Productivity Improvement of the Coconut Water Conveying System Using Simulation Modeling: A Case Study

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Abstract

This study examines the coconut water conveying system through a case study of the coconut company. The applicability of Discrete-Event Simulation (DES), implemented using FlexSim, is demonstrated as a decision-support tool for analyzing and improving the system. The existing operation is characterized by inefficiencies in manual handling and unbalanced workloads, which negatively affect system throughput. Various scenarios were evaluated to determine optimal staffing levels at each workstation. Simulation results indicated that scenario 6 achieved an optimal allocation of labor at each workstation, thereby maximizing average throughput and reducing average work-in-process compared with the current system. Furthermore, a comprehensive simulation model was developed to evaluate potential process improvements, identifying the shell cracking and separation operations as the primary bottleneck constraining overall system throughput. The optimized conveyor-based configuration increases average throughput by 45.89%, reduces average work-in-process by 59.70%, and decreases average waiting time by 49.86% compared with the current system.

Keywords: Coconut water, Conveying, Productivity, Simulation

1. Introduction

The coconut industry is a vital component of Thailand's agriculture-based economy, particularly in the upper southern region – spanning Prachuap Khiri Khan, Chumphon, and Surat Thani provinces – which are among the country's major coconut-producing areas. Numerous small to medium-scale coconut agro-processing plants in these regions contribute significantly to the agricultural sector. However, problems have emerged due to technical restrictions, particularly in the handling and distribution of coconut water during various processing cycles. At present, most of these operations are performed manually, which is inefficient, costly, and very time-consuming for the business owners. Human labor in such practices introduces uncertainties due to worker fatigue, inconsistent handling processes, and safety risks. These issues act as upstream causes of bottlenecks, work-in-process (WIP) accumulation, and increased cost of goods sold (COGS), which greatly hinder productivity and profitability.

It is well recognized that conveyor systems offer benefits in many areas, including facilitating bulk material movement, lowering dependence on human labor, and accommodating smoother process flows with fewer interruptions. Conveyors also reduce the idle time compared to when waiting for materials to be dumped. Material loss during spilling and handling can be significantly reduced by using conveyors, as well as material damage from human loading on moving products. However, conveyor systems are rarely used in small-scale factories. Coconuts vary in size, shape, and moisture; therefore, special equipment is required, which has become a technical and financial barrier to automation.

Simulation models can be a valuable tool for addressing these challenges. The most common and convenient models are likely to be based on discrete-event simulation (DES), which enables the modeling of complex systems of interest in a safe virtual environment. DES is the formal methodology for comparing alternatives without disrupting current operations. Performance-related metrics (e.g., throughput, cycle time) can be analyzed in relation to different primitives to conduct a comprehensive analysis of potential gains in terms of overall efficiency. This approach enables the transition from high manual-handling operations to conveyance-based automation and helps explain why companies invest in capital projects only after benefits have been realized.

To demonstrate the feasibility of using DES in the process industry, this study models the coconut water conveying system in FlexSim (a widely used DES software for material handling and logistics). The objectives of the research are (i) to collect and analyze real production data from the current manual process; (ii) to develop and validate a FlexSim model that can replicate closely operating conditions; (iii) to identify bottlenecks and waste on the considered baseline system, if there are any; (iv) to test line layouts driven by conveyors with its associated possibilities for throughput improvement, WIP reduction and overall improved performance.

The contributions of this study are both theoretical and practical. From an academic perspective, the study applies DES to a field of agriculture, which still heavily relies on manual labor (in greater need of an in-depth simulation study). In terms of application, it provides information to coconut processors that may offer scientific insights, helping manufacturers decide whether to install conveyor belts or other devices in their establishment to enhance efficiency and productivity by reducing process costs and improving labor efficiency.

The remainder of the paper is organized as follows: Section 2 presents the literature review; Section 3 explains the research methodology; Section 4 provides the results and discussion; Section 5 concludes the study.

2. Theory and Literature reviews

Simulation is an essential technique for analyzing and improving the performance of complex production systems or service systems, particularly when physical experimentation is impractical. Among available approaches, Discrete-Event Simulation (DES) has been extensively used due to its capabilities to model the dynamic interplay between resources, materials, and operators in a changing environment [1]. The adoption of DES, particularly in trials using FlexSim software, has demonstrated impressive growth in manufacturing, logistics, healthcare, and service sectors over the past two decades, demonstrating its broad and robust analytical capabilities.

