corresponds FFB quantity of 250 MT, FFBs arrival at every 5 days, tipping machine repair

time of 6 hours and one sterilisation machine, regardless of the short or long weighing time. In other words, when 250 MT of FFBs arrive at every 5 days, with a short tipping repair time and one sterilising machine, even if the weighing process time is long, the simulated CPO processing time is still the shortest.

Results also showed that for case B, the combination of process factors and corresponding values that yielded the longest simulated CPO processing time (approximately 740 hours) correspond to FFBs quantity of 1150 MT, FFBs arrival at every 1 day, tipping machine repair time of 12 hours, regardless of the short or long weighing time and one or three sterilisation machines. In other words, when 1150 MT of FFBs arrive at every 1 day, regardless of the short weighing time and three sterilisation machines, if the tipping machine repair time is long, the simulated CPO processing time is still the longest.

As for case C, results showed that the combination of process factors and corresponding values that resulted the shortest simulated CPO processing time (approximately 72 hours) corresponds to weighbridge repair of 3 hours, sterilising time of TRIA (90, 100, 110) minutes and tipping machine repair time of 6 hours. In other words, when 250 metric tons of FFBs arrive at every 1 day, with a short weighbridge and tipping machine repair time, together with short sterilising time, the simulated CPO processing time would be the shortest.

Results also show that for case C, the combination of process factors and corresponding values that resulted the longest simulated CPO processing time (approximately 153 hours) correspond to weighbridge repair time of 6 hours, sterilising time of TRIA (130, 140, 150) minutes and tipping machine repair time of 12 hours. In other words, when 250 metric tons of FFBs arrive at every 1 day, with a long weighbridge and

tipping machine repair time, together with long sterilising time, simulated CPO processing time would be the longest.

As for case D, results showed that the combination of process factors and corresponding values resulting the shortest simulated CPO processing time (approximately 342 hours) corresponds to weighing time of TRIA (5, 10, 15) minutes, weighbridge repair of 3 hours, sterilising time of TRIA (90, 100, 110) minutes and tipping machine repair time of 6 hours. In other words, when 1150 MT of FFBs arrive at every 1 day, with short weighing time, weighbridge and tipping machine repair time, together with short sterilising time, the simulated CPO processing time would be the shortest.

Finally, results also show that for case D, the combination of process factors and corresponding values yielding the longest simulated CPO processing time (approximately 694 hours) correspond to weighing time of TRIA (25, 30, 35) minutes, weighbridge repair time of 6 hours, sterilising time of TRIA (130, 140, 150) minutes and tipping machine repair time of 12 hours. In other words, when 1150 MT of FFBs arrive at every 1 day, with long weighing time, weighbridge and tipping machine repair time, together with long sterilising time, the simulated CPO processing time would be the longest.

4.4 Proposal for Managerial Strategies/Actions that Reduces the Crude Palm Oil Processing Time

To enhance the performance of crude palm oil (CPO) production system of the case company, some methods are proposed.

For case A there are five process factors (FFBs quantity, tipping machine repair time, FFBs inter-arrival time, weighbridge repair time, and sterilizing time) that significantly affect the simulated processing time. While for case B, there are three factors (FFBs quantity,

tipping machine repair time and FFBs inter-arrival time) that significantly affect the simulated processing time. Then, the three common process factors for case A and case B are FFBs quantity, tipping machine repair time and FFBs inter-arrival time.

For the process factor FFBs quantity, the manager should monitor the load of FFBs received (MT) for each delivery, and ensure there is remaining load to start the process for the next morning. For example, a remaining of 10 cages should be available for the next morning to start the daily processing. If the FFBs quantity to be processed is high, the supervisor needs to strictly monitor that the arriving FFBs is processed according to the first in first out (FIFO) rule at the grading station area. This means that the FFBs delivered to the mill at early hours will be transferred first to the loading ramp door and loaded to the empty cages at the loading ramp station. Next, ensure that the shovel machinery is available and in working condition, so that FFBs can be lifted or transferred to other stations in a short time.

For the process factor tipping machine to avoid long downtime during repair process, the manager should (a) allocate more additional time for maintenance days such as every Sunday, (b) identify minor or major maintenance works (such as changing bearings, inspection for belting for which station that critical, (c) conduct a proper training for the operators to use the machine based on the correct standard operating procedures (SOP), (d) ensure the “logbook” for each machine are filled by the operator and monitored by the supervisor on duty and (e) monitor the maintenance schedule (3 to 6 month and 6 to 12 months periodically).

To avoid long processing time due to infrequent FFBs inter-arrival time, the mill manager should notify the estate or other shareholders to send the FFB at the designated time. For example, it is mandatory to deliver FFBs in the morning (7am-9am), noon (12-

1pm), (3pm-5pm) and avoid delivery after 9 pm. Also, manager should monitor delivery of FFBs to the mill (based on number of trips) for FFBs delivery from own mill's estate or outside estate. If the number of trips is higher in the morning, then CPO production can be started early during the morning shift and ended at the evening shift. However, if the number of trips received are low at the morning time, then CPO production would begin during the next morning shift.

For the process factor weighbridge machine, to avoid long downtime during repair process, the manager should (a) allocate appropriate maintenance schedule to avoid the major breakdown at the weighbridge station, (b) allocate a special number of mechanics or technician who repairs the weighbridge so that there is no waiting time to fixed the weighbridge when breakdown happen, (c) ensure weighbridge machine is always calibrated, and (d) ensure the truck driver vehicle follow the weighing SOP when delivering the FFBs at the weighbridge station to avoid overloading the weighbridge.

For the process factor sterilising time, to ensure it is short, the manager must ensure (a) the capacity of two units steriliser at the mill must follows the maximum standard of 5 full cages and (b) train the steriliser operator the proper or correct way for steriliser handling. For example, avoid the used of wire rope slip from the transfer carriage. This will take longer time to pull the slip cages using the wire rope, (c) use the correct sterilising time based on the type of FFBs ripeness (unripe, under ripe, ripe, over ripe) for daily processing day, (d) ensure sufficient delivery of steam from the boiler house into the steriliser. If there is insufficient supply of steam, the FFBs needed to be re-sterilised and the sterilising time is set to the maximum time, and (e) ensure no steam leakage during sterilisation process. If there is steam leakage, this problem needs to be fixed first, thus the sterilising process need

to be stopped, and this would affect the CPO processing time since, especially when there is only steriliser in operation.

For case C there are (2) process factors that significantly affect the simulated processing time. These factors are tipping machine repair time and weighbridge repair time. While for case D, there are four process factors that significantly affect the simulated processing time, namely tipping machine repair time, weighbridge repair time, sterilising time, and weighing time. Thus, for case C and D, there are two common factors (tipping machine repair time, and weighbridge repair time) that significantly affect the simulated processing time. Given these two process factors are similar to case A and case B, then similar strategies could be proposed to manage tipping and weighbridge machines repair times. Also, for process factor sterilising time, which is also significant for case A, similar strategies proposed for case A could be proposed for case C.

Finally, the process factor weighing time, manager needs to ensure (a) the FFBs truck driver complete the delivery form with correct information (driver's name, estate name, vehicle number, and driver signature) which help the clerk to quickly update the information into the system (b) the clerk on duty at the weighbridge follows the correct SOP such as not weighing wet consignment and making sure nobody sits inside truck during weighing process, (c) ensure the weighbridge is regularly calibrated to ensure correct reading according to the prescribed range of scale, (d) ensure the FFBs delivery vehicle is in good condition to avoid breakdown during the weighing process, (e) ensure stable internet connection to save time used for the data update process in the MPOB system.

4.5 Summary

This Chapter 4 has presented results related to the research objectives. Specifically, subsection 4.1 has introduces the chapter content, section 4.2.1 has presented architecture of the CPO production system's simulation model that included eight (8) segments, segment 1 (FFB arrival, weighbridge repair and weighing process), segment 2 (grading process), segment 3 (loading process), segment 4 (sterilising process), segment 5 (cages and tipping machine repair), segment 6 (digestion process), segment 7 (pressing process) and segment 8 (clarification and downstream process). Subsection 4.2.2 has presented validation of the simulation model output against data from the case study company. Section 4.2.3 has discussed validation of the simulation model output against production theory. Based on results in subsections 4.2.2 and 4.2.3 the simulation model is valid. Sections 4.3.1, 4.3.2, 4.3.3 and 4.3.4 have presented results from the simulation experiments under the assumed four (4) industrial settings (case A, B, C, D). In both cases A and B fourteen process factors (14) have been considered; with mill operating time are 8 hours and 12 hours respectively. For case C and D twelve (12) process factors have been considered, with FFBs arriving quantity of 250 MT and 1150 MT respectively. Section 4.3.5 has provided analysis of process factors combinations that resulted in the shortest and longest simulated CPO processing time under the assumed four industrial settings. Section 4.4 provides proposals for strategies and actions to manage the CPO processing time, and section 4.5 provided the chapter summary.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Section 5.1 provides conclusions to the research objectives defined in Chapter 1. Specifically, conclusions observed from this research work are presented in section 5.1.1, 5.1.2, 5.1.3 and 5.2.

5.1.1 Simulation Model Development, Verification and Validation

A simulation model of the crude palm oil (CPO) production system has been created using the ARENA simulation platform. The model consists of eight segments, including FFB arrival, weighbridge repair, grading, loading, sterilizing, cages and tipping machine operation, digestion, pressing, and clarification. The model was rigorously verified using standard animation techniques to accurately reflect the operational assumptions of the actual production system. The model's outputs were validated against real-world industry data, revealing a minor 5% deviation in average CPO processing time. Sensitivity analysis was conducted to ensure consistency with theoretical production time trends. The results confirmed the model's reliability and effectiveness in simulating CPO production processes. This rigorous validation process has made the simulation model a robust tool for assessing and optimizing various aspects of CPO production, enabling informed decision-making and process improvements in the industry.

5.1.2 Factors Analysis Under Four Industrial Settings

For A and B, 14 process factors were considered and CPO production system operating time were 8 and 12 hours respectively. For C and D, twelve process factors were considered and with FFBs quantity being were 250 MT and 1150 MT respectively.

For Case A, five process factors (FFBs quantity, tipping machine repair time, FFBs interarrival time, weighbridge repair time, and sterilising time) are significant. For Case B, three process factors (FFBs quantity, tipping machine repair time, and FFBs interarrival time) are significant. For case A, four interactions between factors (FFBs quantity*tipping machine repair Time; FFBs quantity*FFB interarrival time; FFBs interarrival time*tipping machine repair time; weighbridge repair time*tipping machine repair time) are significant. The combination of FFB quantity and tipping machine repair time was the topmost interaction affecting the CPO processing time. For case B, three interactions between factors (FFBs quantity*tipping machine repair Time; FFBs quantity*FFBs interarrival time, FFB sinter-arrival time*tipping machine repair time.) are significant. Similar to Case A, the combination of FFB quantity and tipping machine repair time was the topmost interaction affecting the CPO processing time. Case A experience more accumulation of FFBs in the system than Case B due to the shorter operating time for processing the FFBs. These FFBs accumulation is more when weighbridge machine repair time and sterilising time are longer. Thus, weighbridge machine repair time, sterilising time, interaction between weighbridge repair time*tipping machine repair time are significant only in Case A.

In Case C, two process factors (tipping machine repair time and weighbridge machine repair) are significant. In Case D, four process factors (tipping machine repair time, weighbridge machine repair time, sterilising time, and weighing time) are significant. For

case C, no interactions between these factors are significant. For case D, the combination of (i) weighing time and weighbridge repair time, and (ii) combination of weighbridge repair time and sterilizing time are significant. Case D experience more FFBs quantity in the system than case C, due to higher volume of incoming FFBs per batch. These FFBs accumulates more when the weighing time and sterilising time are longer. Thus, weighing time, sterilising time, interaction between weighing time*weighbridge repair time and weighbridge repair time*sterilising time are significant only in Case D.

5.1.3 Managerial Strategies

Strategies for managing fresh fruit bunches (FFBs) are monitoring load of FFBs received, ensuring first-in-first-out (FIFO) processing, monitoring delivery FFBs to the mill, notifying shareholders, and ensuring completion of correct form, maintaining accurate records. For the weighbridge station, management strategies are to ensure shovel machine in working condition, equipment available, compliance with standard operating procedures (SOPs), on time calibration and maintenance schedules, mechanics or technicians are allocated, delivery truck in good condition, and stable internet connection. For machine maintenance strategies are to train operators, maintain comprehensive maintenance logbooks, allocate extra maintenance time, identify minor or major maintenance works and monitor maintenance schedules periodically. Finally, for sterilizer strategies are to ensure capacity complying with the maximum standard, proper training of operators, correct sterilization time based on FFBs ripeness, sufficient steam supply and piping systems in good condition.

Efficient management of FFBs is the most impactful managerial strategy for increasing productivity in CPO production. By accurately tracking FFBs quantity received, processing according to FIFO rules, and adjusting processing schedules, production workflow is smoothened, bottlenecks caused by prioritizing certain batch are prevented, idle time is minimised, and utilisation of machines are maximised. By ensuring on time deliveries of FFBs from mill's own estates and external suppliers at designated times, steady flow of FFBs is received, idle time is minimised, and resources utilisation are maximised.

5.2 Limitation and Recommendations for Future Works

Limitations and recommendations are as follows. First, processing time for each process was based on case study company's daily reports, which may not be accurate as time were estimated based visual observations. It is recommended to use proper recording devices (stopwatch) to capture the start and end time for each process. Second, the tipping machine repair time was assumed to follow Constant distribution for the overall repair process. It is recommended to collect data on individual components repair process, determine the statistical distribution for each component repair time and simulate this individual repair process being performed by trained technicians. Third, FFBs after grading were not sorted into the correct grade (under ripe, ripe, over ripe) before the next process. Thus, one sterilising mode was assumed for the same batch of FFBs, despite different levels of ripeness. It is recommended to grade the FFBs into the correct grade (under ripe, ripe, over ripe) and then use the corresponding sterilising mode to process the different grade.

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APPENDIX: CONFERENCE AND JOURNAL PUBLICATIONS

Inyang, J., Andrew-Munot, M., Shazali, S. T. S, & Tanjong, S. J. (2019). A Model to Manage Crude Palm Oil Production System. *In: Proceedings of Engineering Application of Artificial Intelligence Conference 2018 (EAAIC 2018)*, Sutera Harbour Resort, Kota Kinabalu, Malaysia, 3-5 December, 2018. EDP Sciences.

Andrew-Munot, M., **Inyang**, J., Tanjong, S. J., Syed-Tarmizi, S. T. & Junaidi, E. (2023). Effects of Multiple Variable Factors on Crude Palm Oil Processing Time: A Simulation-Based Approach. *Journal of Engineering Science and Technology*, 18(4), 1805-1830.

APPENDIX: CHAPTER A

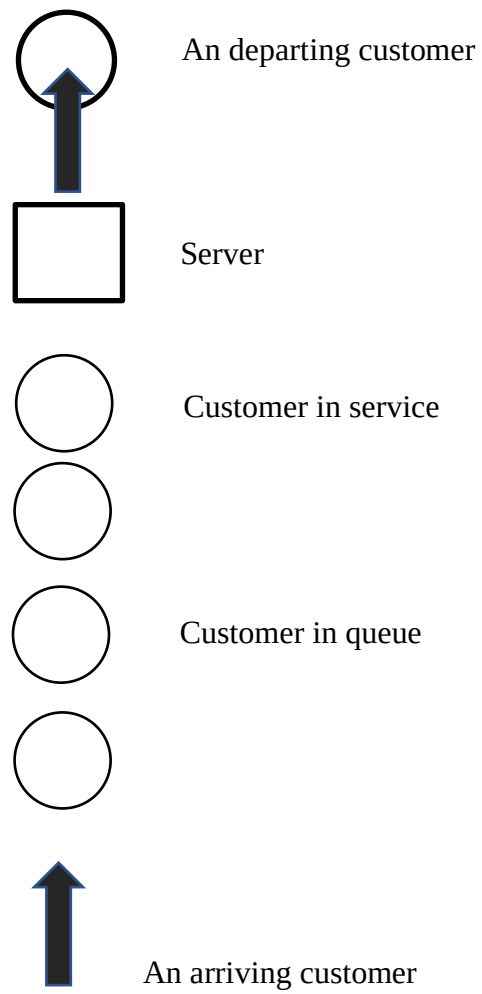


Figure A2.1: A single-server queueing system

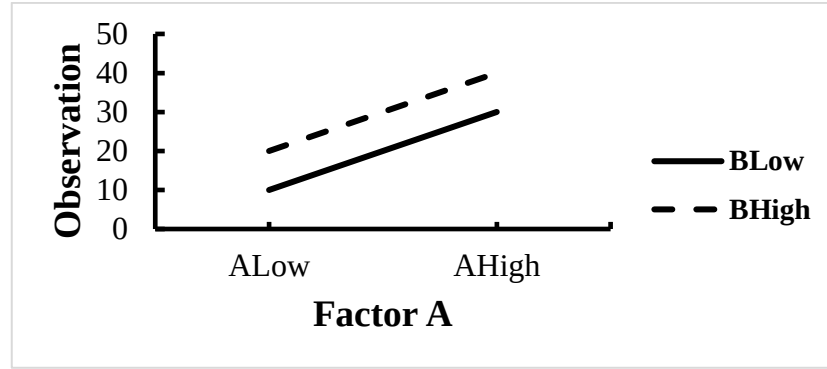


Figure A2.2: Factorial experiment, no interaction

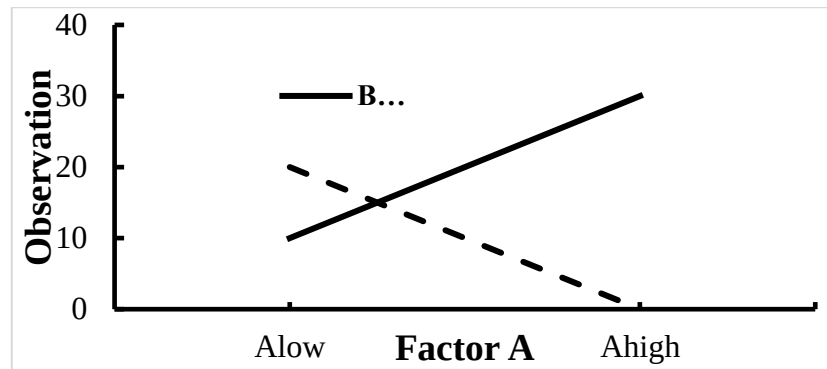


Figure A2.3: Factorial experiment with interaction

Table A2.1: ANOVA Table for a Two-Factor Factorial

Source of Variation	Sum of Squares	Degrees of freedom	Mean Square	Fo
Factor A	SS_A	$a-1$	$MS_A = \frac{SS_A}{a-1}$	$\frac{MS_A}{MS_E}$
Factor B	SS_B	$b-1$	$MS_B = \frac{SS_B}{b-1}$	$\frac{MS_B}{MS_E}$

