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Research Paper

Discrete Simulation Model Development for Enhancing the Efficiency of Seaweed Production Processes at PT. IHFIM

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Abstract: This study focuses on improving the efficiency of seaweed production at PT. IHFIM through the development of a discrete event simulation model. The production system includes several main stages such as Pre-Treatment, Initial Rinse, Quality Check, Thermal Drying, Disinfection, and Final Blending. Field observation and actual production data were used to build the simulation model using ProModel software. Model verification was done through running simulations, and validation was conducted statistically using a t-test, confirming that the simulation outputs were consistent with actual conditions. The analysis identified two bottlenecks in the system: Pre-Treatment with 12.88% blocked time and Initial Rinse with 11.60% blocked time. To address these issues, two improvement scenarios were tested. Scenario 1 added an extra tank to the Pre-Treatment stage, which successfully reduced the blockage to 0%. Scenario 2 introduced additional buffer capacity at the Initial Rinse and Quality Check stages, resulting in a 4% reduction in blockage. The results show that increasing capacity at key points can improve material flow and reduce delays. This study concludes that discrete simulation is an effective method for identifying bottlenecks and evaluating operational improvements in agro-industrial production systems.

Keywords: Discrete Event Simulation, Production Efficiency, Seaweed Processing, Bottleneck Analysis, Agro-industrial Systems.

1. Introduction

The seaweed processing industry plays a vital role in Indonesia's economy, particularly as one of the world's leading producers of carrageenan [1]. PT. IHFIM, as a key player in the industry, faces numerous operational challenges in its production processes, including raw material supply uncertainty, market demand fluctuations, and the complexity of production flows [2]. Inefficiencies in the production process can lead to significant resource waste and increased operational costs [3]. These challenges necessitate a systematic approach to analyze and optimize the production system to improve efficiency and competitiveness [4].

Discrete event simulation technology has proven effective in modeling complex and dynamic production systems [5]. This approach enables the analysis of various operational scenarios without disrupting ongoing production activities [6]. A simulation model can represent critical elements in the production system, such as material flow, process time, machine capacity, and resource constraints [7]. By utilizing this technology, companies can identify production bottlenecks, evaluate alternative improvements, and predict the impact of policy changes before they are implemented [8].

The implementation of simulation modeling in seaweed production processes is particularly crucial due to the unique and seasonal characteristics of the raw material [9]. As an agricultural

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commodity, seaweed requires specific handling from the sorting and washing stages to extraction and drying [10]. Each stage involves critical parameters such as temperature, processing time, and chemical composition, which interact in complex ways. Accurate simulation modeling can help optimize the interactions among these parameters to achieve maximum production efficiency [11].

Previous studies on the application of discrete event simulation in the food industry have demonstrated potential productivity increases of 15–25% through production flow optimization [12]. However, research specifically focusing on simulation modeling for seaweed processing remains limited, despite the process's significantly different characteristics compared to other food products [13]. This research gap forms the foundation for the present study, which aims to develop a simulation model tailored to the seaweed processing industry [14].

This study aims to develop a discrete event simulation model that accurately represents the seaweed production system at PT. IHFIM. The model is expected to serve as a decision-support tool for identifying improvement areas, testing optimization scenarios, and predicting system performance under various operational conditions. The findings of this study are expected to be beneficial not only for the company but also as an academic reference for further development of simulation models in the marine product processing industry [15].

The significance of this study lies in its approach, which integrates principles of production systems with modern simulation technology to solve real-world industrial problems. In addition to providing practical solutions for PT. IHFIM, this research contributes to the advancement of modeling methodologies for natural resource-based production systems that exhibit unique and non-continuous characteristics. The research findings may also serve as a foundation for future studies on the application of simulation technology in other segments of the marine product processing industry.

2. Research and Methodology

This study employs a simulation method using ProModel software with a discrete event simulation approach based on actual operational data from PT. IHFIM. Data collection involved field observations, interviews with production staff, and documentation review, including SOPs, production reports, and machine records. Secondary data were obtained from company records over the past 12 months, covering production parameters, process times, and machine capacities [16]. The system was modeled using a bottom-up approach, beginning with the identification of entities and attributes, development of process flowcharts, formulation of system logic in ProModel, and implementation of operational parameters. Model validation was conducted through black-box testing by comparing simulation outputs with historical production data.