2.1 FlexSim in Manufacturing Systems

In industry, manufacturing process scenario simulation has been in the ascendant, and FlexSim has become a practical tool for designing and testing production processes. Wang et al. [1] combined FlexSim with time Petri nets to model automotive production logistics, and supported engineers' decision-making for faster response to inefficient scheduling and routing. Likewise, Leks and Gwiazda [2] demonstrated that the ability of FlexSim to simulate machining and assembly processes, highlighting the benefits of avoiding trial-and-error decisions by working with true digital twins. Yuan et al. [3] studied the assembly lines of refrigerators, employing DES to identify bottlenecks and suggested re-layout decisions that lead to a considerable improvement in throughput. Kumar et al. [4] evaluated a complex Flexible Manufacturing System (FMS) using FlexSim and demonstrated that simulation provided a cost-effective and resource-efficient solution for system analysis. Chawla and Singari [5] developed a simulation model for a two-wheeler crankcase cover manufacturing process and identified Scenario 2 as the most effective configuration, resulting in improved performance of Die-Casting Machines and Vertical Milling Centers. Similarly, Jidong et al. [6] proposed and evaluated an improvement scenario for a furniture production line using FlexSim, achieving a 34.7% enhancement in the production balance rate.

Additional research emphasized the applicability of FlexSim in lean manufacturing. Through virtual experimentation, simulation enables companies to reduce waste, minimize waiting times, and optimize production lines. These align with the broader objectives of Lean Manufacturing and Industry 4.0, which emphasize system integration, predictive analytics, and continuous process improvement [7].

2.2 Logistics and Material Handling

The logistics sector has increasingly embraced simulation methods recently, especially for inbound and outbound material flows. Akter Mahmud Shihab et al. [8] employed FlexSim to model automotive inbound logistics, demonstrating that simulation enhances scheduling capabilities and reduces lead times. Poloczek et al. [9] simulated warehouse interior operations in the steel industry and applied the DES to compare several storage/retrieval approaches that increased inventory turnover ratio while decreasing congestion of forklifts. Wang et al. [10] optimized the operational performance of logistics distribution centers and demonstrated the suitability of FlexSim as an effective tool for system analysis and decision support. Liu et al. [11] employed three-dimensional modeling technology in logistics engineering to enhance transportation efficiency and improve system visualization.

A related domain for research is the domain of material handling systems (MHS). Berlec et al. [12] proposed a decision-making tool for selecting the appropriate MHS and stated that FlexSim enables comparison between different setups. This is especially valuable when dealing with bulk or nonstandard shapes, for which traditional design guidelines are inadequate. Other authors have also applied simulation for conveyor-based systems, AGVs, and storage buffers, achieving observable increases in throughput, as well as improvements in utilization of space and labor [13],[14].

2.3 Identified Research Gaps

FlexSim has been widely applied across diverse industrial and logistics systems. However, several research gaps still remain. First of all, the majority of the research works have been conducted in a very structured environment, as in manufacturing systems with homogenous materials and a standard production set [15–17]. On the other hand, far fewer studies have been reported in agricultural processing systems, where raw materials typically have irregular shapes and sizes as well as different moisture content. These qualities create special requirements for the design and testing of conveyor-based material handling systems.

Second, although the versatility of simulation is demonstrated elsewhere, few studies use perishable or liquid food products. There exist unique inefficiencies in agricultural processing plants, particularly those for coconuts, such as manual handling, worker fatigue, and uneven flow rates [6],[18]. However, there is limited literature on the application of FlexSim to model systematic and alternative testing issues related to these kinds of problems.

2.4 Implications for Coconut Processing Research

The literature reviewed provides strong evidence of the effectiveness of FlexSim in bottleneck discovery, testing alternative settings, and meshing investments across different industries. Nevertheless, its application in coconut processing remains relatively unexplored, despite the crop's commercial importance in countries such as Southeast Asia. In addition, the irregular geometry of coconuts and the simultaneous handling of solid and liquid products add an inherent level of complexity to the system design. The manual conveying of resources amplifies waste in WIP, leading to bottlenecks and safety issues.