Interaction	SS_{AB}	$(a-1)(b-1)$	MS_{AB} $= \frac{SS_{AB}}{(a-1)(b-1)}$	$\frac{MS_{AB}}{MS_E}$
Error	SS_E	$ab(n-1)$	$MS_E = \frac{SS_E}{ab(n-1)}$	
Total	SST	$abn-1$		

APPENDIX: CHAPTER B

BELAGA PALM OIL MILL
Daily Sterilisation Log Sheet

Date 21 April 2018

Sterilizer Operation			Door Close Time		Crop Received Visual		True Start Steam In		Duration Time (min)		Peak 1			Peak 2			Peak 3			Holding Time			By Pass Open Close		Door Open Time		Test Cages		Actual Steaming Time (min)		Cycle Interval		Sterilization Delay Due To				Operator Initial
Sterilize No	Auto	Manual									Build Up Time (min)	Pressure (psi)	Condensate Time (min)	Exhaust Time (min)	Build Up Time (min)	Pressure (psi)	Condensate Time (min)	Exhaust Time (min)	Build Up Time (min)	Pressure (psi)	Condensate Time (min)	Exhaust Time (min)							No. Trays at empty	Steam Pressure Low	Decomment	Wash B/D					
1	✓		1140	1	1401	2	12	7:08	1	1	10	2207	1	1	15	2401	20	3638	5	5	1400	7:10	✓		✓		✓	MOULDING	SATIF								
2	✓		1215	1	1520	2	12	854	1	1	10	1363	1	1	15	1842	20	3682	5	5	1715	5	✓		✓		✓										
1	✓		1624	1	1645	2	12	1146	1	1	10	1871	1	1	15	3948	20	3952	5	5	1830	5	✓		✓		✓	FFB	PROCESS	5		CG					
2	✓		1730	1	1755	2	12	609	1	1	10	1146	1	1	15	2530	20	2637	5	5	1940	5	✓		✓		✓	FFB	COOKED	10		CG					
1	✓		1840	1	1910	2	12	1073	1	1	10	1668	1	1	15	3713	20	3694	5	5	2125	5	✓		✓		✓	FFB	UNCOOKED	16		CG					
2	✓		1947	1	2036	2	12	1711	1	1	10	2408	1	1	15	2078	20	3553	5	5	2050	5	✓		✓		✓	FFB	UNCOOKED	16		CG					
1	✓		2135	1	2200	2	12	1343	1	1	10	2029	1	1	15	3608	20	3608	5	5																	
2	✓		2300	1	2317	2	12	1940	1	1	10	1740	1	1	15	3810	20	3553	5	5																	
NIGHT SHIFT																																					
FFB PROCESS 3S																																					
FFB COOKED 10																																					
FFB UNCOOKED -																																					

Operator Name (1): S. Gauthin
Operator Name (1): ALIF FADILAH
Time Start Sterilisation: 13:55 HOURS
Time Stop Sterilisation: _____
Total Cages Sterilised: _____

Shift End

Steriliser No.1
Cooked / Uncooked / Empty / To Add Steam _____ (mins)

Steriliser No.2
Cooked / Uncooked / Empty / To Add Steam _____ (mins)

Remarks: _____

Process Supervisor _____
Date: 2/4/18

Mill Engineer _____
Date: _____

Mill Manager
Date:

Note All station records need to be checked and signed by Supervisor/Process Executive/Assistant Engineer every 2 hours.

H_m H_m H_m
1710 hrs 1900 hrs 2200 hrs

Figure A3.1: Lab Sheet 1



BELAGA PALM OIL MILL
Tippler Log Sheet

Date 2.4.2018

NO CAGES	1	2	3	4	5	6	7	8	9	10	REMARKS	
Masa Mula	13.55	14.09	14.24	14.38	14.50	15.06	15.21	15.34	15.53	16.06		SEBAB LAMBAT TIPPING :- 1. Digester penuh DP 2. Cages sangkut CS 3. Winch Capstain rosak WCR 4. Electrical breakdown EB 5. Conveyer jammed CI 6. Operator rehat masa makan OM 7. Thresher Drum rosak TDR 8. Transfer carriage rosak TCR 9. Lain-lain LL
Masa Berhenti	14.06	14.21	14.36	14.48	15.03	15.18	15.34	15.50	16.04	16.19		
Jumlah Masa	11	11	12	10	13	12	13	13	12	13		
Sebab Lambat												
NO CAGES	11	12	13	14	15	16	17	18	19	20		
Masa Mula	16.22	16.34	16.53	17.20	17.35	17.50	18.06	18.22	18.39	18.55		
Masa Berhenti	16.34	16.50	17.06	17.30	17.44	18.03	18.19	18.36	18.52	19.08		
Jumlah Masa	12	13	13	12	12	13	13	14	13	12		
Sebab Lambat												
NO CAGES	21	22	23	24	25	26	27	28	29	30		
Masa Mula	19.11	19.27	19.43	19.58	20.13	20.38	20.54	21.10	21.26	21.41		
Masa Berhenti	19.24	19.40	19.55	20.10	20.36	20.51	21.04	21.23	21.38	21.54		
Jumlah Masa	13	13	12	12	12	13	13	13	12	12		
Sebab Lambat												
NO CAGES	31	32	33	34	35	36	37	38	39	40		
Masa Mula	22.20	22.35	22.51	23.06	23.04	23.38	23.55	00.00	00.15	00.31		
Masa Berhenti	22.32	22.40	23.03	23.19	23.35	23.50	00.06	00.12	00.28	00.45		
Jumlah Masa	12	13	12	13	13	12	13	13	13	14		
Sebab Lambat												
NO CAGES	41	42	43	44	45	46	47	48	49	50		
Masa Mula												
Masa Berhenti												
Jumlah Masa												
Sebab Lambat												
NO CAGES	51	52	53	54	55	56	57	58	59	60		
Masa Mula												
Masa Berhenti												
Jumlah Masa												
Sebab Lambat												
NO CAGES	61	62	63	64	65	66	67	68	69	70		
Masa Mula												
Masa Berhenti												
Jumlah Masa												
Sebab Lambat												

SHIFT PERTAMA

Jumlah cages tipped : 5068

Jumlah masa : _____

Operator : Dani SoRuhya...

Supervisor/Mandor : _____

SHIFT KEDUA

Jumlah cages tipped : 35068

Jumlah masa : _____

Operator : han

Supervisor/Mandor : han 2/4/18

Checked By : _____ Certified Correct By : _____

Process Executive _____ Mill Manager _____

han 1720 hrs han 1910 hrs han 2210 hrs

Figure A3.2: Lab Sheet 2

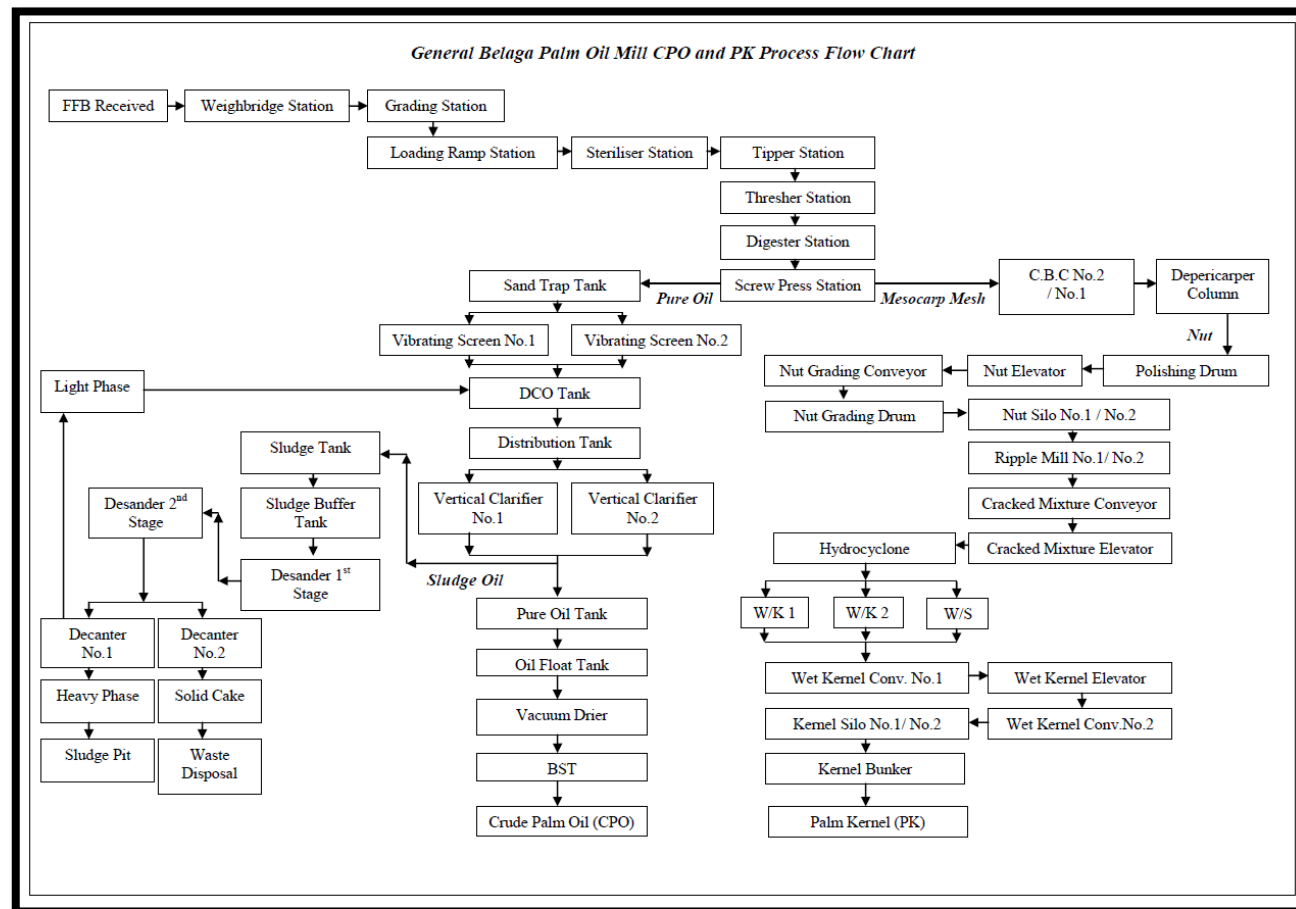


Figure A3.3: Process Flow Diagram from Industry

Table A3.1: Actual Processing Time for each Machine (Min, Avg, Max)

No	Station	Type of Machine	No of Machine Industry	Activity	Time Taken Machine Operation (Industry)		
			(Units)		Min	Avg	Max
1	Weighbridge Station	Weighbridge	1	Weighing Process	5 Min	30 Min	35 Min
			(n)	Weighbridge Breakdown	1 Hours	3 Hours	6 Hours
2	Grading Station	Grading Bay	1	Grading Process	10 Min	20 Min	30 Min
3	Loading Ramp	Loading Ramp	5	Loading Process	10 Min	20 Min	30 Min
4	Sterilizers Station	Sterilizer	2	Sterilization Time (Mode)	90 Min	130 Min	150 Min
5	Tipper & Threshing Station	Tipper & Thresher	1	Tipping Repair	3 Hours	6 Hours	12 Hours

6	Digester Station	Digester	3	Digestion Processing Time	90 Min	100 Min	110 Min
7	Pressing Station	Screw Press	3	Pressing Processing Time	90 Min	100 Min	110 Min
8	Clarification Station	Vibrating Screen	2	N/A	5 Min		
		Crude Oil Tank	1	N/A			
		Clarifier	1	N/A			
		Pure Oil Tank	1	N/A			
		Oil Purifier	1	N/A			
		Vacuum Drier	1	N/A			

Table A3.2: Simulation Module Processing Time for each Machine (Min, Avg, Max)

No	Station	Type of Machine	No of Machine Industry	Activity	Time Taken Machine Operation (Industry)		
			(Units)		Min	Avg	Max

1	Weighbridge Station	Weighbridge	1	Weighing Process	5 Min	30 Min	35 Min
			(n)	Weighbridge Breakdown	1 Hours	3 Hours	6 Hours
2	Grading Station	Grading Bay	1	Grading Process	10 Min	20 Min	30 Min
3	Loading Ramp	Loading Ramp	5	Loading Process	10 Min	20 Min	30 Min
4	Sterilizers Station	Sterilizer	2	Sterilization Time (Mode)	90 Min	130 Min	150 Min
5	Tipper & Threshing Station	Tipper & Thresher	1	Tipping Repair	3 Hours	6 Hours	12 Hours
6	Digester Station	Digester	3	Digestion Processing Time	90 Min	100 Min	110 Min
7	Pressing Station	Screw Press	3	Pressing Processing Time	90 Min	100 Min	110 Min

8	Clarification Station	Vibrating Screen	2	N/A	5 Min
		Crude Oil Tank	1	N/A	
		Clarifier	1	N/A	
		Pure Oil Tank	1	N/A	
		Oil Purifier	1	N/A	
		Vacuum Drier	1	N/A	

Table A3.3: No of Machine (Table each Station, Min, Avg, Max)

No	Station	Type of Machine	No of Machine Industry
			(Units)
1	Weighbridge Station	Weighbridge	1
2	Grading Station	Grading Bay	1
3	Loading Ramp	Loading Ramp	5
4	Sterilizers Station	Sterilizer	2
5	Tipper & Threshing Station	Tipper & Thresher	1
6	Digester Station	Digester	3
7	Pressing Station	Screw Press	3
8	Clarification Station	Vibrating Screen	2

		Crude Oil Tank	1
		Clarifier	1
		Pure Oil Tank	1
		Oil Purifier	1
		Vacuum Drier	1

BELAGA PALM OIL MILL
DAILY QUALITY & PRODUCTION REPORT

To : Director (Plantation)
: Chief Finance Officer
Cc : Head (Overseas Plantations & Marketing)
: General Manager (Head of Plantation)
: Asst. General Manager (Belaga Plantation)
: Asst. General Manager (Group Mills)
From : Mill Manager, BPOM
Date : 31 December 2022

Director's Comments:

A) FFB PRODUCTION ON : 31 December 2022

FFB PRODUCTION				BUDGET		
Own Estate	Today	MoT Today	Yr Today	Month	Year Today	Year
Belaga 1 Estate	114.70	2935.55	14813.44	2496	14034	28027
Belaga 2 Estate	55.84	2189.86	12495.37	1548	9972	16668
Belaga 3 Estate	54.56	1634.62	9925.17	1711	9994	18911
Own Estates Total	225.10	6760.03	37233.98	5755	34000	63606
Urus Plantation Phase 1	30.64	816.20	4894.19	3000	18000	33000
Urus Plantation Phase 2	102.27	1799.52	14052.87			
Jalalong 4 Estate	-	-	-	927	6374	11588
Outside Estate Total	132.91	2615.72	18947.06	3927	24374	44588
GRAND TOTAL	358.01	9375.75	56181.04	9682	58374	108194

PRODUCTION DATA

Description	Today	Month Today	Year Today
FFB Processed (MT)	601.34	9375.75	56181.04
Balance FFB (MT)	-	-	-
CPO Production	135.44	2122.83	12517.87
PK Production	25.24	398.09	2353.13
CPO Dispatch	2.77	2225.08	12194.92
PK Dispatch	1.10	394.83	2391.39
OER%	22.22%	22.64%	22.28%
KER%	4.20%	4.25%	4.19%
Processing Time (hrs)	19.50	307.00	1843.25
Downtime (hrs)	-	-	-
Breakdown	-	15.00	68.00
Throughput	30.84	30.54	30.48
Rainfall (mm)	47	203	1205

Remark :

B) PRODUCTS STOCK & QUALITY ON : 31 December 2022

STOCK					
Description	Tank 1	Tank 2	Tank 3	Tank 4	TOTAL
Tank Capacity (MT)	1000	2000	1000	2000	6000
CPO (MT)	270.89	326.66	486.15	-	1083.70
CPO FFA CONTENT (%)	6.32	5.96	4.80	-	-
DOSE	2.33	2.34	2.50	-	-
TEMPERATURE °C	52	50	50	-	-
Description	TOTAL				
PK (MT)	82.00				

Production Quality (CPO)

Description	FFA %	YM %	Dirt %	Dati
CPO	5.01	0.18	0.042	2.49
FFA(> 5%): 72.5/mt				
FFA(< 5%): 61.0/mt				
Dispatch CPO				
Production Quality (PK)				
PK		4.81	5.35	
Dispatch PK		-	-	

C) FFB QUALITY ON : 31 December 2022

Estate	Underripe %	Underripe %	Ripe %	Over Ripe %	Empty/ Rotten %	Total	Robust (Damage %)	Parthenocarp y %	Long Link (Total Ratio)	Harvesting Interval (Daily)
LIMIT	0%	<5%	>90%	0.05	0.00		-	-	-	Maximum(Day)
Belaga 1 Estate	-	15.00	73.33	11.67	-	100.00	-	5.33	-	-
Belaga 2 Estate	-	14.00	74.00	12.00	-	100.00	-	-	-	-
Belaga 3 Estate	-	10.00	75.00	15.00	-	100.00	-	-	-	-
Own Estates (Average)	0.00	13.00	74.11	12.89	0.00	100.00	0	5.33	0.00	-
Urus Plantation Sdn. Bhd.	5.50	16.63	57.63	17.75	2.50	100.00	-	-	0.75	-
Jalalong 4 Estate	-	-	-	-	-	0.00	-	-	-	-
Outside Estate (Average)	5.50	16.63	57.63	17.75	2.50	100.00	0	0.00	0.75	-
ALL Estates (Average)	2.92	15.07	65.27	15.40	1.33	100.00	0	5.33	0.75	-

