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# Optimization of Palm Kernel Unloading Queue Waiting Time at the Kernel Crushing Plant Using the Promodel Approach

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A B S T R A C T

Optimization is an effort to improve process outcomes in an ideal and effective manner. One approach to solving queuing system problems is through simulation. The Kernel Crushing Plant faces queuing issues due to uneven workload distribution among the sampling tower, laboratory, and weighbridge. This condition requires improvements to the queuing system model to achieve a more efficient process flow. Using Promodel software, the queuing system at the Kernel Crushing Plant can be virtually visualized by developing a new model. The proposed model includes separating palm kernel analysis from production analysis, implementing a robotic system for palm kernel sampling, and adding Foss NIRS equipment. The implementation of this model has been proven to reduce laboratory workload (percentage of operation) by nearly 23%, resulting in a more balanced productivity across all locations.

## 1. INTRODUCTION

The palm oil industry is a strategic sector in agriculture that has been rapidly growing in tropical countries such as Indonesia, Malaysia, and Thailand. In Indonesia, this industry serves as the backbone of the plantation and agricultural sector, contributing around 3.5% to the total Gross Domestic Product (GDP), 13.5% to total non-oil and gas exports, and providing employment for more than 16 million workers [1].

One of the main by-products of the palm oil processing industry is the palm kernel (PK). The PK processing begins with the receipt of raw materials through the weighbridge, followed by unloading at the intake, and then continues to the processing machines to produce two main products, namely Crude Palm Kernel Oil (CPKO) and Palm Kernel Expeller (PKE) [2].

The smoothness of the PK unloading process in the plant plays an important role in maintaining production continuity. However, in practice, one of the main obstacles is the lengthy quality analysis process of the palm kernel before unloading can be carried out. This analysis includes examining moisture content, oil content, free fatty acid (FFA) levels, broken kernels, and most crucially, the impurity level such as fiber, shell, stones, and wood chips. If the impurity level exceeds the standard threshold of 6%, the analysis process will take longer [3], [4].

This problem is exacerbated by the limited unloading area, which can only accommodate four vehicles at a time, forcing other vehicles to wait outside the unloading zone. This condition leads to long queues and logistical inefficiencies, especially when palm kernel prices are high in the market, where distribution delays can have a direct impact on the plant's productivity and profitability [5].

These queues and delays also have negative impacts on transportation partners and vendors. Long waiting times reduce fleet productivity, increase fuel consumption, and cause degradation in PK quality due to prolonged storage without processing. The accumulation of these issues can strain relationships between the plant and suppliers as well as reduce the overall competitiveness of the palm oil industry [6].

Several studies have shown that PK quality is strongly influenced by impurity levels and moisture content, which can be controlled through the optimization of the drying process and the separation of foreign materials [7].

In addition, the use of modern technology such as NIRS (Near Infrared Reflectance Spectroscopy) can also accelerate the kernel quality analysis process without compromising accuracy [8].

Therefore, a comprehensive study of the current palm kernel receiving and quality analysis system is needed, including an evaluation of the unloading area efficiency and the adoption of rapid analytical technologies such as NIRS. This effort aims to reduce vehicle waiting time, accelerate the receiving process, and maintain palm kernel quality for the sake of operational efficiency and the future competitiveness of Indonesia's palm oil industry [9].

## 2. LITERATURE REVIEW

### 2.1. Palm Oil Processing Industry

The oil palm (Elaeis guineensis Jacq.) belongs to the Palmae family and thrives in tropical regions. This plant has several main parts, namely roots, stem, leaves, flowers, and fruit. The most widely utilized part is the fruit, which is processed in palm oil mills to produce vegetable oil. From the processing of the fruit, two types of oil are obtained: Crude Palm Oil (CPO), which comes from the mesocarp (fruit flesh), and Palm Kernel Oil (PKO), which is derived from the endocarp (seed kernel). The oil content in the fruit continues to increase along with the ripening process [10].