This study aims to bridge the knowledge gap by utilizing the FlexSim simulation package to investigate the transition from a manual process to a conveyor-based automation in coconut water conveying systems. Extending the utility of DES from manufacturing, logistics, and healthcare, this research demonstrates the use of DES in agricultural systems. From a scientific point of view, it extends the application of simulation modeling in underrepresented sectors. Operationally, it provides useful tips and actionable insights for small and medium-sized coconut processors seeking to achieve higher throughput, reduced labor dependence, and increased security in their operations.

3. Methodology

This research investigates the process of conveying coconut water within a coconut manufacturing facility, using a case study approach. This section describes the coconut water conveying system using a simulation technique, as shown in **Figure 1**

The research procedure began with an examination of the coconut water conveying system, followed by data collection. The next step involved developing and parameterizing the simulation model. The model was then verified and validated before use. Following the validation, experimental analyses were conducted.

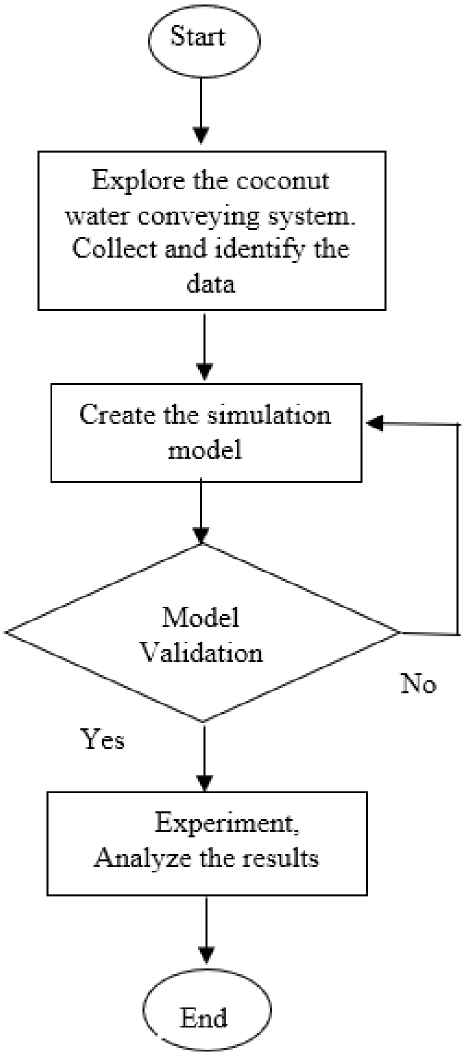

Figure 1 The research framework

3.1 The Coconut Water Conveying System.

The case study coconut factory is a small factory located in Prachuap Khiri Khan province that processes coconuts. The main products are coconut water and coconut meat, which are exported to a coconut processing factory as illustrated in **Figure 2**. This study began with an investigation of coconut water conveying systems in the selected case study companies.

Figure 2 The coconut manufacturing, a case study in Prachuap Khiri Khan province

The empirical input data used in the simulation model were collected directly from the coconut water production line. Cycle times for each processing step were obtained through on-site time studies using stopwatch measurements. For each workstation, a total of 30 observations were recorded. Data collection was conducted over one month to capture seasonal and shift-related variability. Data were analyzed to obtain comprehensive and accurate information. The coconut water production and conveying steps are described as follows:

3.1.1 Peeling (Dehusking)

This is the initial step in removing the fibers and outer shell of the coconut fruit.

3.1.2 Shell cracking and separation

After peeling, the inner shell is cracked to gain access to the flesh and coconut water inside. This step is crucial for the quality of the output, as an improper cracking tool may result in the loss of coconut water or pulp. Once the hard shell is opened, the coconut water is carefully separated from the pulp to prevent contamination. The coconut pulp is stored separately for further use in food production or other industries.

3.1.3 Filtration and Bagging

The resulting coconut water is filtered to remove any remaining impurities, such as fibers or shell debris. After that, it is packaged into bags or containers prepared in accordance with food safety standards.

Packaged coconut water is stored at a suitable temperature to maintain its quality and freshness, extend shelf life, and slow microbial growth.

3.1.4 Transportation and Storage

It is the final step that transports the entire processed coconut water to a storage area or warehouse.

3.2 The Simulation Modeling Using FlexSim Simulation

The model was executed using FlexSim simulation software (version 2021). The details of the current situation of the process are illustrated in **Figure 3**.