D) OWN ESTATES CROP BALANCE FORECAST FOR 2 December, 2022

OWN BELAGA ESTATE	Crop B/F	Harvested Yesterday	Total Crop	Total Dispatched Yesterday	Crop Balance	Estimated Harvest Today	Estimated Total Crop
Belaga 1 Estate	-	-	-	-	-	-	-
Belaga 2 Estate	-	-	-	-	-	-	-
Belaga 3 Estate	-	-	-	-	-	-	-
TOTAL	0.00	0.00	0.00	0.00	0.00	0.00	0.00

E) CONTAMINATION SUMMARY : 31 December 2022

Estate	Fertilizer (Bag)	Fertilizer	Stone	Sand & Soil	Diesel Oil	Hydraulic Oil	Engine Oil
Belaga 1 Estate	-	-	-	-	-	-	-
Belaga 2 Estate	-	-	-	-	-	-	-
Belaga 3 Estate	-	-	-	-	-	-	-
Urus Plantation S/B	-	-	-	-	-	-	-
Jalalong 4 Estate	-	-	-	-	-	-	-
TOTAL	0.00	0.00	0.00	0.00	0.00	0.00	-

F) FFB FRESHNESS : 31 December 2022

Estate	1 night (%)	2 nights (%)	3 nights (%)	Fresh LF (%)	Old LF (%)
Belaga 1 Estate	48.00	31.00	21.00	83.64	16.36
Belaga 2 Estate	53.75	37.50	8.75	81.25	18.75
Belaga 3 Estate	42.50	42.50	15.00	75.00	25.00
Own Estates (Average)	48.08	37.00	14.92		
Urus Plantation S/B	11.25	58.75	30.00	57.50	42.50
Jalalong 4 Estate	-	-	-	-	-
Outside Estate (Average)	11.25	58.75	30.00		

REGISEREN D GUDOMON

Figure A3.4: Daily Report For Year 2022

Table A3.4: Design of Simulation Experiment Matric for Validation of Simulation Model

Run Order	FFB Quantity (MT)	FFB InterArrival Time (days)	WB Repair Time (hours)	Tipping Machine Repair Time (hours)	Processing time (hours)
1	250	1	5	8	100.4
2	500	1	5	8	200.6
3	750	1	5	8	300.3
4	1000	1	5	8	400.7
5	1250	1	5	8	500.3
6	250	3	5	8	74.4
7	500	3	5	8	169.8
8	750	3	5	8	268.4
9	1000	3	5	8	369.1
10	1250	3	5	8	468.5
11	250	5	5	8	60.4
12	500	5	5	8	143.9
13	750	5	5	8	239.3
14	1000	5	5	8	341.6
15	1250	5	5	8	436.6
16	250	3	3	8	72
17	500	3	3	8	169
18	750	3	3	8	267
19	1000	3	3	8	368
20	1250	3	3	8	468
21	250	3	5	8	74
22	500	3	5	8	170
23	750	3	5	8	268
24	1000	3	5	8	369
25	1250	3	5	8	469
26	250	3	7	8	76
27	500	3	7	8	170
28	750	3	7	8	272
29	1000	3	7	8	373
30	1250	3	7	8	473
31	250	3	5	6	52
32	500	3	5	6	121.6
33	750	3	5	6	192.3
34	1000	3	5	6	268.4

35	1250	3	5	6	342
36	250	3	5	8	74.4
37	500	3	5	8	169.8
38	750	3	5	8	268.4
39	1000	3	5	8	369.1
40	1250	3	5	8	468.5
41	250	3	5	10	98.4
42	500	3	5	10	220.4
43	750	3	5	10	344.3
44	1000	3	5	10	470.2
45	1250	3	5	10	594.6
46	250	1	5	8	100.4
47	250	2	5	8	86.3
48	250	3	5	8	74.4
49	250	4	5	8	64.5
50	250	5	5	8	60.4
51	750	1	5	8	300.3
52	750	2	5	8	284.4
53	750	3	5	8	268.4
54	750	4	5	8	254.9
55	750	5	5	8	239.3
56	1250	1	5	8	500.3
57	1250	2	5	8	485.7
58	1250	3	5	8	468.5
59	1250	4	5	8	453.6
60	1250	5	5	8	436.6
61	750	1	3	8	298.3
62	750	2	3	8	281.4
63	750	3	3	8	266.6
64	750	4	3	8	251.1
65	750	5	3	8	235.3
66	750	1	5	8	300.3
67	750	2	5	8	284.4
68	750	3	5	8	268.4
69	750	4	5	8	254.9
70	750	5	5	8	239.3
71	750	1	7	8	302.3
72	750	2	7	8	286
73	750	3	7	8	272.2
74	750	4	7	8	254.7
75	750	5	7	8	240.3

76	750	1	5	6	224.1
77	750	2	5	6	207.7
78	750	3	5	6	192.3
79	750	4	5	6	179.7
80	750	5	5	6	164.1
81	750	1	5	8	300.3
82	750	2	5	8	284.4
83	750	3	5	8	268.4
84	750	4	5	8	254.9
85	750	5	5	8	239.3
86	750	1	5	10	376.9
87	750	2	5	10	360.7
88	750	3	5	10	344.3
89	750	4	5	10	327.8
90	750	5	5	10	314.6
91	250	3	3	8	72.2
92	250	3	4	8	74
93	250	3	5	8	74.4
94	250	3	6	8	75.2
95	250	3	7	8	76
96	750	3	3	8	266.6
97	750	3	4	8	267.1
98	750	3	5	8	268.4
99	750	3	6	8	270.4
100	750	3	7	8	272.2
101	1250	3	3	8	468.1
102	1250	3	4	8	466.6
103	1250	3	5	8	468.5
104	1250	3	6	8	469.1
105	1250	3	7	8	472.5
106	750	1	3	8	298.3
107	750	1	4	8	299.5
108	750	1	5	8	300.3
109	750	1	6	8	301.1
110	750	1	7	8	302.3
111	750	3	3	8	266.6
112	750	3	4	8	267.1
113	750	3	5	8	268.4
114	750	3	6	8	270.4
115	750	3	7	8	272.2
116	750	5	3	8	235.3

117	750	5	4	8	237.4
118	750	5	5	8	239.3
119	750	5	6	8	239.8
120	750	5	7	8	240.3
121	750	3	3	6	191.3
122	750	3	4	6	192.9
123	750	3	5	6	192.3
124	750	3	6	6	195.9
125	750	3	7	6	231.4
126	750	3	3	8	266.6
127	750	3	4	8	267.1
128	750	3	5	8	268.4
129	750	3	6	8	270.4
130	750	3	7	8	272.2
131	750	3	3	10	342.7
132	750	3	4	10	344.4
133	750	3	5	10	344.3
134	750	3	6	10	346.1
135	750	3	7	10	346.7
136	250	3	5	6	52
137	250	3	5	7	63.7
138	250	3	5	8	74.4
139	250	3	5	9	87.1
140	250	3	5	10	98.4
141	750	3	5	6	192.3
142	750	3	5	7	230.1
143	750	3	5	8	268.4
144	750	3	5	9	307.6
145	750	3	5	10	344.3
146	1250	3	5	6	342
147	1250	3	5	7	405.9
148	1250	3	5	8	468.5
149	1250	3	5	9	531.7
150	1250	3	5	10	594.6
151	750	1	5	6	224.1
152	750	1	5	7	262.5
153	750	1	5	8	300.3
154	750	1	5	9	337.9
155	750	1	5	10	375.9
156	750	3	5	6	192.3
157	750	3	5	7	230.1

158	750	3	5	8	268.4
159	750	3	5	9	307.6
160	750	3	5	10	344.3
161	750	5	5	6	164.1
162	750	5	5	7	199.3
163	750	5	5	8	239.3
164	750	5	5	9	275.1
165	750	5	5	10	314.6
166	750	3	3	6	191.3
167	750	3	3	7	228
168	750	3	3	8	266.6
169	750	3	3	9	303.6
170	750	3	3	10	342.7
171	750	3	5	6	192.3
172	750	3	5	7	230.1
173	750	3	5	8	268.4
174	750	3	5	9	307.6
175	750	3	5	10	344.3
176	750	3	7	6	231.4
177	750	3	7	7	233.9
178	750	3	7	8	272.2
179	750	3	7	9	309.5
180	750	3	7	10	346.7

Table A3.5: Variable Factors and Ranges for Factor Screening for Case A and B

Factor	Name	Units	Min.	Max.	SPSS	
					Coded Low	Coded High
A	FFB Quantity*	Unit	250	1150	5 == 1	23 == 3
B	FFB InterArrival Time*	days	1	5	1 == 1	5 == 3
C	Weighbridge Machine#	Unit	1	3	1 == 3	3 == 3
D	Weighing Time*	Mins	Tria (5,10,15)	Tria (25,30, 35)	Tria (5,10,15) == 1	Tria (25, 30, 35) == 3

E	Weighbridge Machine Repair time*	Hour s	3	6	3 == 1	6 == 3
F	Grading Machine#	Unit	1	3	1 == 1	3 == 3
G	Grading Time*	Mins .	Tria (21,25,31)	Tria (41, 46, 51)	Tria (21, 25, 31) == 1	Tria (41, 46, 51) == 3
H	Workers at Loading Station#	Unit	1	3	1 == 1	3 == 3
I	Loading Time*	Mins .	Tria (5, 10, 15)	Tria (25, 30, 35)	Tria (5, 10, 15) == 1	Tria (25, 30, 35) == 3
J	Steriliser Machine#	Unit	1	3	1 == 1	3 == 3
K	Sterilising Time*	Mins .	Tria (90, 100, 110)	Tria (130, 140, 150)	Tria (90, 100, 110) == 1	Tria (130, 140, 150) == 3
L	Tipping Machine Repair Time*	Hour s	6	12	6 == 1	12 == 3
M	Digesters Machine#	Unit	1	3	1 == 1	3 == 3
N	Presser Machine#	Unit	1	3	3 == 1	3 == 3

** factors observed at the case study company*

#factors observed from literature review

Table A3.6: Selected 2k-p Fractional Factorial Design

	No. of Factors, k	Fraction	No. of Runs	Design Generators	No. of Factors, k	Fraction	No. of runs	Design Generators
1	3	2_{III}^{3-1}	4	C = $\pm$ AB	9	2_{VI}^{9-2}	128	H = $\pm$ ACDFG J = $\pm$ BCEFG
2	4	2_{IV}^{4-1}	8	D = $\pm$ ABC		2_V^{9-3}	64	G = $\pm$ ABCD H = $\pm$ ACEF J = $\pm$ CDEF
3	5	2_V^{5-1}	16	E = $\pm$ ABCD		2_{IV}^{9-4}	32	F = $\pm$ BCDE G = $\pm$ ACDE H = $\pm$ ABDE J = $\pm$ ABCE
4		2_{III}^{5-2}	8	D = $\pm$ AB E = $\pm$ AC		2_{III}^{9-5}	16	E = $\pm$ ABC F = $\pm$ BCD G = $\pm$ ACD H = $\pm$ ABD J = $\pm$ ABCD
5	6	2_{VI}^{6-1}	32	F = $\pm$ ABCDE	10	2_V^{10-3}	128	H = $\pm$ ABCG J = $\pm$ BCDE K = $\pm$ ACDF
6		2_{IV}^{6-2}	16	E = $\pm$ ABC F = $\pm$ BCD		2_{IV}^{10-4}	64	G = $\pm$ BCDF H = $\pm$ ACDF J = $\pm$ ABDE K = $\pm$ ABCE
7		2_{III}^{6-3}	8	D = $\pm$ AB E = $\pm$ AC F = $\pm$ BC		2_{IV}^{10-5}	32	F = $\pm$ ABCD G = $\pm$ ABCE H = $\pm$ ABDE J = $\pm$ ACDE K = $\pm$ BCDE
8	7	2_{VII}^{7-1}	64	G = $\pm$ ABCDEF		2_{III}^{10-6}	16	E = $\pm$ ABC F = $\pm$ BCD G = $\pm$ ACD H = $\pm$ ABD J = $\pm$ ABCD K = $\pm$ AB

9		2_{IV}^{7-2}	32	F=±ABCD G=±ABDE	11	2_{IV}^{11-5}	64	G=±CDE H=±ABCD J=±ABF K=±BDEF L=±ADEF
10		2_{IV}^{7-3}	16	E=±ABC F=±BCD G=±ACD		2_V^{11-6}	32	F=±ABC G=±BCD H=±CDE J=±ACD K=±ADE L=±BDE
11		2_{III}^{7-4}	8	D=±AB E=±AC F=±BC G=±ABC		2_{III}^{11-7}	16	E=±ABC F=±BCD G=±ACD H=±ABD J=±ABCD K=±AB L=±AC
12	8	2_V^{8-2}	64	G=±ABCD H=±ABEF	12	2_{III}^{12-8}	16	L=±AC E=±ABC F=±ABD G=±ACD H=±BCD J=±ABCD K=±AB L=±AC M=±AD
13		2_{IV}^{8-3}	32	F=±ABC G=±ABD H=±BCDE	13	2_{III}^{13-9}	16	E=±ABC F=±ABD G=±ACD H=±BCD J=±ABCD K=±AB L=±AC M=±AD N=±BC

14		2_{VI}^{8-4}	16	$E=\pm BCD$ $F=\pm ACD$ $G=\pm ABC$ $H=\pm ABD$	14	2_{III}^{14-10}	16	$E=\pm ABC$ $F=\pm ABD$ $G=\pm ACD$ $H=\pm BCD$ $J=\pm ABCD$ $K=\pm AB$ $L=\pm AC$ $M=\pm AD$ $N=\pm BC$ $O=\pm BD$
					15	2_{III}^{15-11}	16	$E=\pm ABC$ $F=\pm ABD$ $G=\pm ACD$ $H=\pm BCD$ $J=\pm ABCD$ $K=\pm AB$ $L=\pm AC$ $M=\pm AD$ $N=\pm BC$ $O=\pm BD$ $P=\pm CD$

Table A3.7: Design of Matrix for Factor Screening Simulation Experiment (Case A and B)

Run Order	A	B	C	D	E	F	G	H	I	J	K	L	M	N	Proc. time (hours) CASE A	Proc. time (hours) CASE B
1	250	1	1	Tria(5,10, 15)	3	1	Tria(21,26,3 1)	1	Tria(25,30,3 5)	3	Tria(130,140,1 50)	12	3	3	151	132.2
2	1150	1	1	Tria(5,10, 15)	6	3	Tria(41,46,5 1)	1	Trai(5,10,15)	1	Tria(90,100,11 0)	6	3	3	345.1	337.9
3	250	5	1	Tria(5,10, 15)	6	3	Tria(21,26,3 1)	3	Tria(5,10,15)	1	Tria(130,140,1 50)	12	1	1	101.9	85.8
4	1150	5	1	Tria(5,10, 15)	3	1	Tria(41,46,5 1)	3	Tria(25,30,3 5)	3	Tria(90,100,11 0)	6	1	1	280.1	244.5

5	250	1	3	Tria(5,10, 15)	6	1	Tria(41,46,5 1)	3	Tria(5,10,15)	3	Tria(90,100,11 0)	12	1	3	153.1	144.4
6	1150	1	3	Tria(5,10, 15)	3	3	Tria(21,26,3 1)	3	Tria(25,30,3 5)	1	Tria(130,140,`5 0)	6	1	3	342.6	334.6
7	250	5	3	Tria(5,10, 15)	3	3	Tria(41,46,5 1)	1	Tria(25,30,3 5)	1	Tria(90,100,11 0)	12	3	1	96.7	82.6
8	1150	5	3	Tria(5,10, 15)	6	1	Tria(21,26,3 1)	1	Tria(5,10,15)	3	Tria(130,140,1 50)	6	3	1	284.7	250.1
9	250	1	1	Tria(25,30 ,35)	3	3	Tria(41,46,5 1)	3	Tria(5,10,15)	3	Tria(130,140,1 50)	6	3	1	73.3	65.8
10	1150	1	1	Tria(25,30 ,35)	6	1	Tria(21,26,3 1)	3	Tria(25,30,3 5)	1	Tria(90,100,11 0)	12	3	1	693.3	686.2
11	250	5	1	Tria(25,30 ,35)	6	1	Tria(41,46,5 1)	1	Tria(25,30,3 5)	1	Tria(130,140,1 50)	6	1	3	46.2	40.4
12	1150	5	1	Tria(25,30 ,35)	3	3	Tria(21,26,3 1)	1	Tria(5,10,15)	3	Tria(90,100,11 0)	12	1	3	628.1	588.7

13	250	1	3	Tria(25,30 ,35)	6	3	Tria(21,26,3 1)	1	Tria(25,30,3 5)	3	Tria(90,100,11 0)	6	1	1	75.9	68.3
14	1150	1	3	Tria(25,30 ,35)	3	1	Tria(41,46,5 1)	1	Tria(5,10,15)	1	Tria(130,140,1 50)	12	1	1	691.8	683.9
15	250	5	3	Tria(25,30 ,35)	3	1	Tria(21,26,3 1)	3	Tria(5,10,15)	1	Tria(90,100,11 0)	6	3	4	41.3	35.6
16	1150	5	3	Tria(25,30 ,35)	6	3	Tria(41,46,5 1)	3	Tria(25,30,3 5)	3	Tria(130,140,1 50)	12	3	3	631.4	595.1