Various products can be derived from palm oil processing, including cooking oil, margarine, cakes or biscuits, oleochemical raw materials, and biodiesel. Oleochemical derivatives include fatty acids, fatty alcohols, glycerin, metallic soaps, stearic acid, methyl esters, and stearin [11].

### 2.2. Palm Kernel Unloading Process

The palm kernel unloading process involves several stages. The initial stage begins with the kernel being sampled by an analyst, which is then analyzed in the laboratory to determine impurity levels, moisture content, FFA, and oil content. The results of this analysis are used to decide whether the kernel can be unloaded or not, with quality standards set at a maximum impurity level of 6% and moisture content of 7%. Before unloading, the kernel is weighed for its gross weight at the weighbridge, then directed to the intake (unloading area), and subsequently transferred to the hopper (kernel storage) to be processed in the first press and second press machines into PKO (Palm Kernel Oil), with PKE (Palm Kernel Expeller) as a by-product [12].

### 2.3. Palm Kernel Impurity Level

Palm kernel is the inner part of the oil palm fruit that is further processed to produce Palm Kernel Oil (PKO). Before unloading, the received kernels must undergo quality inspection. According to SNI 01-0002-1987, the parameters analyzed include moisture content, oil content, free fatty acids, and impurity levels.

High impurity levels in palm kernels can prolong the testing process as they require further identification of foreign materials such as fiber, stones, wood, residual metal materials, or other unwanted substances. Based on SNI 01-0002-1987 concerning palm kernels, the quality requirement for impurities is a maximum of 6%. This process is mandatory to maintain the quality of palm kernel processed products [4].

If the impurity level of palm kernels does not meet the established quality standards, delivery to partners will be delayed, resulting in losses [13] and longer queuing times. Therefore, controlling impurity levels becomes an important aspect of the quality management system in the palm oil industry.

### 2.4. Queue Problems in the Unloading Area

The unloading area is the starting point of the raw material receiving process in the palm oil industry. One common problem that often occurs in this area is the queue of transport vehicles, which causes long waiting times and hampers the smooth operation of the plant [14].

Queues can be caused by various factors such as limited unloading area capacity, uneven truck arrival times, manual weighing and recording processes, as well as delays in unloading due to poor material quality (e.g., high impurity levels). This condition not only results in high downtime but also affects labor efficiency, increases vehicle fuel consumption, and creates potential operational conflicts [15].

A well-designed facility layout can improve the efficiency of material flow and minimize waiting time. An optimal layout supports increased storage capacity and reduces conflicts between activities within a single work area [16].

### 2.5. Unloading Facility Management

Unloading facilities are a series of tools and infrastructure designed to support the activity of transferring loads from transport vehicles to receiving or storage areas at a production site. In the context of palm oil mills, palm kernel unloading facilities refer to the area, equipment, and work systems used to unload kernels from transport vehicles to the initial storage area (such as a kernel silo) before entering the drying process or further processing.

Main Components of Unloading Facilities, which usually consist of the following components::

a. *Unloading/Loading Vicinity*
   This refers to the physical space (yard or platform) provided for transport trucks to stop and carry out unloading. The vicinity must be spacious enough, equipped with a proper drainage system, and capable of accommodating several vehicles at the same time.
b. *Unloading Equipment*
   This equipment includes:
   A hydraulic system to lift the truck bed so that the load flows out by gravity,
c. *Conveyor* (belt conveyor) to transfer the kernels to the silo or storage area.
d. *Hopper,* a large funnel where the kernels are first collected before being transported to the next unit.

Supporting Facilities include:

a. Vehicle weighbridge to measure load weight,
b. Statistical recording system (manual or digital),
c. Vehicle washing area to reduce soil contamination,
d. CCTV or sensors for monitoring and security,
e. Personnel and SOPs.