Following validation, sensitivity analysis was performed to assess the model's robustness to input variations, while simulation experiments were designed using a factorial design method to evaluate the effects of various operational interventions [6]. System performance was measured through key performance indicators (KPIs) such as throughput, machine utilization, cycle time, and raw material waste levels. Validation was carried out in three stages: face validity with production experts, statistical validation using t-tests, and operational validation by running the model under real production conditions for a limited period [7]. The model was considered successful if it achieved at least 90% accuracy in predicting production output.

3. Results and Discussion

The seaweed production process at PT. IHFIM consists of six main stages, which have been modeled and analyzed using actual data measured in seconds. Based on field observations and the collection of both primary and secondary data, the production workflow can be described as follows:

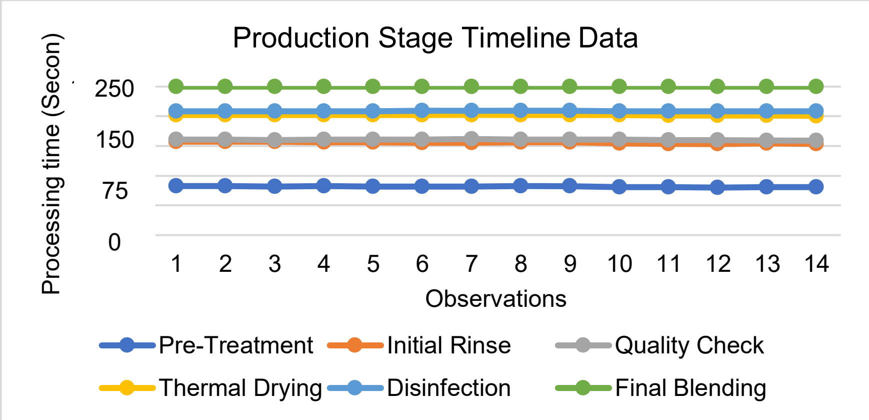


Figure 1. Processing Time per Production Stage (in Seconds)

Figure 1 presents processing times from 14 observations across six main stages in the seaweed production process at PT. IHFIM. The Pre-Treatment stage is the longest and most consistent, ranging from 235 to 241 seconds. The Initial Rinse stage follows with stable times between 214 and 217 seconds. Thermal Drying and Final Blending are also consistent, ranging from 118 to 123 seconds. Disinfection increases slightly from 19 to 23 seconds, while Quality Check shows the most variation, between 9 and 20 seconds. These findings indicate that Pre-Treatment and Final Blending are the most time-intensive stages, and Quality Check is the least predictable [17].

a. Locations

A Location represents a fixed point in the system where entities undergo processes, are temporarily stored, or transition between activities. In this seaweed production simulation, a total of 13 locations are defined, consisting of 7 processing stations and 6 transitional or distribution points, as shown in Figure 2 below:

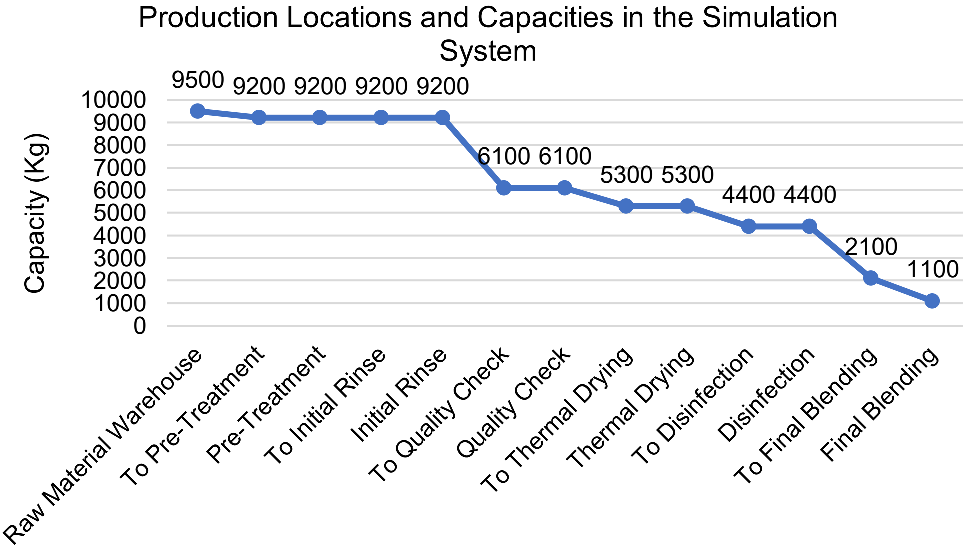


Figure 2. Production Locations and Capacities in the Simulation System

Figure 2 shows the capacities of each location involved in the seaweed production simulation at PT. IHFIM. There are 13 locations in total, including processing stations and transfer points between them. All locations operate under Time Series logic, meaning entities move through each stage based on predefined processing times. The Raw Material Warehouse is excluded from the chart due to its infinite capacity. The production flow shows a decreasing capacity trend from upstream to downstream. Early stages, such as Pre-Treatment and Initial Rinse, have the highest capacities (9200 kg), while stages like Quality Check and Thermal Drying have lower limits due to equipment or space constraints. The lowest capacity appears at Final Blending (1100 kg), indicating a potential bottleneck. This pattern reflects real production conditions, where material volume reduces as it progresses through more specialized processes.

b. Entities

Entities (entitas) are defined as any objects that undergo a process within the simulation system. In this model, there are three types of entities representing the transformation of seaweed material throughout the production line. Each entity flows through the system based on the *Time Series* logic with a fixed movement speed, as detailed in Figure 3 below:

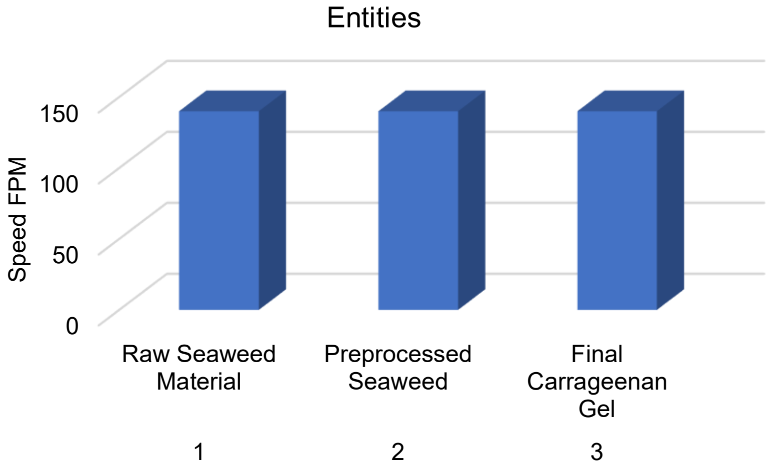


Figure 3. Speed of Entities in the Seaweed Production Simulation

Figure 3 presents the movement speed of entities within the seaweed production simulation, measured in feet per minute (FPM). There are three types of entities represented: Raw Seaweed Material, Preprocessed Seaweed, and Final Carrageenan Gel, corresponding to different stages of material transformation. All entities move at a uniform speed of 140 FPM, reflecting consistent flow through the system. These entities operate under the Time Series state, indicating that their movement and progression are governed by time-based parameters defined within the simulation model. This uniform speed ensures smooth material flow across processing stages and supports accurate time-based performance analysis throughout the simulation [18].

c. Arrivals

Arrivals in this section describe the mechanism by which entities enter the simulation system, including the number of entry points, the quantity of each arrival, the time of the first arrival, and its frequency. These details are summarized in Table 1 below:

Table 1. Entity Arrivals in the Seaweed Production Simulation

No	Entity	Location	Qty Each (Kg)	First Time (min)	Frequency (Kg)
1	Raw Seaweed Material	Raw Material Warehouse	300	0	1500

2	Raw Seaweed Material	Pre-Treatment	9200	60	9200
3	Raw Seaweed Material	To Initial Rinse	9200	240	9200
4	Raw Seaweed Material	Initial Rinse	9200	270	9200
5	Raw Seaweed Material	To Quality Check	6000	400	6000
6	Preprocessed Seaweed	Quality Check	6000	520	6000
7	Preprocessed Seaweed	To Thermal Drying	6000	540	6000
8	Preprocessed Seaweed	Thermal Drying	6000	600	6000
9	Preprocessed Seaweed	To Disinfection	4500	660	4500
10	Final Carrageenan Gel	Disinfection	4500	700	4500
11	Final Carrageenan Gel	To Final Blending	1500	740	1500
12	Final Carrageenan Gel	Final Blending	1000	800	1000

Note: Qty = Quantity per arrival; First Time = Time of first arrival (in minutes); Frequency = Arrival repetition amount.