Table A3.8: Variable Factors and Ranges for Factor Screening Case C and D

Factor	Name	Units	Min.	Max.	SPSS	
					Coded Low	Coded High
A	Number of weighbridge machines	Unit	1	3	1 == 3	3 == 3
B	Weighing time at weighing stations	Mins	Tria (5,10,15)	Tria (25, 30, 35)	Tria (5,10,15) == 1	Tria (25, 30, 35) == 3
C	Weighbridge repair time	Hours	3	6	3 == 1	6 == 3
D	Number of grading machines	Unit	1	3	1 == 1	3 == 3
E	Grading time at grading stations	Mins	Tria (21, 25, 31)	Tria (41, 46, 51)	Tria (21, 25, 31) == 1	Tria (41, 46, 51) == 3
F	Number of workers at loading ramp	Unit	1	3	1 == 1	3 == 3
G	Loading time at loading ramp	Mins	Tria (5, 10, 15)	Tria (25, 30, 35)	Tria (5, 10, 15) == 1	Tria (25, 30, 35) == 3
H	Number of sterilisers	Unit	1	3	1 == 1	3 == 3
I	Sterilising Time	Mins	Tria (90, 100, 110)	Tria (130, 140, 150)	Tria (90, 100, 110) == 1	Tria (130, 140, 150) == 3
J	Tipping machine repair time	Hours	6	12	6 == 1	12 == 1

K	Number digesters	of	Unit	1	3	1 == 1	3 == 3
L	Number pressers	of	Unit	1	3	3 == 1	3 == 3

Table A3.9: Design of Matrix for Factor Screening Simulation Experiment (Case C and D)

Run Order	A	B (Tria, minutes)	C	D	E (Tria, minutes)	F	G (Tria, minutes)	H	I (Tria, minutes)	J (Const, hours)	K	L	PT (hours) 250 MT	PT (hours) 1150 MT
1	1	(5,10,15)	3	1	(21,26,31)	1	(5,10,15)	1	(130,140,150)	(12)	3	3	150.5	690.6
2	3	(5,10,15)	3	1	41, 46, 51	3	25, 30, 35	1	90, 100, 110	(6)	1	1	72.9	343
3	1	(25, 30, 35)	3	1	41, 46, 51	3	5,10,15	3	90, 100, 110	6	3	3	72.6	342.8
4	3	(25, 30, 35)	3	1	21, 26, 31	1	25, 30, 35	3	130, 140, 150	12	1	1	151	690.8
5	1	(5, 10, 15)	6	1	41, 46, 51	1	25, 30, 35	3	90, 100, 110	12	1	3	153.5	693.3
6	3	(5, 10, 15)	6	1	21, 26, 31	3	5,10,15	3	130, 140, 150	6	3	1	75.8	345.5
7	1	(25, 30, 35)	6	1	21, 26, 31	3	25, 30, 35	1	130, 140, 150	6	1	3	76.4	346.5
8	3	25, 30, 35	6	1	41, 46, 51	1	5,10,15	1	90, 100, 110	12	3	1	153.2	693.8
9	1	5, 10, 15	3	3	21, 26, 31	3	25, 30, 35	3	90, 100, 110	12	3	1	150.3	690
10	3	5, 10, 15	3	3	41, 46, 51	1	5,10,15	3	130, 140, 150	6	1	3	73.8	342.3
11	1	25, 30, 35	3	3	41, 46, 51	1	25, 30, 35	1	130, 140, 150	6	3	1	73.9	343.5
12	3	25, 30, 35	3	3	21, 26, 31	3	5,10,15	1	90, 100, 110	12	1	3	150.6	690.7
13	1	5, 10, 15	6	3	41, 46, 51	3	5,10,15	1	130, 140, 150	12	1	1	153.7	694
14	3	5, 10, 15	6	3	21, 26, 31	1	25, 30, 35	1	90, 100, 110	6	3	3	75.2	345.1
15	1	25, 30, 35	6	3	21, 26, 31	1	5,10,15	3	90, 100, 110	6	1	1	75.9	345.3
16	3	25, 30, 35	6	3	41, 46, 51	3	25, 30, 35	3	130, 140, 150	12	3	3	154.5	695

Table A3.10: Variable Factors and Ranges for 9 factors full factorial experiment

Factor	Name	Units	Min.	Max.	Coded Low	Coded High
A	FFB Quantity	Unit	250	1150	5 == 1	23 == 3
B	FFBunch InterArrival Time	days	1	5	1 == 1	5 == 3
D	Weighing time at weighing stations	Mins	Tria (5,10,15)	Tria (25, 30, 35)	Tria (5,10,15) == 1	Tria (25, 30, 35) == 3
E	Weighbridge repair time	Hours	3	6	3 == 1	6 == 3
F	Number of grading machines	Unit	1	3	1 == 1	3 == 3
J	Number of sterilers	Unit	1	3	1 == 1	3 == 3
K	Sterilising Time	Mins	Tria (90, 100,110)	Tria (130, 140, 150)	Tria (90, 100, 110) == 1	Tria (130, 140, 150) == 3
L	Tipping machine repair time	Hours	6	12	6 == 1	12 == 1
N	Number of pressers	Unit	1	3	3 == 1	3 == 3

Table A3.11: Design of Matrix for Two Level Full Factorial Simulation Experiment (Case A)

	FFB Quantity (MT)	FFB Interarrival time (days)	Weighing Time (Tria, minutes)	Weighbridge Machine Repair time (Const, hours)	Number of Grading Machines	Number of Sterilisers	Sterilising Time (Tria, minutes)	Tipping Machine Repair Time (Const, hours)	Number of Pressers	PT (hours)
Case	A	B	C	D	E	F	G	H	I	
1	250	1	5, 10, 15	3	1	1	90, 100, 110	6	1	72.3
2	1150	1	5, 10, 15	3	1	1	90, 100, 110	6	1	342.1
3	250	5	5, 10, 15	3	1	1	90, 100, 110	6	1	41.6
4	1150	5	5, 10, 15	3	1	1	90, 100, 110	6	1	276.6
5	250	1	25, 30, 35	3	1	1	90, 100, 110	6	1	72.3
6	1150	1	25, 30, 35	3	1	1	90, 100, 110	6	1	343
7	250	5	25, 30, 35	3	1	1	90, 100, 110	6	1	42.2
8	1150	5	25, 30, 35	3	1	1	90, 100, 110	6	1	279.2
9	250	1	5, 10, 15	6	1	1	90, 100, 110	6	1	75.8
10	1150	1	5, 10, 15	6	1	1	90, 100, 110	6	1	345.2
11	250	5	5, 10, 15	6	1	1	90, 100, 110	6	1	43.9
12	1150	5	5, 10, 15	6	1	1	90, 100, 110	6	1	285.3
13	250	1	25, 30, 35	6	1	1	90, 100, 110	6	1	76.1
14	1150	1	25, 30, 35	6	1	1	90, 100, 110	6	1	345.8
15	250	5	25, 30, 35	6	1	1	90, 100, 110	6	1	44.5
16	1150	5	25, 30, 35	6	1	1	90, 100, 110	6	1	285.8
17	250	1	5, 10, 15	3	3	1	90, 100, 110	6	1	72.3
18	1150	1	5, 10, 15	3	3	1	90, 100, 110	6	1	342.1
19	250	5	5, 10, 15	3	3	1	90, 100, 110	6	1	41.6
20	1150	5	5, 10, 15	3	3	1	90, 100, 110	6	1	276.6
21	250	1	25, 30, 35	3	3	1	90, 100, 110	6	1	72.3
22	1150	1	25, 30, 35	3	3	1	90, 100, 110	6	1	343
23	250	5	25, 30, 35	3	3	1	90, 100, 110	6	1	42.2
24	1150	5	25, 30, 35	3	3	1	90, 100, 110	6	1	279.2
25	250	1	5, 10, 15	6	3	1	90, 100, 110	6	1	75.8
26	1150	1	5, 10, 15	6	3	1	90, 100, 110	6	1	345.2
27	250	5	5, 10, 15	6	3	1	90, 100, 110	6	1	43.9

28	1150	5	5, 10, 15	6	3	1	90, 100, 110	6	1	285.3
29	250	1	25, 30, 35	6	3	1	90, 100, 110	6	1	76.1
30	1150	1	25, 30, 35	6	3	1	90, 100, 110	6	1	345.8
31	250	5	25, 30, 35	6	3	1	90, 100, 110	6	1	44.5
32	1150	5	25, 30, 35	6	3	1	90, 100, 110	6	1	285.8
33	250	1	5, 10, 15	3	1	3	90, 100, 110	6	1	72.6
34	1150	1	5, 10, 15	3	1	3	90, 100, 110	6	1	342.8
35	250	5	5, 10, 15	3	1	3	90, 100, 110	6	1	41.8
36	1150	5	5, 10, 15	3	1	3	90, 100, 110	6	1	279.6
37	250	1	25, 30, 35	3	1	3	90, 100, 110	6	1	73.2
38	1150	1	25, 30, 35	3	1	3	90, 100, 110	6	1	342.7
39	250	5	25, 30, 35	3	1	3	90, 100, 110	6	1	42.7
40	1150	5	25, 30, 35	3	1	3	90, 100, 110	6	1	279.3
41	250	1	5, 10, 15	6	1	3	90, 100, 110	6	1	76.4
42	1150	1	5, 10, 15	6	1	3	90, 100, 110	6	1	346
43	250	5	5, 10, 15	6	1	3	90, 100, 110	6	1	44.3
44	1150	5	5, 10, 15	6	1	3	90, 100, 110	6	1	284.6
45	250	1	25, 30, 35	6	1	3	90, 100, 110	6	1	76.5
46	1150	1	25, 30, 35	6	1	3	90, 100, 110	6	1	346.4
47	250	5	25, 30, 35	6	1	3	90, 100, 110	6	1	45
48	1150	5	25, 30, 35	6	1	3	90, 100, 110	6	1	286.1
49	250	1	5, 10, 15	3	3	3	90, 100, 110	6	1	72.6
50	1150	1	5, 10, 15	3	3	3	90, 100, 110	6	1	342.8
51	250	5	5, 10, 15	3	3	3	90, 100, 110	6	1	41.8
52	1150	5	5, 10, 15	3	3	3	90, 100, 110	6	1	280
53	250	1	25, 30, 35	3	3	3	90, 100, 110	6	1	73.2
54	1150	1	25, 30, 35	3	3	3	90, 100, 110	6	1	342.7
55	250	5	25, 30, 35	3	3	3	90, 100, 110	6	1	42.7
56	1150	5	25, 30, 35	3	3	3	90, 100, 110	6	1	279.3
57	250	1	5, 10, 15	6	3	3	90, 100, 110	6	1	76.4
58	1150	1	5, 10, 15	6	3	3	90, 100, 110	6	1	346
59	250	5	5, 10, 15	6	3	3	90, 100, 110	6	1	44.3
60	1150	5	5, 10, 15	6	3	3	90, 100, 110	6	1	284.6
61	250	1	25, 30, 35	6	3	3	90, 100, 110	6	1	76.5
62	1150	1	25, 30, 35	6	3	3	90, 100, 110	6	1	346.4

63	250	5	25, 30, 35	6	3	3	90, 100, 110	6	1	45
64	1150	5	25, 30, 35	6	3	3	90, 100, 110	6	1	286.1
65	250	1	5, 10, 15	3	1	1	130, 140, 150	6	1	73
66	1150	1	5, 10, 15	3	1	1	130, 140, 150	6	1	342.3
67	250	5	5, 10, 15	3	1	1	130, 140, 150	6	1	42.2
68	1150	5	5, 10, 15	3	1	1	130, 140, 150	6	1	280.3
69	250	1	25, 30, 35	3	1	1	130, 140, 150	6	1	73.3
70	1150	1	25, 30, 35	3	1	1	130, 140, 150	6	1	342.9
71	250	5	25, 30, 35	3	1	1	130, 140, 150	6	1	42.7
72	1150	5	25, 30, 35	3	1	1	130, 140, 150	6	1	280.2
73	250	1	5, 10, 15	6	1	1	130, 140, 150	6	1	76.3
74	1150	1	5, 10, 15	6	1	1	130, 140, 150	6	1	346.1
75	250	5	5, 10, 15	6	1	1	130, 140, 150	6	1	44.7
76	1150	5	5, 10, 15	6	1	1	130, 140, 150	6	1	283.5
77	250	1	25, 30, 35	6	1	1	130, 140, 150	6	1	76.4
78	1150	1	25, 30, 35	6	1	1	130, 140, 150	6	1	346.5
79	250	5	25, 30, 35	6	1	1	130, 140, 150	6	1	45.2
80	1150	5	25, 30, 35	6	1	1	130, 140, 150	6	1	286
81	250	1	5, 10, 15	3	3	1	130, 140, 150	6	1	73
82	1150	1	5, 10, 15	3	3	1	130, 140, 150	6	1	342.8

83	250	5	5, 10, 15	3	3	1	130, 140, 150	6	1	42.2
84	1150	5	5, 10, 15	3	3	1	130, 140, 150	6	1	280.3
85	250	1	25, 30, 35	3	3	1	130, 140, 150	6	1	73.3
86	1150	1	25, 30, 35	3	3	1	130, 140, 150	6	1	342.9
87	250	5	25, 30, 35	3	3	1	130, 140, 150	6	1	42.7
88	1150	5	25, 30, 35	3	3	1	130, 140, 150	6	1	280.2
89	250	1	5, 10, 15	6	3	1	130, 140, 150	6	1	76.3
90	1150	1	5, 10, 15	6	3	1	130, 140, 150	6	1	346.1
91	250	5	5, 10, 15	6	3	1	130, 140, 150	6	1	44.7
92	1150	5	5, 10, 15	6	3	1	130, 140, 150	6	1	283.5
93	250	1	25, 30, 35	6	3	1	130, 140, 150	6	1	76.4
94	1150	1	25, 30, 35	6	3	1	130, 140, 150	6	1	346.5
95	250	5	25, 30, 35	6	3	1	130, 140, 150	6	1	45.2
96	1150	5	25, 30, 35	6	3	1	130, 140, 150	6	1	286
97	250	1	5, 10, 15	3	1	3	130, 140, 150	6	1	73
98	1150	1	5, 10, 15	3	1	3	130, 140, 150	6	1	342.8
99	250	5	5, 10, 15	3	1	3	130, 140, 150	6	1	42.2
100	1150	5	5, 10, 15	3	1	3	130, 140, 150	6	1	280.3
101	250	1	25, 30, 35	3	1	3	130, 140, 150	6	1	73.3

102	1150	1	25, 30, 35	3	1	3	130, 140, 150	6	1	342.9
103	250	5	25, 30, 35	3	1	3	130, 140, 150	6	1	42.7
104	1150	5	25, 30, 35	3	1	3	130, 140, 150	6	1	280.2
105	250	1	5, 10, 15	6	1	3	130, 140, 150	6	1	76.3
106	1150	1	5, 10, 15	6	1	3	130, 140, 150	6	1	346.1
107	250	5	5, 10, 15	6	1	3	130, 140, 150	6	1	44.7
108	1150	5	5, 10, 15	6	1	3	130, 140, 150	6	1	283.5
109	250	1	25, 30, 35	6	1	3	130, 140, 150	6	1	76.4
110	1150	1	25, 30, 35	6	1	3	130, 140, 150	6	1	346.5
111	250	5	25, 30, 35	6	1	3	130, 140, 150	6	1	45.2
112	1150	5	25, 30, 35	6	1	3	130, 140, 150	6	1	286
113	250	1	5, 10, 15	3	3	3	130, 140, 150	6	1	73
114	1150	1	5, 10, 15	3	3	3	130, 140, 150	6	1	342.8
115	250	5	5, 10, 15	3	3	3	130, 140, 150	6	1	42.2
116	1150	5	5, 10, 15	3	3	3	130, 140, 150	6	1	280.3
117	250	1	25, 30, 35	3	3	3	130, 140, 150	6	1	73.3
118	1150	1	25, 30, 35	3	3	3	130, 140, 150	6	1	342.9
119	250	5	25, 30, 35	3	3	3	130, 140, 150	6	1	42.7
120	1150	5	25, 30, 35	3	3	3	130, 140, 150	6	1	280.2

121	250	1	5, 10, 15	6	3	3	130, 140, 150	6	1	76.3
122	1150	1	5, 10, 15	6	3	3	130, 140, 150	6	1	346.1
123	250	5	5, 10, 15	6	3	3	130, 140, 150	6	1	44.7
124	1150	5	5, 10, 15	6	3	3	130, 140, 150	6	1	283.5
125	250	1	25, 30, 35	6	3	3	130, 140, 150	6	1	76.4
126	1150	1	25, 30, 35	6	3	3	130, 140, 150	6	1	346.5
127	250	5	25, 30, 35	6	3	3	130, 140, 150	6	1	45.2
128	1150	5	25, 30, 35	6	3	3	130, 140, 150	6	1	286
129	250	1	5, 10, 15	3	1	1	90, 100, 110	12	1	150.3
130	1150	1	5, 10, 15	3	1	1	90, 100, 110	12	1	690
131	250	5	5, 10, 15	3	1	1	90, 100, 110	12	1	100.4
132	1150	5	5, 10, 15	3	1	1	90, 100, 110	12	1	629.1
133	250	1	25, 30, 35	3	1	1	90, 100, 110	12	1	150.3
134	1150	1	25, 30, 35	3	1	1	90, 100, 110	12	1	690.2
135	250	5	25, 30, 35	3	1	1	90, 100, 110	12	1	99
136	1150	5	25, 30, 35	3	1	1	90, 100, 110	12	1	627.9
137	250	1	5, 10, 15	6	1	1	90, 100, 110	12	1	153.2
138	1150	1	5, 10, 15	6	1	1	90, 100, 110	12	1	693.1
139	250	5	5, 10, 15	6	1	1	90, 100, 110	12	1	101.1
140	1150	5	5, 10, 15	6	1	1	90, 100, 110	12	1	629.2
141	250	1	25, 30, 35	6	1	1	90, 100, 110	12	1	153.4
142	1150	1	25, 30, 35	6	1	1	90, 100, 110	12	1	693.3
143	250	5	25, 30, 35	6	1	1	90, 100, 110	12	1	101.7
144	1150	5	25, 30, 35	6	1	1	90, 100, 110	12	1	630.2
145	250	1	5, 10, 15	3	3	1	90, 100, 110	12	1	150.3
146	1150	1	5, 10, 15	3	3	1	90, 100, 110	12	1	690
147	250	5	5, 10, 15	3	3	1	90, 100, 110	12	1	104
148	1150	5	5, 10, 15	3	3	1	90, 100, 110	12	1	629.1
149	250	1	25, 30, 35	3	3	1	90, 100, 110	12	1	150.3