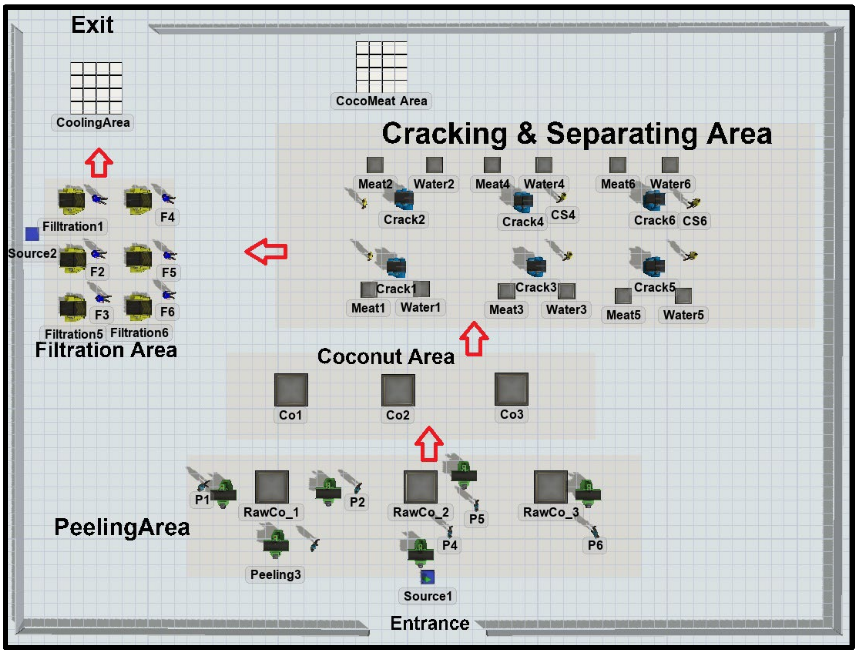

Figure 3 Simulation modeling of the current processing situation

Figure 3 shows the flow process of coconut processing. When the coconuts are brought into the factory, they are transported to the peeling station. Six employees are responsible for peeling and preparing the coconuts for the next step. The coconuts are then forwarded to the cracking and separation station, with six employees responsible for cracking the shells and separating the coconut juice from the coconut pulp. After that, the separated produce is passed on to the coconut water filtration station, where six employees are responsible for filtering, bagging, and preparing the products to be forwarded to the warehouse for further processing.

For the simulation setup, the model was run for 300 minutes, corresponding to the actual work hours (five hours per day), representing one full production shift per day. A 30-minute warm-up period was applied to eliminate initialization bias. Each scenario was simulated using 30 replications. Random seeds were varied across replications to avoid autocorrelation. The key modeling assumptions include constant worker walking speed, the absence of machine breakdowns or unexpected interruptions, and a fixed coconut size.

3.3 Model verification and validation

The measured variations were used to define the probability distributions in the simulation model. The ExpertFit function in the FlexSim license software was used for data validation. **Figure 4** illustrates the ExpertFit validation of the peeling process. The best-fitting distribution was selected. Thus, the Beta distribution, with parameters, has been specified for the peeling process in this model.

Relative Evaluation of Candidate Models

Model	Relative Score	Parameters	
1 - Beta	97.50	Lower endpoint	19.95130
		Upper endpoint	60.60122
		Shape #1	0.91051
		Shape #2	0.96310
2 - Johnson SB	97.50	Lower endpoint	19.67880
		Upper endpoint	61.11245
		Shape #1	0.05970
		Shape #2	0.58241
3 - Rayleigh(E)	89.17	Location	14.86123
		Scale	27.62388

31 models are defined with scores between 0.00 and 97.50

Absolute Evaluation of Model 1 - Beta

Evaluation: Good

Suggestion: Additional evaluations using Comparisons Tab might be informative. See Help for more information.

Additional Information about Model 1 - Beta

"Error" in the model mean relative to the sample mean -0.00251 = 0.01%

Figure 4 Data validation using ExpertFit

This research also performed a goodness-of-fit test [19] of the data by using the Anderson-Darling test. The results in **Figure 5** demonstrate that the hypothesis that the sample is beta-distributed is not rejected. All other test procedures also failed to reject the hypothesis. Therefore, the beta distribution is selected for this model.