Table 1 outlines the arrival configuration of entities within the seaweed production simulation model, detailing how and when materials enter various locations throughout the process. The entities-Raw Seaweed Material, Preprocessed Seaweed, and Final Carrageenan Gel are distributed across 12 arrival points, each with specific arrival quantities, initial entry times (in minutes), and repetition frequencies (in kilograms). For instance, Raw Seaweed Material enters the system first at the Raw Material Warehouse with 300 kg at time 0, and continues entering at various processing stages, such as Pre-Treatment and Initial Rinse, with consistent batch sizes of 9200 kg. As the material transforms into Preprocessed Seaweed and later into Final Carrageenan Gel, the arrival quantities decrease to reflect process refinement and concentration, reaching 1000 kg at the Final Blending stage. This structured arrival setup ensures the simulation accurately represents real-time input flows and supports effective analysis of throughput, bottlenecks, and production capacity.

d. Process

The simulation process model is constructed using a conceptual representation of the actual seaweed production flow at PT. IHFIM. The production begins with the delivery of raw seaweed to the Pre-Treatment area, where it undergoes an initial soaking process. After soaking, the material is transferred through a conveyance system to the Initial Rinse stage. Once rinsed, the seaweed proceeds to the Quality Check section for manual sorting and removal of foreign materials. The next step involves the Thermal Drying process using specialized equipment to reduce the moisture content to an optimal level. Following drying, the product enters the Disinfection stage, ensuring microbial safety before being directed to the Final Blending unit. In this final stage, the semi-processed seaweed is homogenized into a consistent carrageenan product ready for packaging and export. Within the ProModel simulation environment, all of these operational stages are defined under the processing module. Each process element is structured with essential attributes, including: entity, location, operation, block, output, destination, rule, and move logic, enabling accurate and dynamic modeling of the entire production workflow [19].

The second step in simulation development is testing data distribution using real field data from the production site, focusing on material arrival and processing times. Arrival times follow a Poisson distribution, while processing times use an Exponential distribution, both common in discrete-event simulations [20]. These distributions model random events like raw material flow. The analysis is done using the Stat:Fit tool in ProModel, which helps identify the best-fitting distribution for each process. Summary results are shown in Table 2.

Table 2. Distribution Testing Results Using Stat:Fit

No	Process Location	Distribution Type	Parameter Result	Fit Rank (%)
1	To Pre-Treatment	Poisson	6.21	89.4
2	Pre-Treatment	Exponential	230, 0.645	52.3
3	To Initial Rinse	Poisson	53.8	93.1
4	Initial Rinse	Exponential	215, 0.412	26.7
5	To Quality Check	Poisson	48.3	97.8
6	Quality Check	Exponential	7.2, 5.12	81.6
7	To Thermal Drying	Poisson	2.94	91.7
8	Thermal Drying	Exponential	110, 0.893	68.2
9	To Disinfection	Poisson	2.61	100
10	Disinfection	Exponential	18.9, 1.14	98.4
11	To Final Blending	Poisson	6.53	59.6
12	Final Blending	Exponential	15.2, 1.02	96.1

Table 2 shows the results of distribution testing using Stat:Fit to find the best-fit distribution for each production stage. The test compares Poisson and Exponential models, along with their parameters and fit ranks. For example, "To Pre-Treatment" fits best with a Poisson distribution (parameter: 6.21, fit rank: 89.4%), while "Pre-Treatment" fits an Exponential distribution (parameters: 230, 0.645, fit rank: 52.3%). The best fit is for "To Disinfection" with 100% (Poisson), and the lowest is "Initial Rinse" with 26.7% (Exponential). This helps ensure accurate modeling and process optimization [21].

The third step in simulation development is model verification and validation.

a. Model Verification

Prior to executing the simulation model, it is essential to ensure that all system components have been correctly built. In the context of ProModel, model verification can be performed directly by clicking the “Run” icon. If any configuration or logic errors exist, the system will display an error notification during the execution attempt. This indicates that the model setup is not yet aligned with the expected system behavior. Conversely, if the model runs without any system errors, it can be considered verified and structurally functional.

b. Model Validation

Validation checks whether the simulation model accurately reflects the real seaweed production system. This is done by comparing simulation results with actual field data. A t-test is used to see if the difference in average processing times is statistically significant. The hypotheses are:

H_0: The average simulated time equals the actual time ($\mu_1 = \mu_2$)

H_1: The average simulated time does not equal the actual time ($\mu_1 \neq \mu_2$)

If the t-calculated value is greater than t-critical, H_0 is rejected, meaning the model doesn’t match the real system. If it's smaller, H_0 is accepted, and the model is considered valid.