150	1150	1	25, 30, 35	3	3	1	90, 100, 110	12	1	690.2
151	250	5	25, 30, 35	3	3	1	90, 100, 110	12	1	98.6
152	1150	5	25, 30, 35	3	3	1	90, 100, 110	12	1	628
153	250	1	5, 10, 15	6	3	1	90, 100, 110	12	1	153.2
154	1150	1	5, 10, 15	6	3	1	90, 100, 110	12	1	693.1
155	250	5	5, 10, 15	6	3	1	90, 100, 110	12	1	101.1
156	1150	5	5, 10, 15	6	3	1	90, 100, 110	12	1	629.2
157	250	1	25, 30, 35	6	3	1	90, 100, 110	12	1	153.4
158	1150	1	25, 30, 35	6	3	1	90, 100, 110	12	1	693.3
159	250	5	25, 30, 35	6	3	1	90, 100, 110	12	1	101.7
160	1150	5	25, 30, 35	6	3	1	90, 100, 110	12	1	630.2
161	250	1	5, 10, 15	3	1	3	90, 100, 110	12	1	150.3
162	1150	1	5, 10, 15	3	1	3	90, 100, 110	12	1	690
163	250	5	5, 10, 15	3	1	3	90, 100, 110	12	1	100.4
164	1150	5	5, 10, 15	3	1	3	90, 100, 110	12	1	629.1
165	250	1	25, 30, 35	3	1	3	90, 100, 110	12	1	150.3
166	1150	1	25, 30, 35	3	1	3	90, 100, 110	12	1	690.2
167	250	5	25, 30, 35	3	1	3	90, 100, 110	12	1	98.6
168	1150	5	25, 30, 35	3	1	3	90, 100, 110	12	1	627.9
169	250	1	5, 10, 15	6	1	3	90, 100, 110	12	1	153.2
170	1150	1	5, 10, 15	6	1	3	90, 100, 110	12	1	693.1
171	250	5	5, 10, 15	6	1	3	90, 100, 110	12	1	101.1
172	1150	5	5, 10, 15	6	1	3	90, 100, 110	12	1	629.2
173	250	1	25, 30, 35	6	1	3	90, 100, 110	12	1	153.4
174	1150	1	25, 30, 35	6	1	3	90, 100, 110	12	1	693.3
175	250	5	25, 30, 35	6	1	3	90, 100, 110	12	1	101.7
176	1150	5	25, 30, 35	6	1	3	90, 100, 110	12	1	630.2
177	250	1	5, 10, 15	3	3	3	90, 100, 110	12	1	150.3
178	1150	1	5, 10, 15	3	3	3	90, 100, 110	12	1	690
179	250	5	5, 10, 15	3	3	3	90, 100, 110	12	1	100.4
180	1150	5	5, 10, 15	3	3	3	90, 100, 110	12	1	629.1
181	250	1	25, 30, 35	3	3	3	90, 100, 110	12	1	150.3
182	1150	1	25, 30, 35	3	3	3	90, 100, 110	12	1	690.2
183	250	5	25, 30, 35	3	3	3	90, 100, 110	12	1	98.6
184	1150	5	25, 30, 35	3	3	3	90, 100, 110	12	1	627.9

185	250	1	5, 10, 15	6	3	3	90, 100, 110	12	1	153.2
186	1150	1	5, 10, 15	6	3	3	90, 100, 110	12	1	693.1
187	250	5	5, 10, 15	6	3	3	90, 100, 110	12	1	101
188	1150	5	5, 10, 15	6	3	3	90, 100, 110	12	1	629.2
189	250	1	25, 30, 35	6	3	3	90, 100, 110	12	1	153.4
190	1150	1	25, 30, 35	6	3	3	90, 100, 110	12	1	693.3
191	250	5	25, 30, 35	6	3	3	90, 100, 110	12	1	101.7
192	1150	5	25, 30, 35	6	3	3	90, 100, 110	12	1	630.2
193	250	1	5, 10, 15	3	1	1	130, 140, 150	12	1	151
194	1150	1	5, 10, 15	3	1	1	130, 140, 150	12	1	690.4
195	250	5	5, 10, 15	3	1	1	130, 140, 150	12	1	99.1
196	1150	5	5, 10, 15	3	1	1	130, 140, 150	12	1	629.1
197	250	1	25, 30, 35	3	1	1	130, 140, 150	12	1	150.8
198	1150	1	25, 30, 35	3	1	1	130, 140, 150	12	1	690.8
199	250	5	25, 30, 35	3	1	1	130, 140, 150	12	1	98.5
200	1150	5	25, 30, 35	3	1	1	130, 140, 150	12	1	630.3
201	250	1	5, 10, 15	6	1	1	130, 140, 150	12	1	153.7
202	1150	1	5, 10, 15	6	1	1	130, 140, 150	12	1	693.9
203	250	5	5, 10, 15	6	1	1	130, 140, 150	12	1	103.2
204	1150	5	5, 10, 15	6	1	1	130, 140, 150	12	1	629.8
205	250	1	25, 30, 35	6	1	1	130, 140, 150	12	1	153.8
206	1150	1	25, 30, 35	6	1	1	130, 140, 150	12	1	694.2
207	250	5	25, 30, 35	6	1	1	130, 140, 150	12	1	102.9

208	1150	5	25, 30, 35	6	1	1	130, 140, 150	12	1	630.9
209	250	1	5, 10, 15	3	3	1	130, 140, 150	12	1	151
210	1150	1	5, 10, 15	3	3	1	130, 140, 150	12	1	690.4
211	250	5	5, 10, 15	3	3	1	130, 140, 150	12	1	99.1
212	1150	5	5, 10, 15	3	3	1	130, 140, 150	12	1	629.1
213	250	1	25, 30, 35	3	3	1	130, 140, 150	12	1	150.8
214	1150	1	25, 30, 35	3	3	1	130, 140, 150	12	1	690.8
215	250	5	25, 30, 35	3	3	1	130, 140, 150	12	1	98.5
216	1150	5	25, 30, 35	3	3	1	130, 140, 150	12	1	630.3
217	250	1	5, 10, 15	6	3	1	130, 140, 150	12	1	153.7
218	1150	1	5, 10, 15	6	3	1	130, 140, 150	12	1	693.9
219	250	5	5, 10, 15	6	3	1	130, 140, 150	12	1	103.2
220	1150	5	5, 10, 15	6	3	1	130, 140, 150	12	1	629.8
221	250	1	25, 30, 35	6	3	1	130, 140, 150	12	1	153.8
222	1150	1	25, 30, 35	6	3	1	130, 140, 150	12	1	694.2
223	250	5	25, 30, 35	6	3	1	130, 140, 150	12	1	102.9
224	1150	5	25, 30, 35	6	3	1	130, 140, 150	12	1	630.9
225	250	1	5, 10, 15	3	1	3	130, 140, 150	12	1	151.3
226	1150	1	5, 10, 15	3	1	3	130, 140, 150	12	1	690.4

227	250	5	5, 10, 15	3	1	3	130, 140, 150	12	1	99.8
228	1150	5	5, 10, 15	3	1	3	130, 140, 150	12	1	630.3
229	250	1	25, 30, 35	3	1	3	130, 140, 150	12	1	150.4
230	1150	1	25, 30, 35	3	1	3	130, 140, 150	12	1	690.3
231	250	5	25, 30, 35	3	1	3	130, 140, 150	12	1	97.6
232	1150	5	25, 30, 35	3	1	3	130, 140, 150	12	1	628.5
233	250	1	5, 10, 15	6	1	3	130, 140, 150	12	1	153.3
234	1150	1	5, 10, 15	6	1	3	130, 140, 150	12	1	693.4
235	250	5	5, 10, 15	6	1	3	130, 140, 150	12	1	101.9
236	1150	5	5, 10, 15	6	1	3	130, 140, 150	12	1	629.3
237	250	1	25, 30, 35	6	1	3	130, 140, 150	12	1	153.6
238	1150	1	25, 30, 35	6	1	3	130, 140, 150	12	1	693.7
239	250	5	25, 30, 35	6	1	3	130, 140, 150	12	1	101.8
240	1150	5	25, 30, 35	6	1	3	130, 140, 150	12	1	630.5
241	250	1	5, 10, 15	3	3	3	130, 140, 150	12	1	150.7
242	1150	1	5, 10, 15	3	3	3	130, 140, 150	12	1	690.1
243	250	5	5, 10, 15	3	3	3	130, 140, 150	12	1	99.8
244	1150	5	5, 10, 15	3	3	3	130, 140, 150	12	1	630.3
245	250	1	25, 30, 35	3	3	3	130, 140, 150	12	1	150.4

246	1150	1	25, 30, 35	3	3	3	130, 140, 150	12	1	690.3
247	250	5	25, 30, 35	3	3	3	130, 140, 150	12	1	97.6
248	1150	5	25, 30, 35	3	3	3	130, 140, 150	12	1	628.5
249	250	1	5, 10, 15	6	3	3	130, 140, 150	12	1	153.3
250	1150	1	5, 10, 15	6	3	3	130, 140, 150	12	1	693.4
251	250	5	5, 10, 15	6	3	3	130, 140, 150	12	1	101.9
252	1150	5	5, 10, 15	6	3	3	130, 140, 150	12	1	629.3
253	250	1	25, 30, 35	6	3	3	130, 140, 150	12	1	153.6
254	1150	1	25, 30, 35	6	3	3	130, 140, 150	12	1	693.7
255	250	5	25, 30, 35	6	3	3	130, 140, 150	12	1	101.8
256	1150	5	25, 30, 35	6	3	3	130, 140, 150	12	1	630.5
257	250	1	5, 10, 15	3	1	1	90, 100, 110	6	3	72.3
258	1150	1	5, 10, 15	3	1	1	90, 100, 110	6	3	342.1
259	250	5	5, 10, 15	3	1	1	90, 100, 110	6	3	41.6
260	1150	5	5, 10, 15	3	1	1	90, 100, 110	6	3	276.6
261	250	1	25, 30, 35	3	1	1	90, 100, 110	6	3	72.3
262	1150	1	25, 30, 35	3	1	1	90, 100, 110	6	3	343
263	250	5	25, 30, 35	3	1	1	90, 100, 110	6	3	42.2
264	1150	5	25, 30, 35	3	1	1	90, 100, 110	6	3	279.2
265	250	1	5, 10, 15	6	1	1	90, 100, 110	6	3	75.8
266	1150	1	5, 10, 15	6	1	1	90, 100, 110	6	3	345.2
267	250	5	5, 10, 15	6	1	1	90, 100, 110	6	3	44
268	1150	5	5, 10, 15	6	1	1	90, 100, 110	6	3	285.3
269	250	1	25, 30, 35	6	1	1	90, 100, 110	6	3	76.1
270	1150	1	25, 30, 35	6	1	1	90, 100, 110	6	3	345.8
271	250	5	25, 30, 35	6	1	1	90, 100, 110	6	3	44.5

272	1150	5	25, 30, 35	6	1	1	90, 100, 110	6	3	285.9
273	250	1	5, 10, 15	3	3	1	90, 100, 110	6	3	72.3
274	1150	1	5, 10, 15	3	3	1	90, 100, 110	6	3	342.1
275	250	5	5, 10, 15	3	3	1	90, 100, 110	6	3	41.6
276	1150	5	5, 10, 15	3	3	1	90, 100, 110	6	3	276.6
277	250	1	25, 30, 35	3	3	1	90, 100, 110	6	3	72.3
278	1150	1	25, 30, 35	3	3	1	90, 100, 110	6	3	343
279	250	5	25, 30, 35	3	3	1	90, 100, 110	6	3	42.2
280	1150	5	25, 30, 35	3	3	1	90, 100, 110	6	3	279.2
281	250	1	5, 10, 15	6	3	1	90, 100, 110	6	3	75.8
282	1150	1	5, 10, 15	6	3	1	90, 100, 110	6	3	345.2
283	250	5	5, 10, 15	6	3	1	90, 100, 110	6	3	44
284	1150	5	5, 10, 15	6	3	1	90, 100, 110	6	3	285.3
285	250	1	25, 30, 35	6	3	1	90, 100, 110	6	3	76.1
286	1150	1	25, 30, 35	6	3	1	90, 100, 110	6	3	345.8
287	250	5	25, 30, 35	6	3	1	90, 100, 110	6	3	44.5
288	1150	5	25, 30, 35	6	3	1	90, 100, 110	6	3	285.8
289	250	1	5, 10, 15	3	1	3	90, 100, 110	6	3	72.3
290	1150	1	5, 10, 15	3	1	3	90, 100, 110	6	3	342.1
291	250	5	5, 10, 15	3	1	3	90, 100, 110	6	3	41.6
292	1150	5	5, 10, 15	3	1	3	90, 100, 110	6	3	276.6
293	250	1	25, 30, 35	3	1	3	90, 100, 110	6	3	72.3
294	1150	1	25, 30, 35	3	1	3	90, 100, 110	6	3	343
295	250	5	25, 30, 35	3	1	3	90, 100, 110	6	3	42.2
296	1150	5	25, 30, 35	3	1	3	90, 100, 110	6	3	279.2
297	250	1	5, 10, 15	6	1	3	90, 100, 110	6	3	75.8
298	1150	1	5, 10, 15	6	1	3	90, 100, 110	6	3	345.2
299	250	5	5, 10, 15	6	1	3	90, 100, 110	6	3	44
300	1150	5	5, 10, 15	6	1	3	90, 100, 110	6	3	285.3
301	250	1	25, 30, 35	6	1	3	90, 100, 110	6	3	76.1
302	1150	1	25, 30, 35	6	1	3	90, 100, 110	6	3	345.8
303	250	5	25, 30, 35	6	1	3	90, 100, 110	6	3	44.5
304	1150	5	25, 30, 35	6	1	3	90, 100, 110	6	3	285.8
305	250	1	5, 10, 15	3	3	3	90, 100, 110	6	3	72.3
306	1150	1	5, 10, 15	3	3	3	90, 100, 110	6	3	342.1

307	250	5	5, 10, 15	3	3	3	90, 100, 110	6	3	41.6
308	1150	5	5, 10, 15	3	3	3	90, 100, 110	6	3	276.6
309	250	1	25, 30, 35	3	3	3	90, 100, 110	6	3	72.3
310	1150	1	25, 30, 35	3	3	3	90, 100, 110	6	3	343
311	250	5	25, 30, 35	3	3	3	90, 100, 110	6	3	42.2
312	1150	5	25, 30, 35	3	3	3	90, 100, 110	6	3	279.2
313	250	1	5, 10, 15	6	3	3	90, 100, 110	6	3	75.8
314	1150	1	5, 10, 15	6	3	3	90, 100, 110	6	3	345.2
315	250	5	5, 10, 15	6	3	3	90, 100, 110	6	3	43.9
316	1150	5	5, 10, 15	6	3	3	90, 100, 110	6	3	285.3
317	250	1	25, 30, 35	6	3	3	90, 100, 110	6	3	76.1
318	1150	1	25, 30, 35	6	3	3	90, 100, 110	6	3	345.8
319	250	5	25, 30, 35	6	3	3	90, 100, 110	6	3	44.5
320	1150	5	25, 30, 35	6	3	3	90, 100, 110	6	3	285.8
321	250	1	5, 10, 15	3	1	1	130, 140, 150	6	3	73
322	1150	1	5, 10, 15	3	1	1	130, 140, 150	6	3	342.8
323	250	5	5, 10, 15	3	1	1	130, 140, 150	6	3	42.2
324	1150	5	5, 10, 15	3	1	1	130, 140, 150	6	3	280.3
325	250	1	25, 30, 35	3	1	1	130, 140, 150	6	3	73.3
326	1150	1	25, 30, 35	3	1	1	130, 140, 150	6	3	342.9
327	250	5	25, 30, 35	3	1	1	130, 140, 150	6	3	42.7
328	1150	5	25, 30, 35	3	1	1	130, 140, 150	6	3	280.2
329	250	1	5, 10, 15	6	1	1	130, 140, 150	6	3	76.3
330	1150	1	5, 10, 15	6	1	1	130, 140, 150	6	3	346.1
331	250	5	5, 10, 15	6	1	1	130, 140, 150	6	3	44.7
332	1150	5	5, 10, 15	6	1	1	130, 140, 150	6	3	283.5

333	250	1	25, 30, 35	6	1	1	130, 140, 150	6	3	76.4
334	1150	1	25, 30, 35	6	1	1	130, 140, 150	6	3	346.5
335	250	5	25, 30, 35	6	1	1	130, 140, 150	6	3	45.2
336	1150	5	25, 30, 35	6	1	1	130, 140, 150	6	3	286
337	250	1	5, 10, 15	3	3	1	130, 140, 150	6	3	73
338	1150	1	5, 10, 15	3	3	1	130, 140, 150	6	3	342.8
339	250	5	5, 10, 15	3	3	1	130, 140, 150	6	3	42.2
340	1150	5	5, 10, 15	3	3	1	130, 140, 150	6	3	280.3
341	250	1	25, 30, 35	3	3	1	130, 140, 150	6	3	73.3
342	1150	1	25, 30, 35	3	3	1	130, 140, 150	6	3	342.9
343	250	5	25, 30, 35	3	3	1	130, 140, 150	6	3	42.7
344	1150	5	25, 30, 35	3	3	1	130, 140, 150	6	3	280.2
345	250	1	5, 10, 15	6	3	1	130, 140, 150	6	3	76.3
346	1150	1	5, 10, 15	6	3	1	130, 140, 150	6	3	346.1
347	250	5	5, 10, 15	6	3	1	130, 140, 150	6	3	44.7
348	1150	5	5, 10, 15	6	3	1	130, 140, 150	6	3	283.5
349	250	1	25, 30, 35	6	3	1	130, 140, 150	6	3	76.4
350	1150	1	25, 30, 35	6	3	1	130, 140, 150	6	3	346.5
351	250	5	25, 30, 35	6	3	1	130, 140, 150	6	3	45.2