Anderson-Darling Test with Model 1 - Beta

Sample size 300
Test statistic 0.38100

Note: No critical values exist for this special case. The following critical values are for the case where all parameters are known, and are conservative.

	Critical Values for Level of Significance (alpha)					
Sample Size	0.250	0.100	0.050	0.025	0.010	0.005
300	1.248	1.933	2.492	3.070	3.857	4.500
Reject?	No					

Figure 5: Goodness of fit test of peeling process time

All parameters used in this model are listed in **Table 1**.

Table 1 Process parameter setting for each operation

Process	Distribution	Parameter
Inter arrival rate	Exponential	(0.0,62.00)
Peeling	Beta	(19.95130, 60.60122, 0.91051, 0.96310)
Shell Cracking and Separation	Johnsonbounded	(26.235384, 185.346278, 0.116856, 0.643942)
Filtration and Bagging	Johnsonbounded	(18.015955, 91.445680, -0.053163, 0.684825)

Model verification was conducted to ensure that the simulation model was constructed in accordance with the conceptual design. The logical flow, animation behavior, queue formation, and resource allocation were examined and verified step by step. In addition, extreme-condition tests were performed. When the interarrival time was increased to significant minutes, the system behaved as expected, exhibiting minimal WIP and high idle time. Conversely, reducing the interarrival time to one second resulted in severe congestion, with long queues forming upstream. These outcomes confirm the logical robustness of the model under extreme input conditions.

For the model validation, 30 experimental results of two performance indicators—average throughput and average waiting time—obtained from the simulation model were compared with the results of the current system using a paired t-test at a significance level (α) of 0.05. The hypothesis testing was performed using Minitab 2022.

The hypotheses are Eqs. (1)–(2) as follows.

$$H_0: \mu_0 = \mu_1 \quad (1)$$

$$H_1: \mu_0 \neq \mu_1 \quad (2)$$

where μ_0 is the result of the current situation and μ_1 is the result of the simulation model. If the p-value is greater than 0.05, it indicates that there is no statistically significant difference between the current situation and the simulation model, suggesting that the model accurately represents the actual system [20],[21]. As a result, the p-value of the average throughput is 0.218. For the average waiting time, the p-value is 0.126. Therefore, this simulation model can be used for this study.

4. Results and Discussion

4.1 Experimental Results

Based on the model test in the current situation, this study evaluated material productivity, defined as average throughput in kg/hour. A bottleneck was identified at shell cracking and separation. In addition, at the coconut peeling station, a certain amount of work in the process occurred as shown in **Figure 6**. Therefore, experiments were conducted by adjusting the number of employees at each work station according to the limitations of the factory in the case study as follows: 1) No change in the total number of employees 2) The coconut shell cracking and separation station can increase the maximum number of employees to 10 due to an area limitation. 3) Other workstations can be increased or decreased as appropriate.

Given the above limitations, this research uses the experimenter function in FlexSim to determine the optimal number of employees per workstation, as outlined in **Table 2.** This scenario employs the trial-and-error method [22] to determine the optimal number of workers for the top 10 scenarios.

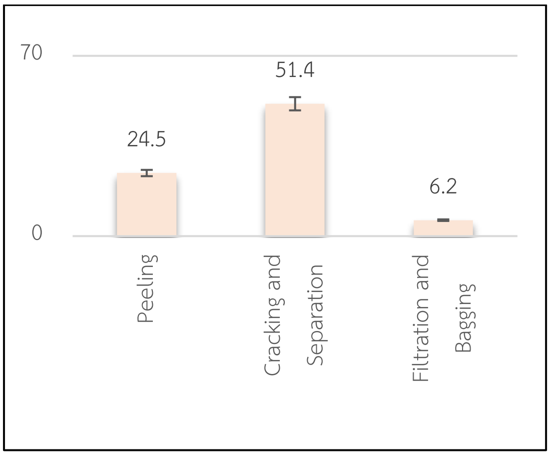

Figure 6: Average work in process occurred in each workstation (kg).

Table 2 illustrates the number of workers or workstations for each process in each scenario. Scenario 1 is the present process. The others represented the alternative approaches to assigning employees (or workstations) to each process. For example, scenario 1 represented the peeling station, shell cracking and separation workstation, and filtration and bagging station, which consists of six workers in each workstation.