The unloading process does not rely solely on equipment but also involves operators who operate the machines, conduct visual inspections of the kernels, and ensure the process runs in accordance with safety and quality procedures.

Functions and Objectives of Unloading Facilities

The main objectives of unloading facilities are:

a. To unload kernels quickly, efficiently, and safely,
b. To minimize raw material damage during the transfer process,
c. To avoid truck congestion, which can cause delays in the production process,
d. To ensure smooth internal plant logistics flow, from the unloading point to the drying and storage processes.

Characteristics of a Good Unloading Facility

According to industrial facility engineering principles, a good unloading facility must meet the following criteria:

a. Time efficiency: minimize unloading time per truck,
b. Accessibility: easily accessible for large vehicles,
c. Work safety: complies with occupational health and safety (OHS) standards,
d. Top-rated capacity: able to handle truck volumes according to production needs,

e. Information system support: unloading data recorded accurately and in real time. [17].

By paying attention to the design, capacity, and management of unloading facilities, palm oil mills can avoid operational delays and losses caused by unloading delays. In industrial case studies, poor management of unloading facilities can create bottlenecks that ultimately reduce the efficiency of the entire production system.

### 2.6. Queueing Theory

The concept of queue analysis was first introduced by A.K. Erlang in 1913 when he studied variations in the demand for telephone facilities and the delays in their service. Today, queueing theory has been widely applied in various sectors such as business (banks, supermarkets), industry (automated machine operations), transportation (land, sea, air), and postal services. Queue analysis provides probabilistic information known as operation characteristics, which can help managers or decision-makers design service systems that are able to anticipate random service demands while balancing between service costs and waiting time costs.

The phenomenon of long queues is often encountered, for example, in banks when customers wait for their turn at the teller, at airports during passenger check-in, at supermarket cashiers, or at car wash stations. In the service sector, waiting too long is often considered tedious and may drive customers to switch to other service providers, ultimately causing losses to the company.

To maintain customer loyalty, companies strive to provide the best quality of service, one of which is through faster service so that customers do not wait too long. However, accelerating service generally incurs additional costs because the organization must add facilities or service staff. Nevertheless, faster service can increase customer satisfaction and contribute to long-term profit growth.

Queues occur when the demand for service exceeds the available service capacity, resulting in arriving customers not being served immediately. In certain conditions, additional facilities can be provided to reduce or avoid queues, but the consequence is higher operational costs. If the cost of additional services is too high, the company's profit may fall below the expected threshold. Conversely, if queues are left too long, the company risks losing customers or clients.

One approach that is widely used today is the mathematical model. In general, solving a mathematical model can be carried out through two procedures: the analytical approach and the simulation approach. In the simulation method, the solution is not derived deductively but by testing the model with certain values of decision variables according to predetermined conditions, and then observing its effect on the criterion variables. Therefore, simulation models are essentially inductive in nature. For instance, in a queuing problem, the effects of various service system designs can be tested to find solutions for the situation at hand.

### 2.7. Components and Basic Structure of the Queuing Process

The components and basic structure of the queueing process are presented in the following figure:

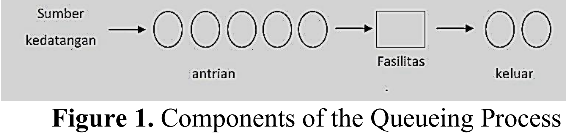


**Figure 1.** Components of the Queueing Process

a. Arrival

In every queueing system, there is always an element of arrival, whether in the form of people, vehicles, or phone calls requiring service. This part is also referred to as the input process, which includes the source of arrivals (calling population) and the pattern of arrivals, which is generally random.

b. Service

The service mechanism may be provided by one or several servers, or through one or more service facilities. For example, in a supermarket checkout, there may be only one cashier, but sometimes an assistant is present to help with bagging. Similarly, in banks, service may be provided by a single teller or multiple tellers. It is also important to understand how the service is delivered, since in some cases the service process itself is random.

c. Queue

The main component in queueing system analysis is the queue itself. The formation of a queue is influenced by the arrival pattern and the service mechanism. Another determining factor is the queue discipline, which refers to the rules or policies regarding the order of service. Examples of queue discipline include First Come First Served (FCFS), Last Come First Served (LCFS), priority-based service, alphabetical order, appointment-based systems, and so on. If no queue forms, this indicates idle servers or that the number of service facilities exceeds demand.