352	1150	5	25, 30, 35	6	3	1	130, 140, 150	6	3	285.9
353	250	1	5, 10, 15	3	1	3	130, 140, 150	6	3	73
354	1150	1	5, 10, 15	3	1	3	130, 140, 150	6	3	342.8
355	250	5	5, 10, 15	3	1	3	130, 140, 150	6	3	42.2
356	1150	5	5, 10, 15	3	1	3	130, 140, 150	6	3	280.3
357	250	1	25, 30, 35	3	1	3	130, 140, 150	6	3	73.3
358	1150	1	25, 30, 35	3	1	3	130, 140, 150	6	3	342.9
359	250	5	25, 30, 35	3	1	3	130, 140, 150	6	3	42.7
360	1150	5	25, 30, 35	3	1	3	130, 140, 150	6	3	280.2
361	250	1	5, 10, 15	6	1	3	130, 140, 150	6	3	76.3
362	1150	1	5, 10, 15	6	1	3	130, 140, 150	6	3	346.1
363	250	5	5, 10, 15	6	1	3	130, 140, 150	6	3	44.7
364	1150	5	5, 10, 15	6	1	3	130, 140, 150	6	3	283.5
365	250	1	25, 30, 35	6	1	3	130, 140, 150	6	3	76.4
366	1150	1	25, 30, 35	6	1	3	130, 140, 150	6	3	346.5
367	250	5	25, 30, 35	6	1	3	130, 140, 150	6	3	45.2
368	1150	5	25, 30, 35	6	1	3	130, 140, 150	6	3	285.9
369	250	1	5, 10, 15	3	3	3	130, 140, 150	6	3	73
370	1150	1	5, 10, 15	3	3	3	130, 140, 150	6	3	342.8

371	250	5	5, 10, 15	3	3	3	130, 140, 150	6	3	42.2
372	1150	5	5, 10, 15	3	3	3	130, 140, 150	6	3	280.3
373	250	1	25, 30, 35	3	3	3	130, 140, 150	6	3	73.3
374	1150	1	25, 30, 35	3	3	3	130, 140, 150	6	3	342.9
375	250	5	25, 30, 35	3	3	3	130, 140, 150	6	3	42.7
376	1150	5	25, 30, 35	3	3	3	130, 140, 150	6	3	280.2
377	250	1	5, 10, 15	6	3	3	130, 140, 150	6	3	76.3
378	1150	1	5, 10, 15	6	3	3	130, 140, 150	6	3	346.1
379	250	5	5, 10, 15	6	3	3	130, 140, 150	6	3	44.7
380	1150	5	5, 10, 15	6	3	3	130, 140, 150	6	3	283.5
381	250	1	25, 30, 35	6	3	3	130, 140, 150	6	3	76.4
382	1150	1	25, 30, 35	6	3	3	130, 140, 150	6	3	346.5
383	250	5	25, 30, 35	6	3	3	130, 140, 150	6	3	45.2
384	1150	5	25, 30, 35	6	3	3	130, 140, 150	6	3	285.9
385	250	1	5, 10, 15	3	1	1	90, 100, 110	12	3	150.3
386	1150	1	5, 10, 15	3	1	1	90, 100, 110	12	3	690
387	250	5	5, 10, 15	3	1	1	90, 100, 110	12	3	100.4
388	1150	5	5, 10, 15	3	1	1	90, 100, 110	12	3	629.1
389	250	1	25, 30, 35	3	1	1	90, 100, 110	12	3	150.3
390	1150	1	25, 30, 35	3	1	1	90, 100, 110	12	3	690.2
391	250	5	25, 30, 35	3	1	1	90, 100, 110	12	3	98.6
392	1150	5	25, 30, 35	3	1	1	90, 100, 110	12	3	627.9
393	250	1	5, 10, 15	6	1	1	90, 100, 110	12	3	153.2
394	1150	1	5, 10, 15	6	1	1	90, 100, 110	12	3	693.1

395	250	5	5, 10, 15	6	1	1	90, 100, 110	12	3	101.1
396	1150	5	5, 10, 15	6	1	1	90, 100, 110	12	3	629.2
397	250	1	25, 30, 35	6	1	1	90, 100, 110	12	3	153.4
398	1150	1	25, 30, 35	6	1	1	90, 100, 110	12	3	693.3
399	250	5	25, 30, 35	6	1	1	90, 100, 110	12	3	101.7
400	1150	5	25, 30, 35	6	1	1	90, 100, 110	12	3	630.2
401	250	1	5, 10, 15	3	3	1	90, 100, 110	12	3	150.3
402	1150	1	5, 10, 15	3	3	1	90, 100, 110	12	3	690
403	250	5	5, 10, 15	3	3	1	90, 100, 110	12	3	100.4
404	1150	5	5, 10, 15	3	3	1	90, 100, 110	12	3	629.1
405	250	1	25, 30, 35	3	3	1	90, 100, 110	12	3	150.3
406	1150	1	25, 30, 35	3	3	1	90, 100, 110	12	3	690.2
407	250	5	25, 30, 35	3	3	1	90, 100, 110	12	3	98.6
408	1150	5	25, 30, 35	3	3	1	90, 100, 110	12	3	627.9
409	250	1	5, 10, 15	6	3	1	90, 100, 110	12	3	153.2
410	1150	1	5, 10, 15	6	3	1	90, 100, 110	12	3	693
411	250	5	5, 10, 15	6	3	1	90, 100, 110	12	3	101.1
412	1150	5	5, 10, 15	6	3	1	90, 100, 110	12	3	629.2
413	250	1	25, 30, 35	6	3	1	90, 100, 110	12	3	153.4
414	1150	1	25, 30, 35	6	3	1	90, 100, 110	12	3	693.3
415	250	5	25, 30, 35	6	3	1	90, 100, 110	12	3	101.7
416	1150	5	25, 30, 35	6	3	1	90, 100, 110	12	3	630.2
417	250	1	5, 10, 15	3	1	3	90, 100, 110	12	3	150.3
418	1150	1	5, 10, 15	3	1	3	90, 100, 110	12	3	690
419	250	5	5, 10, 15	3	1	3	90, 100, 110	12	3	100.4
420	1150	5	5, 10, 15	3	1	3	90, 100, 110	12	3	629.1
421	250	1	25, 30, 35	3	1	3	90, 100, 110	12	3	150.3
422	1150	1	25, 30, 35	3	1	3	90, 100, 110	12	3	690.2
423	250	5	25, 30, 35	3	1	3	90, 100, 110	12	3	98.6
424	1150	5	25, 30, 35	3	1	3	90, 100, 110	12	3	627.9
425	250	1	5, 10, 15	6	1	3	90, 100, 110	12	3	153.2
426	1150	1	5, 10, 15	6	1	3	90, 100, 110	12	3	693.1
427	250	5	5, 10, 15	6	1	3	90, 100, 110	12	3	101.2
428	1150	5	5, 10, 15	6	1	3	90, 100, 110	12	3	629.2
429	250	1	25, 30, 35	6	1	3	90, 100, 110	12	3	153.4

430	1150	1	25, 30, 35	6	1	3	90, 100, 110	12	3	693.3
431	250	5	25, 30, 35	6	1	3	90, 100, 110	12	3	101.7
432	1150	5	25, 30, 35	6	1	3	90, 100, 110	12	3	630.2
433	250	1	5, 10, 15	3	3	3	90, 100, 110	12	3	150.3
434	1150	1	5, 10, 15	3	3	3	90, 100, 110	12	3	690
435	250	5	5, 10, 15	3	3	3	90, 100, 110	12	3	100.4
436	1150	5	5, 10, 15	3	3	3	90, 100, 110	12	3	629.1
437	250	1	25, 30, 35	3	3	3	90, 100, 110	12	3	150.3
438	1150	1	25, 30, 35	3	3	3	90, 100, 110	12	3	690.2
439	250	5	25, 30, 35	3	3	3	90, 100, 110	12	3	98.6
440	1150	5	25, 30, 35	3	3	3	90, 100, 110	12	3	627.9
441	250	1	5, 10, 15	6	3	3	90, 100, 110	12	3	153.2
442	1150	1	5, 10, 15	6	3	3	90, 100, 110	12	3	693.1
443	250	5	5, 10, 15	6	3	3	90, 100, 110	12	3	101.1
444	1150	5	5, 10, 15	6	3	3	90, 100, 110	12	3	629.2
445	250	1	25, 30, 35	6	3	3	90, 100, 110	12	3	153.4
446	1150	1	25, 30, 35	6	3	3	90, 100, 110	12	3	696.3
447	250	5	25, 30, 35	6	3	3	90, 100, 110	12	3	101.7
448	1150	5	25, 30, 35	6	3	3	90, 100, 110	12	3	630.2
449	250	1	5, 10, 15	3	1	1	130, 140, 150	12	3	151
450	1150	1	5, 10, 15	3	1	1	130, 140, 150	12	3	690.4
451	250	5	5, 10, 15	3	1	1	130, 140, 150	12	3	99.1
452	1150	5	5, 10, 15	3	1	1	130, 140, 150	12	3	629.1
453	250	1	25, 30, 35	3	1	1	130, 140, 150	12	3	150.8
454	1150	1	25, 30, 35	3	1	1	130, 140, 150	12	3	690.8
455	250	5	25, 30, 35	3	1	1	130, 140, 150	12	3	98.5
456	1150	5	25, 30, 35	3	1	1	130, 140, 150	12	3	630.3
457	250	1	5, 10, 15	6	1	1	130, 140, 150	12	3	153.7

458	1150	1	5, 10, 15	6	1	1	130, 140, 150	12	3	693.9
459	250	5	5, 10, 15	6	1	1	130, 140, 150	12	3	103.2
460	1150	5	5, 10, 15	6	1	1	130, 140, 150	12	3	629.8
461	250	1	25, 30, 35	6	1	1	130, 140, 150	12	3	153.8
462	1150	1	25, 30, 35	6	1	1	130, 140, 150	12	3	694.2
463	250	5	25, 30, 35	6	1	1	130, 140, 150	12	3	102.9
464	1150	5	25, 30, 35	6	1	1	130, 140, 150	12	3	630.9
465	250	1	5, 10, 15	3	3	1	130, 140, 150	12	3	151
466	1150	1	5, 10, 15	3	3	1	130, 140, 150	12	3	690.4
467	250	5	5, 10, 15	3	3	1	130, 140, 150	12	3	99.1
468	1150	5	5, 10, 15	3	3	1	130, 140, 150	12	3	629.1
469	250	1	25, 30, 35	3	3	1	130, 140, 150	12	3	150.8
470	1150	1	25, 30, 35	3	3	1	130, 140, 150	12	3	690.8
471	250	5	25, 30, 35	3	3	1	130, 140, 150	12	3	98.5
472	1150	5	25, 30, 35	3	3	1	130, 140, 150	12	3	630.3
473	250	1	5, 10, 15	6	3	1	130, 140, 150	12	3	153.7
474	1150	1	5, 10, 15	6	3	1	130, 140, 150	12	3	693.9
475	250	5	5, 10, 15	6	3	1	130, 140, 150	12	3	103.2
476	1150	5	5, 10, 15	6	3	1	130, 140, 150	12	3	630

477	250	1	25, 30, 35	6	3	1	130, 140, 150	12	3	153.8
478	1150	1	25, 30, 35	6	3	1	130, 140, 150	12	3	694
479	250	5	25, 30, 35	6	3	1	130, 140, 150	12	3	102.9
480	1150	5	25, 30, 35	6	3	1	130, 140, 150	12	3	630.9
481	250	1	5, 10, 15	3	1	3	130, 140, 150	12	3	151
482	1150	1	5, 10, 15	3	1	3	130, 140, 150	12	3	690.4
483	250	5	5, 10, 15	3	1	3	130, 140, 150	12	3	99.1
484	1150	5	5, 10, 15	3	1	3	130, 140, 150	12	3	629.1
485	250	1	25, 30, 35	3	1	3	130, 140, 150	12	3	150.8
486	1150	1	25, 30, 35	3	1	3	130, 140, 150	12	3	690.8
487	250	5	25, 30, 35	3	1	3	130, 140, 150	12	3	98.5
488	1150	5	25, 30, 35	3	1	3	130, 140, 150	12	3	630.3
489	250	1	5, 10, 15	6	1	3	130, 140, 150	12	3	153.7
490	1150	1	5, 10, 15	6	1	3	130, 140, 150	12	3	693.9
491	250	5	5, 10, 15	6	1	3	130, 140, 150	12	3	103.2
492	1150	5	5, 10, 15	6	1	3	130, 140, 150	12	3	629.8
493	250	1	25, 30, 35	6	1	3	130, 140, 150	12	3	153.8
494	1150	1	25, 30, 35	6	1	3	130, 140, 150	12	3	694.2
495	250	5	25, 30, 35	6	1	3	130, 140, 150	12	3	102.9

496	1150	5	25, 30, 35	6	1	3	130, 140, 150	12	3	630.9
497	250	1	5, 10, 15	3	3	3	130, 140, 150	12	3	151
498	1150	1	5, 10, 15	3	3	3	130, 140, 150	12	3	690.4
499	250	5	5, 10, 15	3	3	3	130, 140, 150	12	3	99.1
500	1150	5	5, 10, 15	3	3	3	130, 140, 150	12	3	629.1
501	250	1	25, 30, 35	3	3	3	130, 140, 150	12	3	150.8
502	1150	1	25, 30, 35	3	3	3	130, 140, 150	12	3	690.8
503	250	5	25, 30, 35	3	3	3	130, 140, 150	12	3	98.5
504	1150	5	25, 30, 35	3	3	3	130, 140, 150	12	3	630.3
505	250	1	5, 10, 15	6	3	3	130, 140, 150	12	3	153.7
506	1150	1	5, 10, 15	6	3	3	130, 140, 150	12	3	693.9
507	250	5	5, 10, 15	6	3	3	130, 140, 150	12	3	103.2
508	1150	5	5, 10, 15	6	3	3	130, 140, 150	12	3	630
509	250	1	25, 30, 35	6	3	3	130, 140, 150	12	3	153.8
510	1150	1	25, 30, 35	6	3	3	130, 140, 150	12	3	694.2
511	250	5	25, 30, 35	6	3	3	130, 140, 150	12	3	102.9
512	1150	5	25, 30, 35	6	3	3	130, 140, 150	12	3	630.9

Table A3.12: Design of Matrix for Two Level Full Factorial Simulation Experiment (Case B

	FFB Quantity (MT)	FFB Interarrival (every days)	WB Time (Tria, minutes)	Tipping Repair (Const, hours)	Sterilisers (unit)	PT (hours)
1	250	1	5,10,15	6	1	61.3
2	1150	1	5,10,15	6	1	361.1
3	250	5	5,10,15	6	1	32.5
4	1150	5	5,10,15	6	1	269.1
5	250	1	25, 30, 35	6	1	61.8
6	1150	1	25, 30, 35	6	1	361.3
7	250	5	25, 30, 35	6	1	32.7
8	1150	5	25, 30, 35	6	1	269.2
9	250	1	5,10,15	12	1	138.5
10	1150	1	5,10,15	12	1	739.2
11	250	5	5,10,15	12	1	78.1
12	1150	5	5,10,15	12	1	645
13	250	1	25, 30, 35	12	1	138.7
14	1150	1	25, 30, 35	12	1	740
15	250	5	25, 30, 35	12	1	78.4
16	1150	5	25, 30, 35	12	1	643.7
17	250	1	5,10,15	6	3	61.5
18	1150	1	5,10,15	6	3	362.2
19	250	5	5,10,15	6	3	33.9
20	1150	5	5,10,15	6	3	270.7
21	250	1	25, 30, 35	6	3	63.3
22	1150	1	25, 30, 35	6	3	361.6
23	250	5	25, 30, 35	6	3	34.4
24	1150	5	25, 30, 35	6	3	270.3
25	250	1	5,10,15	12	3	139.1
26	1150	1	5,10,15	12	3	740.4
27	250	5	5,10,15	12	3	80
28	1150	5	5,10,15	12	3	645.2
29	250	1	25, 30, 35	12	3	140
30	1150	1	25, 30, 35	12	3	740.2
31	250	5	25, 30, 35	12	3	80.5
32	1150	5	25, 30, 35	12	3	643.3

Table A3.13: Design of Matrix for Two Level Full Factorial Simulation Experiment (Case C)

Run order	WB Repair (Const, hours)	Sterilising Time (Tria, minutes)	Tipping Repair (Const, hours)	PT (hours)
1	3	90,100,110	6	72.1
2	6	90,100,110	6	75.4
3	3	130, 140, 150	6	72.3
4	6	130, 140, 150	6	76.3
5	3	90,100,110	12	149.9
6	6	90,100,110	12	152.7
7	3	130, 140, 150	12	150.5
8	6	130, 140, 150	12	153.4

Table A3. 14: Design of Matrix for Two Level Full Factorial Simulation Experiment (Case D)

Run Order	WB Time (Tria, minutes)	WB Repair (Tria, minutes)	Sterilising Time (Tria, minutes)	Tipping Repair Time (Const, hours)	PT (hours)
1	5,10,15	3	90, 100, 110	6	342.3
2	25, 30, 35	3	90, 100, 110	6	342.5
3	5,10,15	6	90, 100, 110	6	344.8
4	25, 30, 35	6	90, 100, 110	6	345.3
5	5,10,15	3	130, 140, 150	6	342.8
6	25, 30, 35	3	130, 140, 150	6	342.8
7	5,10,15	6	130, 140, 150	6	345.6
8	25, 30, 35	6	130, 140, 150	6	346.4
9	5,10,15	3	90, 100, 110	12	690.1
10	25, 30, 35	3	90, 100, 110	12	689.8
11	5,10,15	6	90, 100, 110	12	692.8
12	25, 30, 35	6	90, 100, 110	12	693
13	5,10,15	3	130, 140, 150	12	690.6
14	25, 30, 35	3	130, 140, 150	12	690.5
15	5,10,15	6	130, 140, 150	12	693.4
16	25, 30, 35	6	130, 140, 150	12	693.9

APPENDIX: CHAPTER C

Replications: 300 Time Units: Hours

User Specified

Tally

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processing Time	43.5357	< 1.60	24.9414	103.22	20.2766	167.81