To assess the accuracy of the simulation model, a validation test was conducted by comparing actual production output with simulation results across key processing stages in the seaweed production line. The test used a significance level $\alpha = 0.05$ and a degree of freedom (df) = 6 + 6 - 2 = 10. The summary of output values is presented in the following table:

Table 3. Comparison Between Actual and Simulated Output

Processing Stage	Actual Output (X_1)	Simulated Output (X_2)
Pre-Treatment	9300	9280
Initial Rinse	9250	9235
Quality Check	2600	2555
Thermal Drying	5100	5045
Disinfection	4800	4765
Final Blending	1200	1178
N	**6**	**6**
Mean ($\bar{X}$)	**5375.0**	**5343.0**
Standard Deviation (S)	**3052.6**	**3095.3**

Test parameters:

- Significance Level (α) = 0.05
- α/2 = 0.025
- Degrees of Freedom (df) = 10
- t-table = 2.228

The t-statistic was calculated as follows:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - d_0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad \text{...} \quad (1)$$

$$t = \frac{(5375.0 - 5343.0) - 0}{\sqrt{\frac{(3052,6)^2}{6} + \frac{(3095,3)^2}{6}}} \approx 0{,}018$$

Since the calculated t-value (t = 0.018) is much smaller than the critical value from the t-table ($t_{0 \cdot 025}$ = ±2.228), it falls within the acceptance range of the null hypothesis. Therefore, H_0: $\mu_1 = \mu_2$ is accepted, indicating that there is no statistically significant difference between the actual and simulated outputs. This confirms that the simulation model is valid and capable of reliably representing the actual seaweed production process at PT. IHFIM.

3.2 Simulation Model

A simulation model shows the production process from raw material input to final processing. Using ProModel and Discrete Event Simulation, each stage is modeled with specific time and resources. This helps PT. IHFIM find bottlenecks, test scenarios, and improve efficiency before making real changes to the production system.