Table 2: Number of work employees for each alternative scenario

	Scenarios									
Process	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Peeling	6	7	7	8	7	6	6	7	6	5
Shell Cracking and Separation	6	6	7	7	8	8	9	9	10	10
Filtration and Bagging	6	5	4	3	3	4	3	2	2	3

Figure 7 shows the experimental results for average throughput. Among all scenarios, scenario 6 achieves the maximum average throughput, increasing from 108.3 kg/hr in the current system to 163.2 kg/hr. In addition, as shown in **Figure 8**, scenario 6 also performs the minimum average work in process; the Average WIP decreased from 89.7 kg to 32.5 kg, indicating that the optimal number of Peeling stations is six employees, eight employees for Shell Cracking and Separation, and four employees for the Filtration and Bagging station.

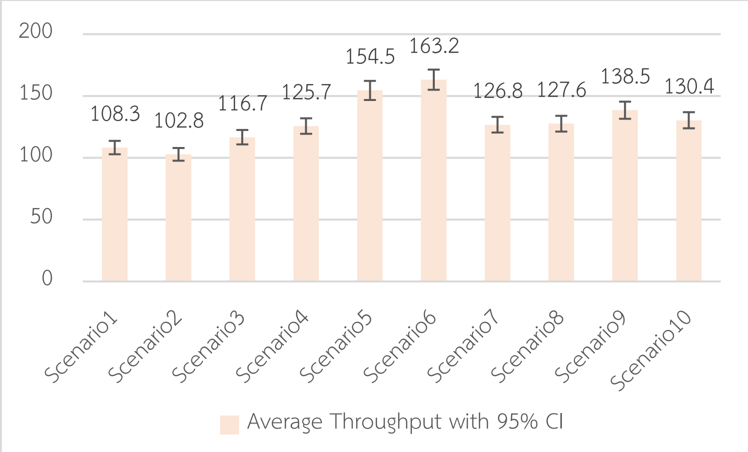

Figure 7: The average throughput of the process (kg/hr).

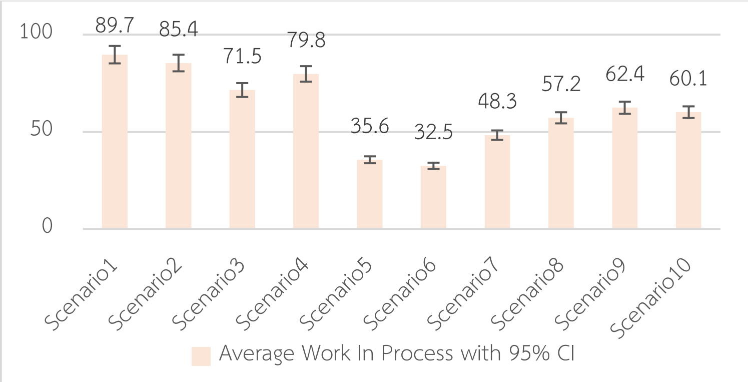

Figure 8: The average work in process of the coconut water conveying system (kg).

In addition, this research has further experimented with a newly developed model using a conveyor system to convey the coconut water at the shell cracking and separating station to enhance the coconut water conveying system. The model is shown in **Figure 9**. The model includes a simple conveyor system operating between eight employees at this station. Therefore, after the employee cracks the coconut, the coconut water is automatically conveyed by conveyor to the next station.