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Production Quantity	25.0000	< 0.00	25.0000	25.0000

Figure A4.1: Processing Time Predicted From The Simulation Model For Validation Process

PRODUCTION DATA			
Description	Today	Month ToDate	Year ToDate
FFB Processed (MT)	601.34	9375.75	56181.04
Balance FFB (MT)	-		
CPO Production	135.44	2122.83	12517.87
PK Production	25.24	398.09	2353.13
CPO Despatch	2.77	2225.08	12194.92
PK Despatch	1.10	394.83	2391.39
OER%	22.52%	22.64%	22.28%
KER%	4.20%	4.25%	4.19%
Processing Time (hrs)	19.50	307.00	1843.25
Downtime (hrs)	-	-	-
Breakdown	-	15.00	68.00
Throughput	30.84	30.54	30.48
Rainfall (mm)	47	203	1205

Figure A4.2: Data Collected From The Case Study Company

Table A4.1: Results for simulated processing times at different values of simulated FFBs inter-arrival time and weighbridge machine repair time

Run Order	F1	F2	F3	F4	Processing Time
	FFB Quantity	FFB InterArrival Time	WB Repair Time	Tipping Repair Time	
61	750	1	3	8	298.3
62	750	2	3	8	281.4
63	750	3	3	8	266.6
64	750	4	3	8	251.1
65	750	5	3	8	235.3
66	750	1	5	8	300.3
67	750	2	5	8	284.4
68	750	3	5	8	268.4
69	750	4	5	8	254.9
70	750	5	5	8	239.3
71	750	1	7	8	302.3
72	750	2	7	8	286
73	750	3	7	8	272.2
74	750	4	7	8	254.7
75	750	5	7	8	240.3

Table A4.2: Results for simulated processing times at different values of simulated weighbridge repair time and tipping machine repair time

Run Order	F1	F2	F3	F4	Processing Time
	FFB Quantity	FFB InterArrival Time	WB Repair Time	Tipping Repair Time	
166	750	3	3	6	191.3
167	750	3	3	7	228
168	750	3	3	8	266.6
169	750	3	3	9	303.6
170	750	3	3	10	342.7
171	750	3	5	6	192.3
172	750	3	5	7	230.1
173	750	3	5	8	268.4
174	750	3	5	9	307.6
175	750	3	5	10	344.3
176	750	3	7	6	231.4
177	750	3	7	7	233.9
178	750	3	7	8	272.2
179	750	3	7	9	309.5
180	750	3	7	10	346.7

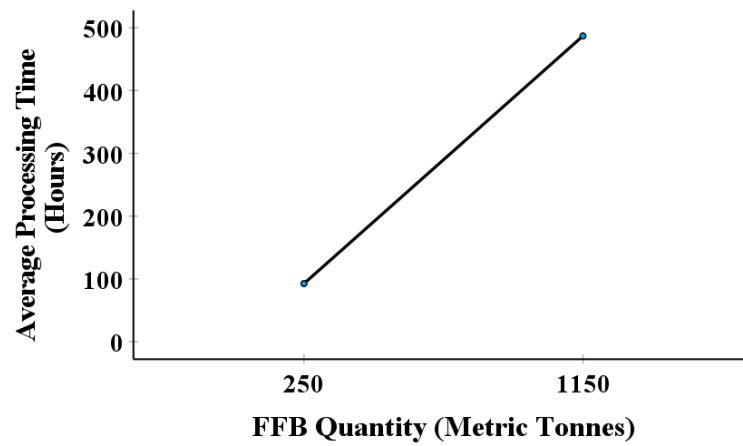
Table A4.3: Results for analysis of variance (ANOVA) – 14 Factors Screening Case A

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	885784.7 ^a	14	63270.338	4049301.617	0.000	1.000
Intercept	1343570.7	1	1343570.766	85988529.000	0.000	1.000
FFB_Quantity	623191.8	1	623191.831	39884277.160	0.000	1.000
FFB Inter Arrival Time	10800.4	1	10800.406	691225.960	0.001	1.000
Weighing Time	79256.3	1	79256.326	5072404.840	0.000	1.000
Weighbridge Repair Time	44.5	1	44.556	2851.560	0.012	1.000
Number of Grading Machines	135.1	1	135.141	8649.000	0.007	1.000
Number of Sterilisers	413.1	1	413.106	26438.760	0.004	1.000
Sterilising Time	5.4	1	5.406	345.960	0.034	0.997
Tipping Machine Repair Time	171830.9	1	171830.976	10997182.440	0.000	1.000
Number of Pressers	105.5	1	105.576	6756.840	0.008	1.000
Error	0.016	1	0.016			
Total	2229355.510	16				
Corrected Total	885784.744	15				
a. R Squared = 1.000 (Adjusted R Squared = 1.000)						
b. Computed using alpha = .05						

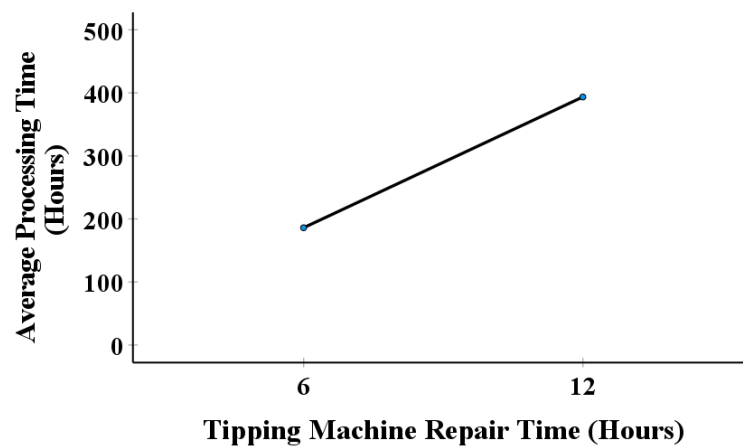
Table A4 4: Results for analysis of variance (ANOVA) – Case A Nine (9) Two-Level Full Factorial

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	28285754.6	45	628572.3	83776.8	0.000	1.000
Intercept	43010435.8	1	43010435.8	5732481.7	0.000	1.000
FFB Quantity	19905880.9	1	19905880.9	2653079.3	0.000	1.000
FFB Inter Arrival Time	342931.7	1	342931.7	45706.3	0.000	0.990
Weighbride Repair Time	1242.8	1	1242.8	165.6	0.000	0.262
Sterilising Time	31.9	1	31.9	4.2	0.040	0.009
Tipping Machine Repair Time	5507444.8	1	5507444.8	734038.7	0.000	0.999
FFB Quantity*FFB Inter Arrival Time	14222.4	1	14222.4	1895.5	0.000	0.803
FFB InterArrival Time*Tipping Machine Repair Time	3392.3	1	3392.3	452.1	0.000	0.492
FFB Quantity*Tipping Machine Repair Time	2510494.2	1	2510494.2	334601.6	0.000	0.999
Weighbride Repair Time*Tipping Machine Repair Time	49.4	1	49.4	6.5	0.011	0.014
Error	3496.3	46	7.5			

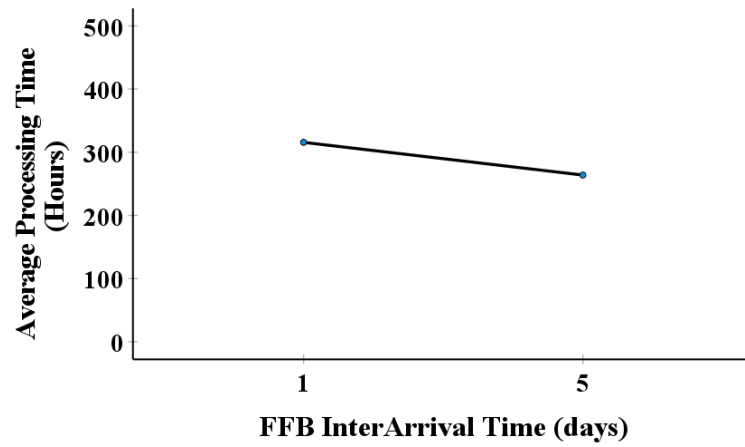
Total	71299686.7	51 2				
Corrected Total	28289250.9	51 1				



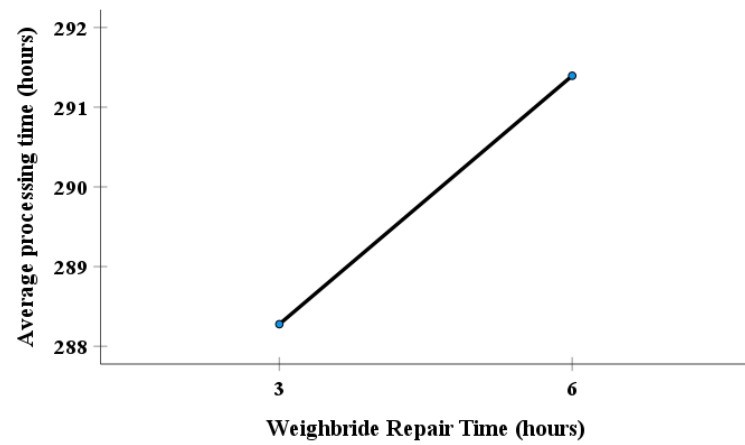
(a): Main effect of fresh fruit bunch (FFB) Quantity



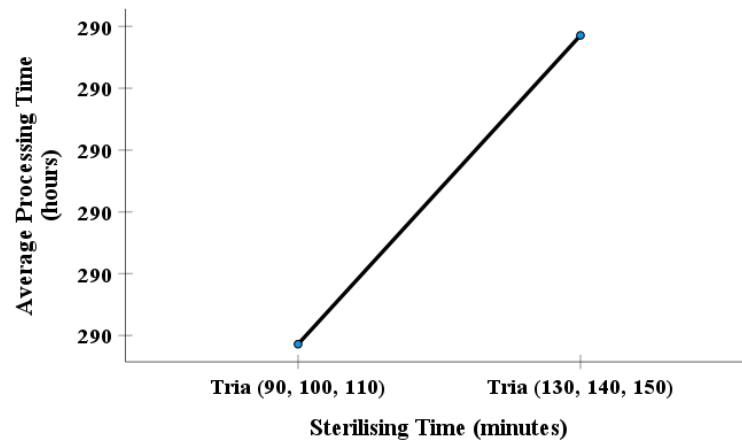
(b): Main effect of Tipping Machine Repair Time



(c) Main effect of fresh fruit bunch (FFB) Interarrival Time

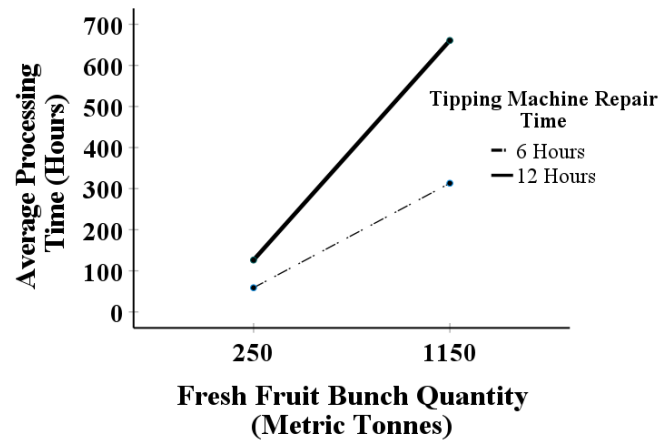


(d) Main effect of Weighbridge Repair Time

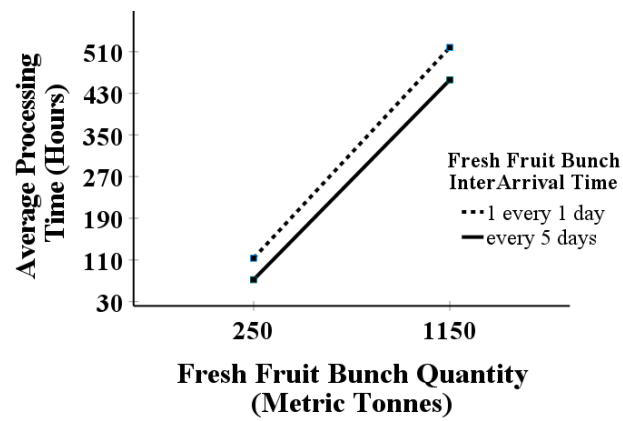


(e) Main effect of Sterilising Time

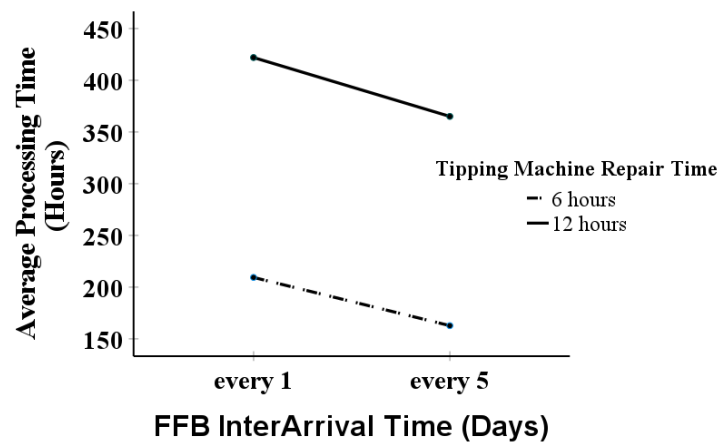
Figure A4. 3(a), (b), (c), (d), (e): Main Effect Plots for Full Factorial Five (5) Factors, Case A



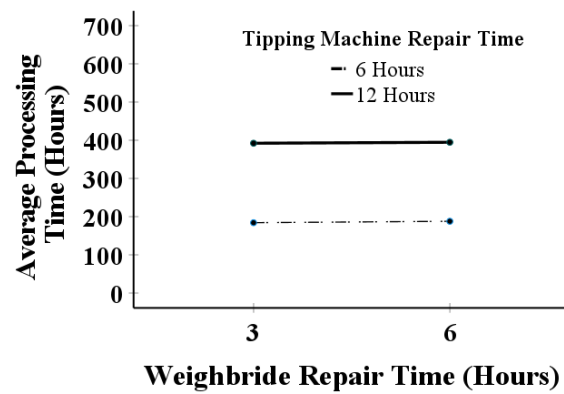
(a) Interaction Effect Between fresh fruit bunch (FFB) Quantity and Tipping Machine Repair Time



(b) Interaction Effect between fresh fruit bunch (FFB) Quantity and fresh fruit bunch (FFB) Inter Arrival Time



(c) Interaction Effect Between fresh fruit bunch (FFB) Inter Arrival Time and Tipping Machine Repair Time



(d) Interaction Effect Between Weighbridge Repair Time and Tipping Machine Repair Time

Figure A4. 4(a), (b), (c), (d): Significant Interaction Effects Plots for Case A

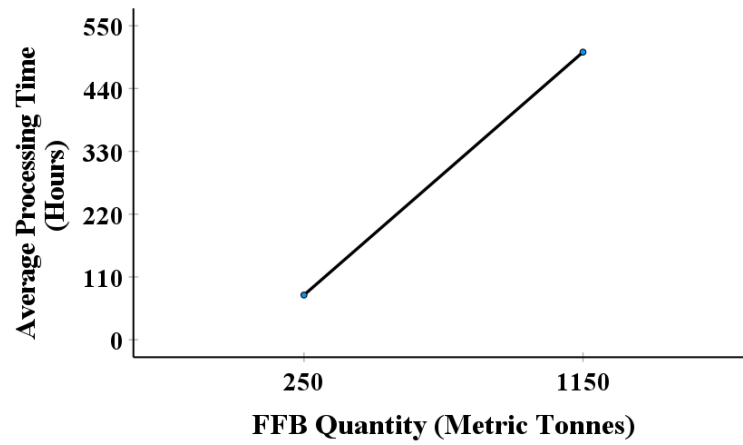
Table A4 5: Results for analysis of variance – 14 Factors Screening Case B

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	855304.605 ^a	14	61093.186	10922.712	0.007	1.000
Intercept	1196857.8	1	1196857.8	213983.5	0.001	1.000
FFB_Quantity	587491.5	1	587491.590	105036.2	0.002	1.000
FFB_InterArrival_Time	17601.329	1	17601.329	3146.902	0.011	1.000
WeighingTime	82920.962	1	82920.962	14825.250	0.005	1.000
Number_of_Sterilisers	2452.230	1	2452.230	438.429	0.030	0.998
TippingMachine_Repair Time	164381.594	1	164381.594	29389.412	0.004	1.000
Error	5.593	1	5.593			
Total	2052168.0	16				

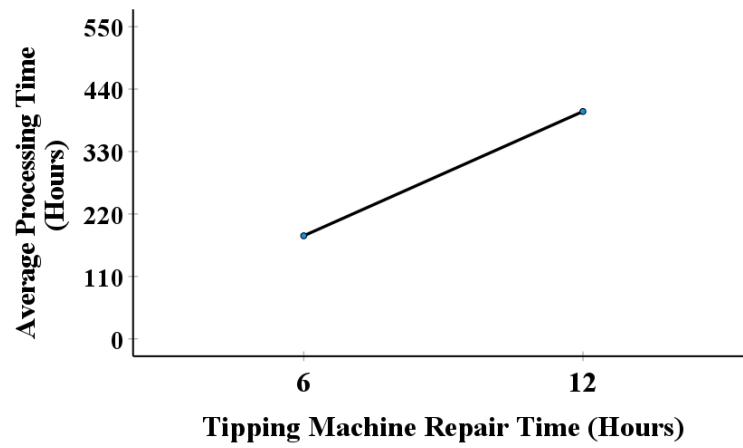
Corrected Total	855310.199	15				
a. R Squared = 1.000 (Adjusted R Squared = 1.000)						
b. Computed using alpha = .05						

Table A4 6: Results for analysis of variance (ANOVA) – Case B Five (5) Two-Level Full Factorial