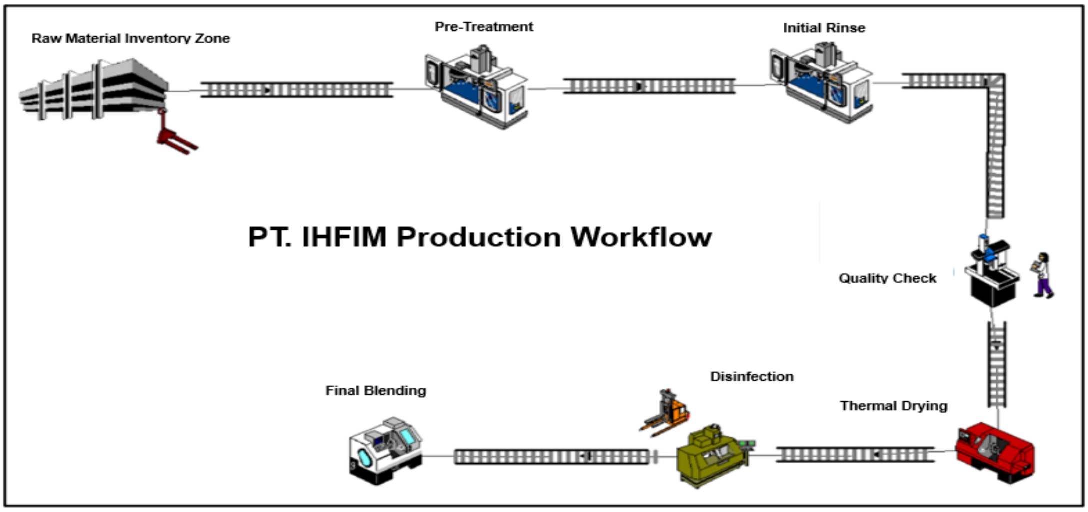


Figure 4. Visual Simulation Model of PT. IHFIM Production Workflow

The image 4 above represents a simulation model of PT. IHFIM's production workflow is illustrated visually and systematically using the Discrete Event Simulation (DES) approach. The model displays the sequence of processes starting from the Raw Material Inventory Zone, followed by Pre-Treatment, Initial Rinse, and Quality Check, which ensures that materials meet the required standards before proceeding. Each stage is depicted as a distinct station connected by a conveyor system, representing the continuous flow of materials throughout the production line. This simulation is developed using ProModel, a software designed to model and analyze real-world systems through discrete event logic. In the diagram, subsequent stages such as Thermal Drying, Disinfection, and Final Blending illustrate the final processing phases that determine the quality of the end product. By using this model, management can test various production scenarios, identify potential bottlenecks, evaluate resource utilization, and optimize overall system performance before making actual changes on the production floor [22].

The simulation run displays the output generated from the production model of PT. IHFIM uses the ProModel application, based on previously entered input data [23]. This process produces a simulation layout that represents the complete production workflow. The following is the output from the simulation results:

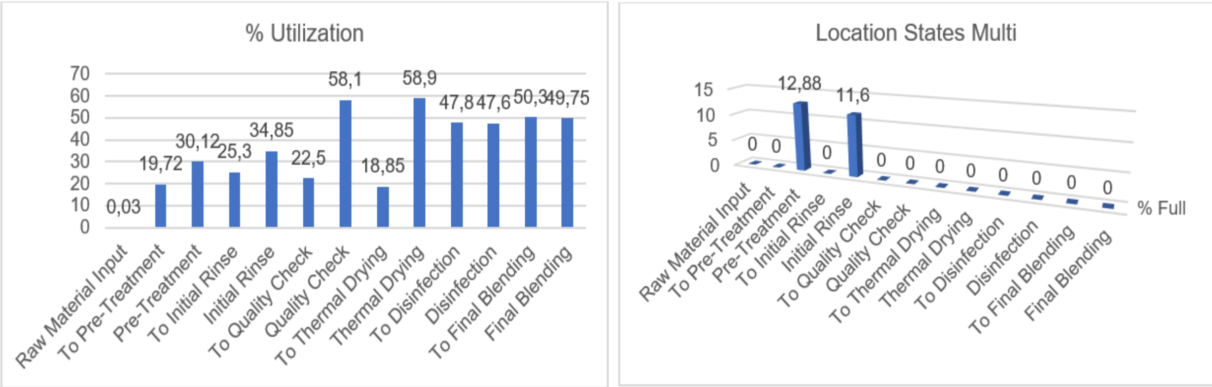
a. Simulation Output (General)

Table 4. General Simulation Output – Aligned with PT. IHFIM Production Process

Parameter Name	Value
Run Date/Time	03/07/2023 09:24
Model Title	Normal Run
Model Path/File	D:\ProductionSimulation\PT_IHFIM\Model\ Production Model_IHFIM.MDO
Warmup Time (HR)	0
Simulation Time (HR)	24

Table 4 above presents the output from the General Report generated after running the simulation model of PT. IHFIM's production process uses ProModel. The output displays the simulation time, which is set to 24 hours with no warm-up period. This duration allows for a comprehensive performance evaluation of the entire production flow, from the Raw Material Inventory Zone to the Final Blending stage. The simulation file is stored locally and executed under normal conditions, providing realistic insights into daily production operations and system efficiency.

b. Locations



a. % Utilization b. Location States Multi

Figure 5. Simulation Output Results

Figure 5 shows bar charts from simulation results highlighting two key aspects of production: capacity utilization and location occupancy (% Full) across stages from Raw Material Input to Final Blending. The Thermal Drying stage shows the highest utilization at 58.9%, followed by the To Thermal Drying at 58.1%, indicating potential bottlenecks. Meanwhile, Raw Material Input has very low utilization at 0.03%, showing extra capacity. The “Location States Multi” report also reveals that Initial Rinse (12.88%) and Quality Check (11.60%) experienced significant occupancy, while most other stages stayed at 0%, suggesting room for improved throughput and better capacity planning.

c. Entity States

Table 5. Percentage of Entity States During Simulation

Entity Name	% In Move Logic	% Waiting	% In Operation	% Blocked
Container Tray	1.25	0.00	48.60	50.15
Plastic Bin	0.00	0.00	0.00	0.00
Drying Rack	2.10	0.00	55.80	42.10

The table shows the state distribution of three entities in the seaweed production simulation. The Container Tray was active for 48.60%, blocked for 50.15%, and in transit for 1.25%, indicating frequent delays. The Plastic Bin remained inactive at 0%, suggesting it wasn’t used or integrated. The Drying Rack had the highest activity at 55.80% and was blocked 42.10%, likely during thermal drying. These results suggest a need to improve material handling and reduce blockages.