The queuing process can be grouped into four basic structures according to the characteristics of the service facilities, namely:

1 Single Channel Single Phase is a queuing system that has only one service line with a single service provider.

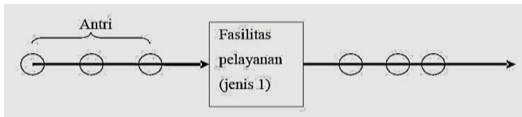


**Figure 2.** *Single channel single phase*

Single Channel Multi Phase means that in the queuing system there is more than one type of service provided, but for each type of service there is only one service provider.

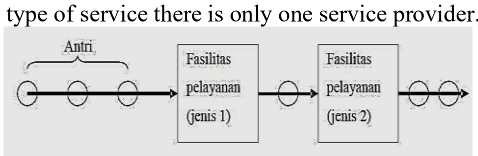


**Figure 3.** *Single channel multi phase*

2 Single Channel Multi Phase describes a queuing system that provides more than one type of service stage, but at each stage there is only one operator or service unit.

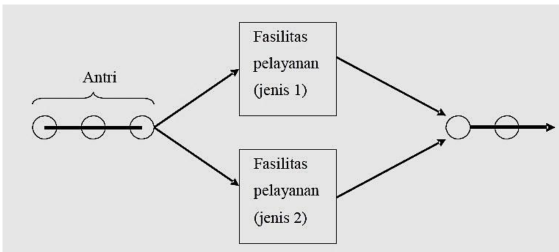


**Figure 4.** *Multi channel single phase*

3 Multi-Channel Multi Phase is a queuing system that has more than one type of service, and in each type of service there is more than one operator providing the service.

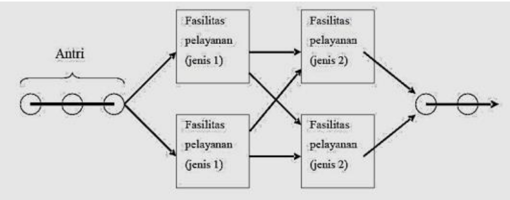


**Figure 5.** *Multi-channel multi phase*

The number of channels in a queue represents the number of parallel services available, while the number of phases indicates how many sequential service processes each customer must go through. Thus, the figure above represents a queuing structure with three channels and one phase. The four categories described earlier are the basic forms of a queuing system.

### 2.8. The Role of Poisson and Exponential Distributions

Consider a queueing system where arrivals and departures (events) within a given time interval are governed by the following conditions:

**Condition 1:** The probability of an event (either an arrival or a departure) occurring between time $t$ and $t + s$ depends only on the length of the interval $s$. In other words, the probability is not influenced by the value of $t$ nor by the number of events that have already occurred during the period $(0, t)$. Mathematically, this probability function has the property of independent stationary increments.

**Condition 2:** The probability of an event occurring in a very small interval $h$ is positive but still less than one.

**Condition 3:** In a very small interval $h$, at most one event can occur.

From these three conditions, it can be shown that the number of events within a given time interval follows a Poisson distribution, while the time between consecutive events follows an Exponential distribution. Thus, these conditions describe a Poisson process.

Next, define:

$Pn(t)$ = the probability that there are $n$ events during time $t$.

Based on Condition 1, the probability of no events occurring in the interval $t + h$ can be written as:

$P_0(t + h) = P_0(t)\, P_0(h)$

For a sufficiently small value of $h > 0$, according to Condition 2, it follows that $0 < P_0(h) < 1$. From this, the above equation has a specific solution form:

$P_0(t) = e^{(-\alpha t)}, t \geq 0$

where $\alpha$ is a positive constant.