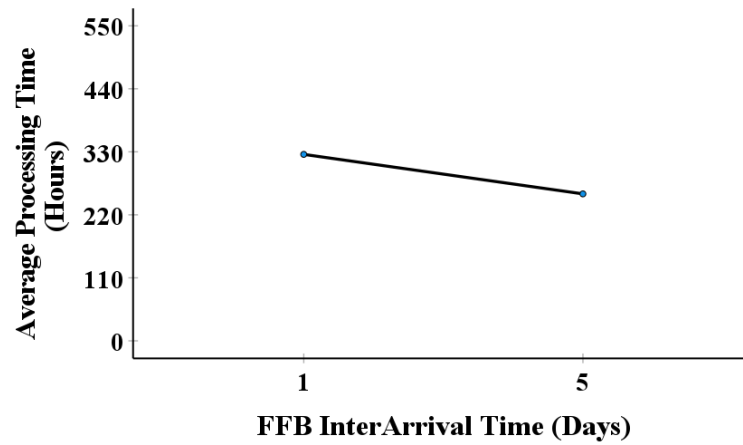
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2073819.4 ^a	15	138254.6	5875.9	0.000	1.000
Intercept	2712819.2	1	2712819.2	115296.5	0.000	1.000
FFB Quantity	1448316.9	1	1448316.9	61554.3	0.000	1.000
FFB InterArrival Time	38032.8	1	38032.8	1616.4	0.000	0.990
Tipping Machine Repair Time	383556.6	1	383556.6	16301.3	0.000	0.999
FFB Quantity*FFB InterArrival Time	4895.5	1	4895.5	208.0	0.000	0.929
FFB InterArrival Time*Tipping Machine Repair Time	617.7	1	617.7	26.2	0.000	0.621
FFB Quantity*Tipping Machine Repair Time	198387.0	1	198387.0	8431.5	0.000	0.998
Error	376.4	16	23.5			
Total	4787015.1	32				
Corrected Total	2074195.8	31				
a. R Squared = 1.000 (Adjusted R Squared = 1.000)						
b. Computed using alpha = .05						



(a) Main effect of FFB Quantity

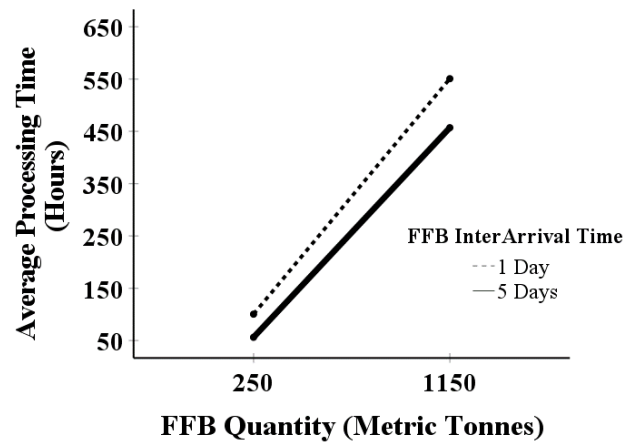


(b) Main effect of Tipping Machine Repair Time

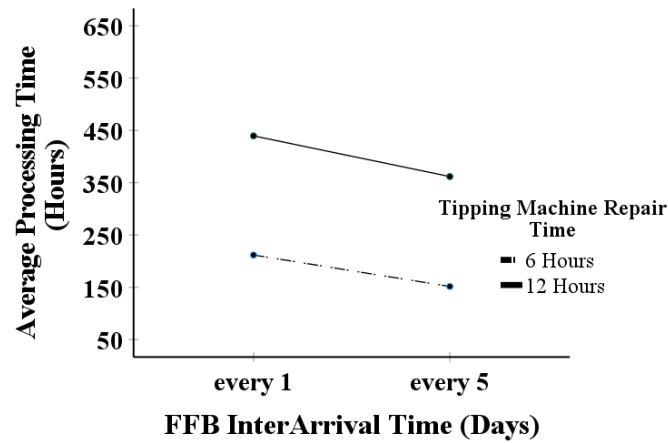


(c) Main effect of fresh fruit bunch (FFB) Interarrival Time

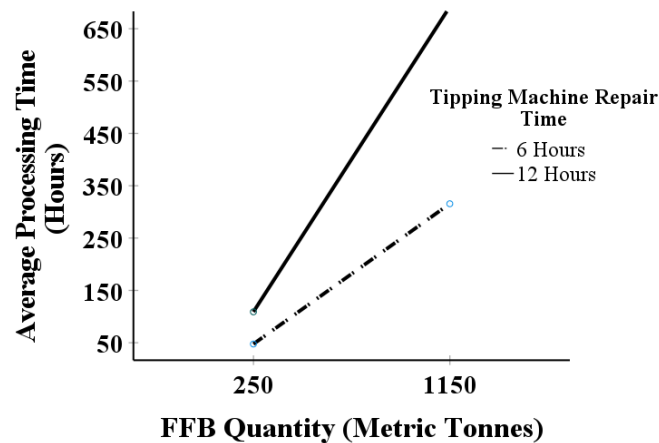
Figure A4.5 (a), (b), (c) : Main Effect Plots for Full Factorial Five (5) Factors, Case B



(a) Interaction effect of fresh fruit bunch (FFB) Quantity with fresh fruit bunch (FFB) Inter Arrival Time



(b) Interaction effect of fresh fruit bunch (FFB) Inter Arrival Time with Tipping Machine Repair Time



(c) Interaction effect of fresh fruit bunch (FFB) Quantity with Tipping Machine Repair Time

Figure A4.6 (a), (b), (c): Significant Interaction Effects Plots For Full Factorial, Case B

Table A4 7: Results for Analysis of Variance for Twelve Factors (12) Screening, Case C

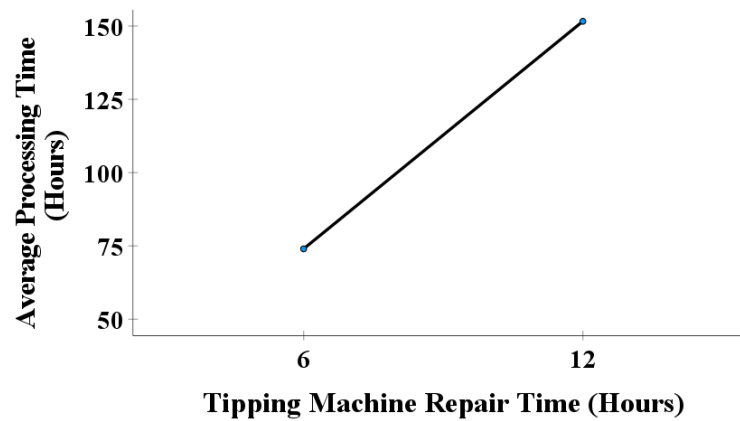
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
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Corrected Model	24122.195 ^a	12	2010.183	19935.698	0.000	1.000
Intercept	205616.903	1	205616.903	2039175.893	0.000	1.000
Weighbridge Repair Time	31.923	1	31.923	316.587	0.000	0.991
Sterilising Time	1.822	1	1.822	18.074	0.024	0.858
Tipping Machine Repair Time	24087.040	1	24087.040	238879.736	0.000	1.000
Error	0.303	3	0.101			
Total	229739.400	16				
Corrected Total	24122.498	15				
a. R Squared = 1.000 (Adjusted R Squared = 1.000)						

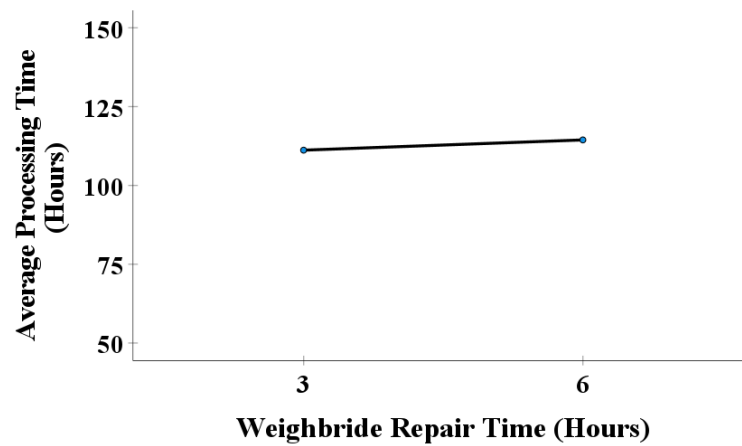
Table A4 8: Results for Analysis of Variance for Three (3) Factors Full Factorial , Case C

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	12065.7	6	2010.9	44688.0	0.004	1.000
Intercept	101835.8	1	101835.8	2263018.7	0.000	1.000
Weighbridge Repair Time	21.1	1	21.125	469.4	0.029	0.998
Sterilising Time	0.720	1	0.720	16.000	0.156	0.941
Tipping Machine Repair Time	12043.5	1	12043.520	267633.7	0.001	1.000
Sterilising Time * Tipping Machine Repair Time	0.005	1	0.005	0.111	0.795	0.100
Weighbridge Repair Time * Sterilising Time	0.080	1	0.080	1.778	0.410	0.640
Weighbridge Repair Time * Tipping Machine Repair Time	0.320	1	0.320	7.111	0.228	0.877
Error	0.045	1	0.045			

Total	113901.660	8				
Corrected Total	12065.815	7				
a. R Squared = 1.000 (Adjusted R Squared = 1.000)						
b. Computed using alpha = .05						



(a) Main effect of Tipping Machine Repair Time



(b) Main effect of Weighbridge Repair Time

Figure A4.7: Main Effect Plots for Two (2) Factors Full Factorial, Case C

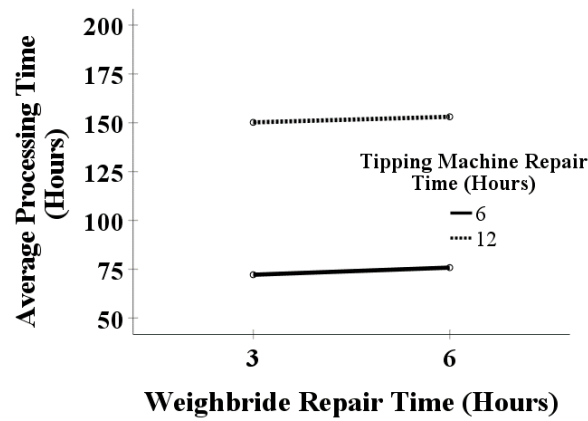


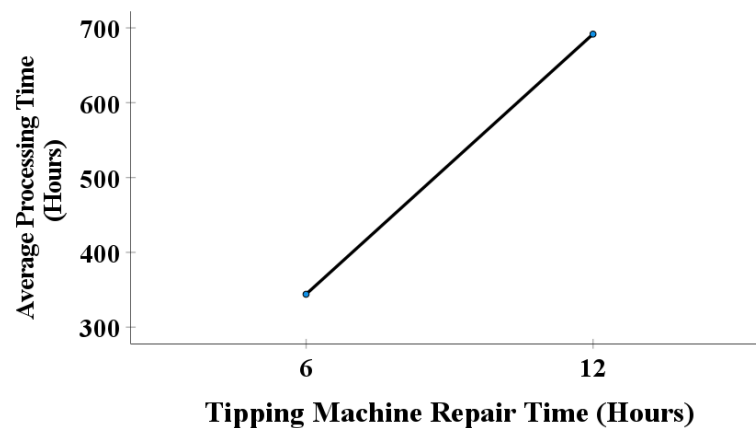
Figure A4.8: None Significant Two-Way Interaction Effects Plots For between weighbridge repair time with tipping machine repair time Full Factorial, Case C

Table A4 9: Results for Analysis of Variance for Twelve Factors (12) Screening Case D

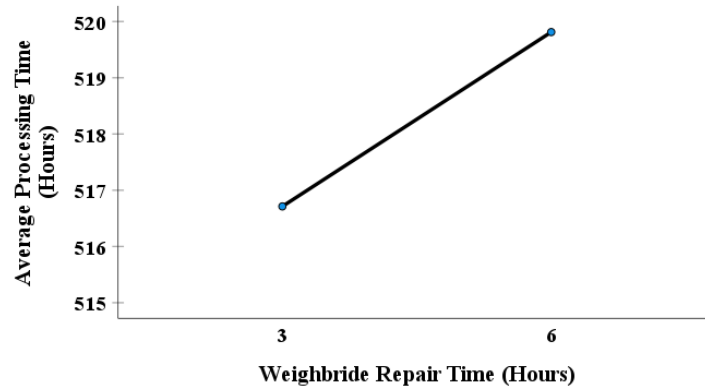
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	484528.2	12	40377.353	461455.462	0.000	1.000
Intercept	4297536.3	1	4297536.303	49114700.600	0.000	1.000
WeighingTime	1.323	1	1.323	15.114	0.030	0.834
WeighbridgeRepairTime	38.440	1	38.440	439.314	0.000	0.993
SterilisingTime	1.103	1	1.103	12.600	0.038	0.808
TippingMachine_RepairTime	484485.6	1	484485.603	5536978.314	0.000	1.000
Error	0.263	3	0.088			
Total	4782064.8	16				
Corrected Total	484528.4	15				
a. R Squared = 1.000 (Adjusted R Squared = 1.000)						

Table A4 10: Results for analysis of variance – four (4) factors full factorial, Case D

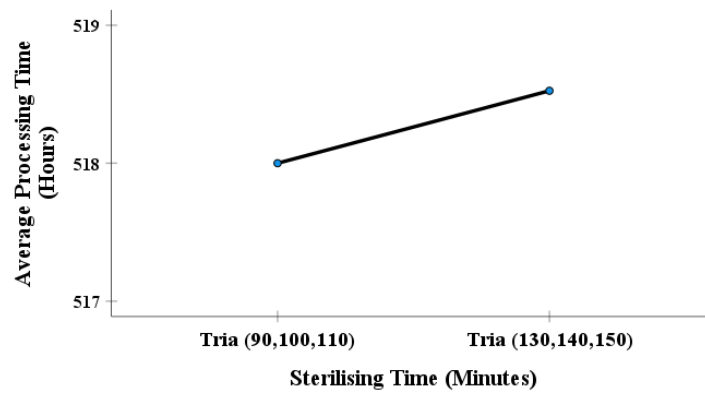
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	483619.135 ^a	10	48361.914	2931025.061	0.000	1.000
Intercept	4291733.723	1	4291733.723	260105074.091	0.000	1.000
Weighing Time	0.203	1	0.203	12.273	0.017	0.711
Weighbridge Repair Time	35.403	1	35.403	2145.606	0.000	0.998
Sterilising Time	1.822	1	1.822	110.455	0.000	0.957
Tipping Machine Repair Time	483581.160	1	483581.160	29307949.091	0.000	1.000
Weighbridge Repair Time * Sterilising Time	0.122	1	0.122	7.424	0.042	0.598
WeighingTime * WeighbridgeRepairTime	0.303	1	0.303	18.333	0.008	0.786
Error	0.082	5	0.016			
Total	4775352.940	16				
Corrected Total	483619.218	15				
a. R Squared = 1.000 (Adjusted R Squared = 1.000)						
b. Computed using alpha = .05						



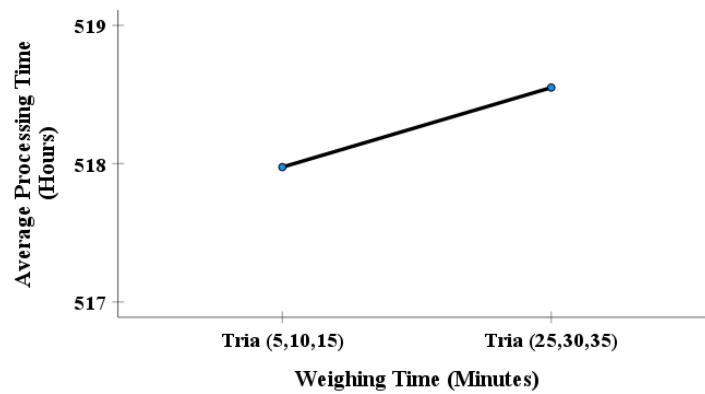
(a) Main effect of Tipping Machine Repair



(b) Main effect of Weighbridge Repair Time

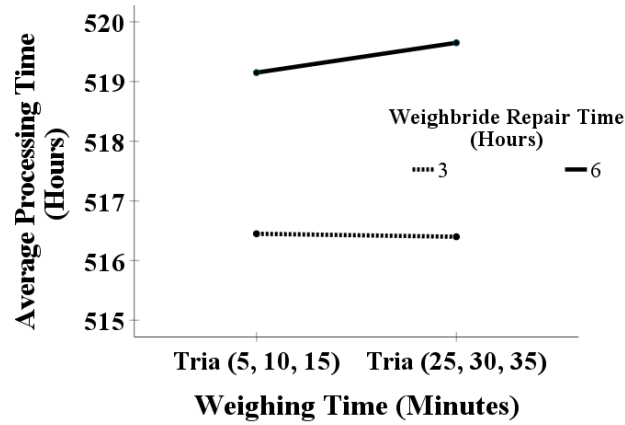


(c) Main effect of Sterilising Time

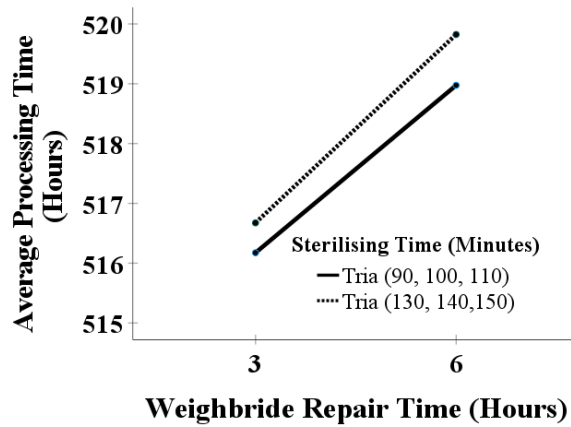


(d) Main effect of Weighing Time

Figure A4.9: Significant Main Effect Plots for Full Factorial four (4) Factors, Case D



(a) Interaction effect Weighing Time with Weighbridge Repair Time



(b) Interaction effect Weighbridge Repair Time with Sterilising Time

Figure A4.10 (a), (b): Significant Interaction Effects Plots for Case D