3.3 Improvement Scenario Development

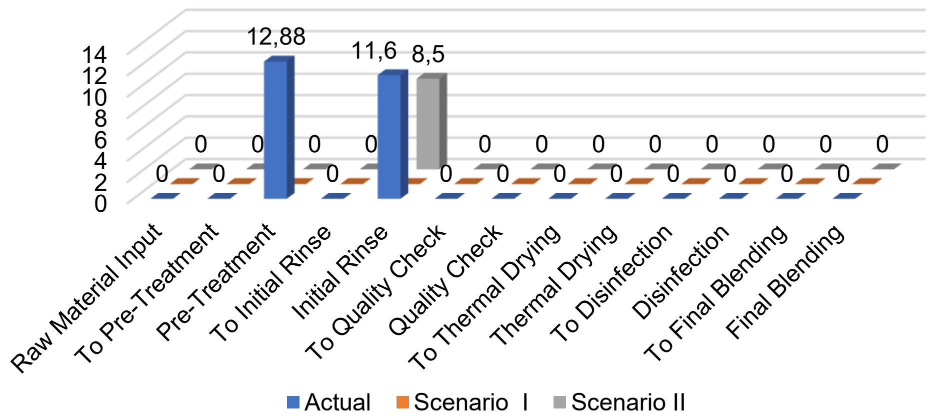


Figure 6. Comparison of Blockage Percentages Between Actual Conditions and Simulation Scenarios

Based on figure 6 above, under actual conditions, the chart indicates that most workstations in the seaweed production system at PT. IHFIM shows 0% blocked time, suggesting that the system still has considerable unused capacity. However, two critical stages—Pre-Treatment (12.88%) and Initial Rinse (11.60%)—stand out due to significant material buildup, which may lead to process bottlenecks and reduced system throughput. These high blockage levels highlight potential delays that could disrupt the production flow if left unaddressed. Therefore, this analysis provides a valuable data-driven foundation for proposing targeted process improvements aimed at balancing workload distribution and minimizing inter-stage delays.

To address the identified bottlenecks, two improvement scenarios were simulated. In Scenario 1, adding an additional tank with the same capacity as the Pre-Treatment stage (9,200 kg) effectively reduced the blockage at that point to 0%, confirming that local capacity expansion can significantly enhance process continuity. In Scenario 2, a temporary buffer with a capacity of 2,500 kg was added at the Quality Check stage, and an extra tank with 14,161 kg capacity was installed at the Initial Rinse stage. This adjustment resulted in a 4% decrease in blockage at the rinsing stage. These outcomes, also reflected in the table above, demonstrate that strategic capacity-based interventions can significantly reduce material congestion, expedite material movement, and improve overall production efficiency.

4. Conclusion

The conclusion of this study is that a discrete event simulation model was successfully developed to evaluate and enhance the efficiency of seaweed production processes at PT. IHFIM. Based on actual operational data and validated through statistical tests, the model accurately represented the production system and identified two critical bottlenecks at the Pre-Treatment and Initial Rinse stages, with blockage rates of 12.88% and 11.60%, respectively. Simulation experiments demonstrated that targeted interventions—such as the addition of a 9,200 kg tank at Pre-Treatment and a 14,161 kg capacity enhancement at Initial Rinse—effectively reduced blockage, improved flow continuity, and minimized idle times across stages. Scenario testing confirmed a 4% decrease in process blockage under optimized conditions, supporting the premise that localized capacity expansion and strategic buffer placement can significantly improve throughput. The findings highlight the practical value of simulation-based analysis in complex agro-industrial systems, enabling data-driven decisions that enhance operational performance without disrupting ongoing production. This research contributes not only to PT. IHFIM's process improvement strategy, but also to the broader application of simulation modeling in natural resource-based industries. Future research is encouraged to incorporate cost-benefit analysis and real-time monitoring integration to strengthen further decision support systems in production planning and resource allocation.

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Conflict of Interest: The authors declare no conflict of interest. All data and analysis were conducted objectively and independently, without any financial or personal influence on the results or conclusions of this study.

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