The process described through $Pn(t)$ shows that the inter-arrival times of consecutive events follow an exponential distribution. Based on the relationship between the exponential and Poisson distributions, it can be concluded that $Pn(t)$ follows a Poisson distribution.

Let $f(t)$ be the probability density function (pdf) of the inter-arrival time $t$ between two consecutive events, with $t \geq 0$. If $T$ is defined as the interval of time since the last event occurred, then:

P {inter-arrival time exceeds T} = P {no event occurs before T}

If the inter-arrival times follow an exponential distribution with a mean of $1/\alpha$, then the number of events in a given period will follow a Poisson distribution with an average event rate of $\alpha$ per unit of time. The Poisson distribution is referred to as a completely random process because it has the property that the waiting time for the next event is not affected by the length of the interval since the last event:

$P \{t > T + S \mid t + S\} = P \{t + T\}$

where $S$ is the time interval since the last event, and since $t$ follows an exponential distribution, this independence property holds.

## 3. METODOLOGI

Tahapan penelitian yang dilakukan meliputi:

a. Penentuan Tema sentral
Tahap awal penelitian adalah menetapkan tema utama yang akan dijadikan fokus penelitian.

b. Rumusan masalah
Masalah dirumuskan berdasarkan isu yang relevan dengan tema sentral dan ditemukan di lokasi penelitian. Identifikasi serta inventarisasi masalah menjadi salah satu langkah krusial dalam proses penelitian.

c. Pengumpulan data
Pada tahap ini, peneliti mengumpulkan informasi terkait sistem antrian, seperti data waktu kedatangan dump truck (*registrasi*), waktu pengambilan sampel, waktu mulai hingga selesai analisis mutu, waktu penimbangan isi, serta waktu keluar.

d. Pengolahan data
Data yang diperoleh kemudian diolah dengan metode yang telah ditentukan, yaitu single channel multi server menggunakan pendekatan simulasi model.

e. Simulasi model antrian menggunakan software Promodel
Setelah data diproses dan divalidasi, langkah berikutnya adalah memasukkannya ke dalam perangkat lunak Promodel untuk menghasilkan simulasi model antrian.

f. Simpulan
Tahap ini dilakukan dengan menarik kesimpulan berdasarkan hasil pengolahan data yang telah diperoleh dan menghubungkannya dengan permasalahan penelitian.

g. *Flowchart*
Keseluruhan alur penelitian divisualisasikan dalam bentuk bagan alir (*flowchart*).

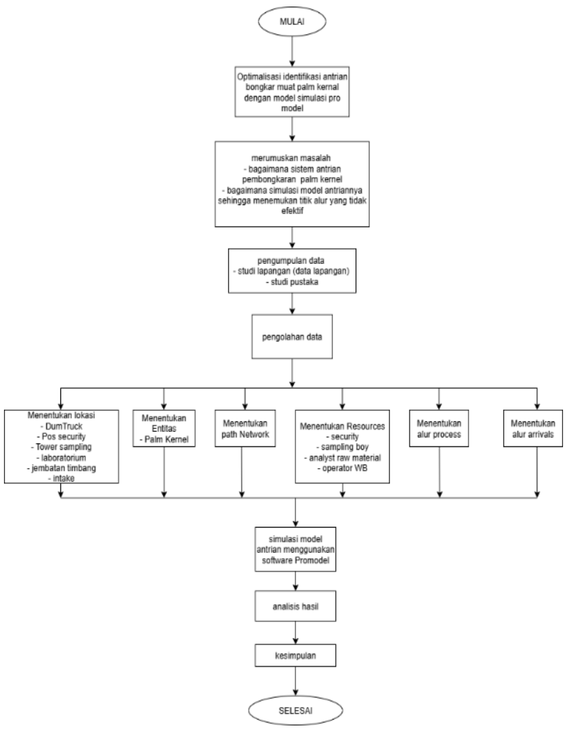


**Figure 6.** Research Flowchart

## 4. RESULTS AND DISCUSSION

Based on our field observations and data collection (registration time, sampling time, analysis time, weighing time, and exit time), the initial model was obtained as follows:

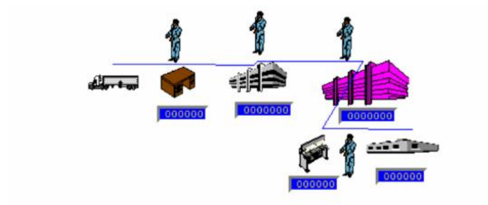


**Figure 7.** Initial Model of Palm Kernel Receiving

Each activity or location in the layout above, when translated into Promodel simulation, is as follows:

Locations

| Icon | Name | Cap. | Units | DTs... | Stats | Rules... |
|---|---|---|---|---|---|---|
| | DT_TRUCK | inf | 1 | None | Time Series | Oldest, FIFO |
| | pos_security | inf | 1 | None | Time Series | Oldest, FIFO |
| | Tower_Sampling | 1 | 1 | None | Time Series | Oldest, FIFO |
| | Laboratorium | 1 | 1 | None | Time Series | Oldest, FIFO |
| | Jembatan_timbang | 1 | 1 | None | Time Series | Oldest, FIFO |
| | Intake | inf | 1 | None | Time Series | Oldest, FIFO |

**Figure 8.** Location Elements in Promodel Queue Simulation

| Icon | Name | Speed (fpm) | Stats |
|---|---|---|---|
| | palm_kernel | 150 | Time Series |

**Figure 9.** Entity Elements in Promodel Queue Simulation

In Promodel, a location is defined as a place that processes each entity activity (palm kernel receiving). The following is a description of each location:

a. DT_Truck: The Dump Truck (DT) first enters the plant area and must register at the security post.
b. Pos_security: Security records the DT license plate number and issues a queue number.
c. Tower_sampling: Analysts perform palm kernel sampling according to the DT queue number.
d. Laboratory: Analysts analyze the palm kernel based on the queue number before unloading.
e. Weighbridge: The DT is weighed after receiving the analysis result from the laboratory confirming that unloading can proceed.
f. Intake: The weighed DT proceeds to unload at the intake.

Next, processing will be carried out based on the layout that has been created.

Process [1]

| Entity... | Location... | Operation... |
|---|---|---|
| palm_kernel | pos_security | |
| palm_kernel | Tower_Sampling | get sampling_boy |
| palm_kernel | Laboratorium | get analyst_raw_material |
| palm_kernel | Jembatan_timbang | get operator_WB |
| palm_kernel | Intake | |

**Figure 10.** Processing Elements in Promodel Queue Simulation

Next, the output from the initial simulation is presented, which serves as one of the inputs for developing the new system model.

General Report (Normal Run - Rep. 1)

General | Locations | Location States Multi | Location States Single | Resources | Resource States | Entity Activity

Tugas_kelompok_2_simulasi_palm kernal_R1.MOD (Normal Run - Rep. 1)

| Name | Scheduled Time (HR) | % Operation | % Setup | % Idle | % Waiting | % Blocked | % Down |
|---|---|---|---|---|---|---|---|
| Tower Sampling | 6.88 | 49.69 | 0.00 | 3.56 | 0.96 | 45.79 | 0.00 |
| Laboratorium | 6.88 | 89.00 | 0.00 | 7.48 | 1.81 | 1.71 | 0.00 |
| Jembatan timbang | 6.88 | 24.45 | 0.00 | 75.55 | 0.00 | 0.00 | 0.00 |

General | Locations | Location States Multi | Location States Single | Resources | Resourc