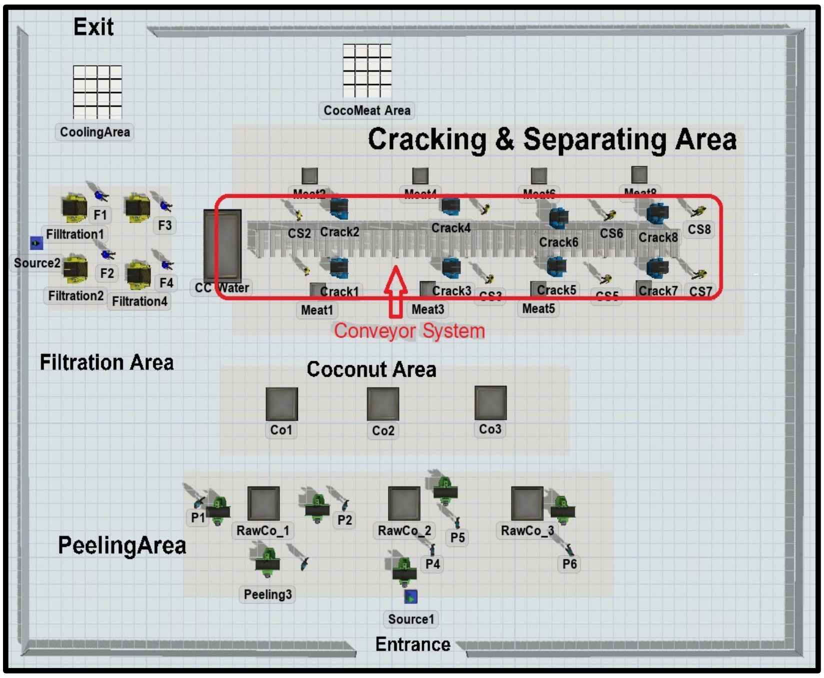

Figure 9: Conveyor system added in the cracking and separating area.

Table 3 compares the results of the conveyor system with those of the current manual system.

Table 3: Experimental results of the manual system and conveyor system

Process	Manual System	Conveyor System	Diff.
Average throughput (kg/hr)	163.2	238.1	45.89% increased
Average work in process (kg)	32.5	13.1	59.70% decreased
Average waiting time (s)	364.6	182.8	49.86% decreased

The experimental results in **Table 3** show that, with the implementation of a conveyor-based coconut water conveying system, average throughput increased by 45.89%, while average work-in-process and average queue waiting time decreased by 59.70% and 49.86%, respectively. These findings demonstrate that the automated conveying system can significantly improve overall operational efficiency.

4.2 Discussion

The results of this study reflect the benefits of its application. This study used Discrete-Event Simulation (DES) with FlexSim to analyze and improve the coconut water conveying process. Experiments have shown that allocating and adjusting the number of employees at each workstation can substantially reduce bottlenecks and work-in-process (WIP) workloads. Therefore, such an approach is considered practical. This is especially true for small processing plants that still rely heavily on manual labor.

However, the manual improvement approach remains limited by human factors, such as fatigue, inconsistent performance, and worker absences. Although the adjustment of the number of workers can increase productivity in the short term, it will not truly meet the needs of process continuity or capacity expansion in the future.

In contrast, the introduction of a conveyor system enables a more continuous and consistent flow of coconut water. This approach reduces dependence on manual labor. This aligns with the Lean Manufacturing principle, which emphasizes waste reduction, the minimization of non-value-added time, and the maintenance of smooth process flow.

In addition, the results of the study reinforce that simulations can serve as effective decision-support tools. Factories can experiment with a variety of improvement approaches in a virtual environment. This allows organizations to evaluate and identify optimal strategies without compromising real-world operations and reduces the risk of investments that may not deliver the expected performance.

4.3 Suggestions for Future Research

This study compares manual labor and automated conveyor systems but does not provide a detailed economic analysis. Therefore, future research should incorporate cost-benefit analysis, calculations, payback periods, and considerations of hybrid approaches between labor and automation. In addition, the integration of real-time data and the use of innovative manufacturing technology may be another direction that further improves the management of the agricultural process and overall operational efficiency.

5. Conclusion

This research examined the process of transporting coconut water within the coconut industry. The study demonstrated the potential of using Discrete-Event Simulation (DES) in conjunction with the FlexSim software to evaluate and develop the coconut water conveying system. The findings indicated that optimizing the number of workers at each workstation can effectively reduce bottlenecks and WIP. Still, this approach remains limited by manual labor dependency, which introduces uncertainties and can affect the continuity and stability of the process in the long term. Therefore, the transition to automation through the implementation of conveyor systems is considered a more sustainable and stable long-term option in terms of production, as it allows continuous workflow, minimizes losses, increases workplace safety, and aligns with the principles of lean manufacturing. Furthermore, the use of simulations in this research adds academic value by extending the scope of DES applications in the agricultural sector, which remains underexplored relative to manufacturing and logistics. Practically, the research provides valuable insights for industry practitioners and entrepreneurs, offering a data-driven foundation for informed investment decisions in process automation and efficiency improvement.

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