Tugas_kelompok_2_simulasi_palm kernal_R1.MOD (Normal Run - Rep. 1)

| Name | Scheduled Time (HR) | % Empty | % Part Occupied | % Full | % Down |
|---|---|---|---|---|---|
| DT TRUCK | 8.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| pos security | 8.00 | 0.38 | 99.62 | 0.00 | 0.00 |
| Intake | 8.00 | 100.00 | 0.00 | 0.00 | 0.00 |

**Figure 11.** Promodel Simulation Output

Based on the simulation output above, it can be concluded that the laboratory has a high utilization rate (89%) compared to the tower_sampling and weighbridge. Therefore, a system modification is necessary. The following is the layout of the new model.

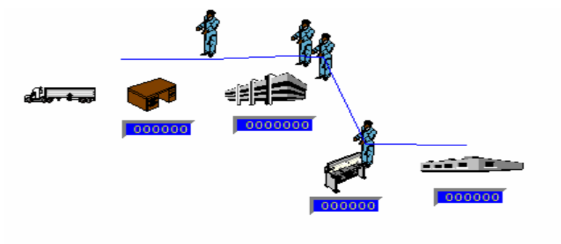


**Figure 12.** New Model Layout

Locations

| Icon | Name | Cap. | Units | DTs... | Stats | Rules... |
|---|---|---|---|---|---|---|
| | DT_TRUCK | inf | 1 | None | Time Series | Oldest, FIFO |
| | pos_security | inf | 1 | None | Time Series | Oldest, FIFO |
| | TowerSampling_danlaboratorium | 1 | 1 | None | Time Series | Oldest, FIFO |
| | Jembatan_timbang | 1 | 1 | None | Time Series | Oldest, FIFO |
| | Intake | inf | 1 | None | Time Series | Oldest, FIFO |

**Figure 13.** Location Elements in the New Promodel Simulation

Based on the simulation using the new model, there is a reduction in locations where the sampling and laboratory processes are combined in one place. Sampling is carried out using a robotic system, and additional equipment is added to the analysis process.

Tugas_kelompok_2_simulasi_palm kernal_model baru.MOD (Normal Run - Rep. 1)

| Name | Scheduled Time (HR) | % Operation | % Setup | % Idle | % Waiting | % Blocked | % Down |
|---|---|---|---|---|---|---|---|
| TowerSampling danlaboratorium | 3.92 | 66.15 | 0.00 | 5.61 | 1.23 | 27.01 | 0.00 |
| Jembatan timbang | 3.92 | 66.08 | 0.00 | 33.92 | 0.00 | 0.00 | 0.00 |

General | Locations | Location States Multi | Location States Single | Resources | Resource

Tugas_kelompok_2_simulasi_palm kernal_model baru.MOD (Normal Run - Rep. 1)

| Name | Scheduled Time (HR) | % Empty | % Part Occupied | % Full | % Down |
|---|---|---|---|---|---|
| DT TRUCK | 8.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| pos security | 8.00 | 0.57 | 99.43 | 0.00 | 0.00 |
| Intake | 8.00 | 100.00 | 0.00 | 0.00 | 0.00 |

**Figure 14.** New Promodel Simulation Output

From the output above, it can be seen that the utilization rate (percentage of operation) is now evenly distributed between the tower_sampling_laboratory and the weighbridge, each at 66%, with a %waiting of 1.23%. With the balanced utilization of each operation and the reduced queue waiting time, the system can be considered stable.

## 5. CONCLUSION

From this study, it can be concluded that queue system optimization is necessary, with modifications to the palm kernel receiving system. The laboratory had a high utilization rate of 89%, which was uneven compared to the tower_sampling and weighbridge. By implementing the new model—where palm kernel analysis is separated from production analysis, sampling is carried out using a robotic system, and Foss NIRS is added—the impact is a reduction in laboratory utilization (percentage of operation) by up to 23%.

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