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Simulation and analyses of shea nuts (*vitallaria paradoxa*) processing plant using FlexSim©

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A B S T R A C T

Manufacturing facilities are systems that require adequate designing, maintenance and reservations for improvement in the future. Layouts need to be effectively designed to reduce operating to the minimum. Computer simulation is a process of investigating and analyzing the behavior of production processes for effective decision-making using computers to generate solutions that will positively impact short, and long-term planning of the Plants and save costs of real-life implementation. This study investigated a 500Kg capacity shea nut processing plant using FlexSim©. The findings from the initial model were not effective and experienced bottlenecks in workstations (Roaster and Milling) sections, poor cycle and lead times coupled with manual labor, Plant efficiency was 35.7%. However, the Improvement Layout Model was able to address these bottlenecks, the results showed the Plant efficiency increased to 83.3%, shorter lead and cycle times, improved machine utilization, and throughput capacity of the Plant. The results were an indication of conformance to the layout design developed to aid in enhancing the traditional shea nut processing that is largely dominated by traditional processing practices.

1. Introduction

Manufacturing Plants are essential to boosting the economic growth and development of any country, however, effective management of resources and design of processes must be enforced to improve efficiency, and productivity, and reduce the cost of production (Theophine, 2021). The rapid increase in global population, varied customer demands and the desire to meet up with these challenges have led to the revolution of the traditional manufacturing processes into a more modern and smart manufacturing system, this revolutionary era is regarded as the Industry 4.0 era; it seeks to integrate information and communication technology, and automation to optimize manufacturing systems (Ricondo et al., 2021), and to generate data to make informed decisions to improve on the operation times, set up times, buffer capacities and efficiency of the manufacturing industry for increased efficiency, profit, productivity and customer satisfaction (Klos et al., 2015). Manufacturing facilities are systems that require adequate attention in designing, maintaining and improving future development, around 50% of the total operating cost of a manufacturing plant is related to material handling, Plant layout needs to be effectively designed to reduce these costs to the barest minimum (Zúñiga et al., 2020; Kovács & Kot, 2017). Facility layout is the physical arrangement of facilities, machines, and workstations relative to one another to convert raw materials into finished goods, and ensure flexibility, space utilization, the flow of materials, health and safety, to effectively improve production capacities, minimize costs and increase market value, plant layouts need to be designed to cater for maximum resource management through short and long-term decisions (Zúñiga et al., 2020; Kłos & Patalas-Maliszewska, 2015).

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Nigeria is a county located on the fringes of Savannah, the western part of Africa, with a population of around 180 million people, the most populous country in Africa, and the largest economy (Knoema, 2019). Nigeria has an estimated 92 million ha land mass, of which 82 million is arable and only around 32 million ha are utilized for crop production (Lokpobiri, 2019). According to the National Bureau of Statistics (NBC), Nigeria's GDP grew by 2.3% in 2019, but to the advent of the global COVID-19 Pandemic, the economy was projected to contract by the end of 2020 because of restrictions to travel and closure of business activities within the country Can & Bello (2022). Micro, Small, and Medium Enterprises (MSMEs) are key players in Nigeria's Economic Transformation and Industrialization, serving as poverty alleviation medium, increased income redistribution, Industrial diversification, and economic development Kale (2019) they constitute around 96% of Nigerian Businesses, while the manufacturing sector contributes around 7% to GDP, Non-oil sector contribution was around 96% with Agriculture having 24.64%, Industries 21.87% and services 53.49% contributions to Gross Domestic Product Olomu et al., (2020). Despite being the largest economy, the Nigerian Agricultural sector is still underutilized because of the inability to properly improve on postharvest handling and value addition, Nigeria losses an estimated 9 million USD annually due to postharvest-related losses (Abdulhakeem et al., 2021; PwC, 2017).

Shea trees (*Vitallaria Paradoxa*), are among the abundant trees found in Nigeria, it is a perennial and deciduous tree that grows naturally across the guinea savannah regions (Olife et al., 2013). It yields fruits upon reaching the age of 20 years and matures fully around 45 years. Most of the parts of the shea tree has its unique economic values ranging from leaves, back of the stem, and kernels (Warra, 2011; Olife et al., 2013). Shea trees have important economic demand globally due to their use in the pharmaceutical, food and beverages, and cosmetics industries. There are international regulations regarding the 5% inclusion of non-cocoa butter in most food industries and other industries requiring cocoa butter equivalent (CBE) oil as key ingredients for their production, this regulation consumes about 90% of shea butter exports from West (Africa Akinsokeji et al., 2017). While Nigeria is among the leading producers of shea nuts in Africa with a production of around 650,000 tons per annum, most of the shea butter produced in Nigeria is not up to export standards of quality due to a lack of modern technology and traditional extraction methods (Tulashie et al., 2020; Akinsokeji et al., 2017). Simulation enables a hitch-free investigation of manufacturing processes and proffers cost-effective solutions for improved decision-making on a system for real-life implementation Peng (2011). FlexSim© is equipped with a 3D visualization of resources, workers and a variety of formats for results analysis (Abdulhakeem et al., 2020), this simulation software enables the experimentation on production lines, logistics, and healthcare systems to investigate the effectiveness of decisions; changes in parameters, and properties of workstations, flexibility, and system capacity, staff requirements, bottlenecks, and performance of the plant among others (Rostkowska, 2014). Several authors have used FlexSim© simulation software to perform simulation and optimization of production lines, logistics, and scheduling problems and yielding positive results, and saving the cost of plant restructuring in real life (Wu et al., 2018; Tokgoz, 2017; Peng, 2011; Kadane & Bhatwadeka, 2011).

This study aimed to perform a simulation analysis on a proposed 500 Kg shea nut processing plant for extraction of shea butter and shea oil using FlexSim© software.

2. Methodology

2.1 Simulation Modeling Using FlexSim©

FlexSim software is an object-oriented environment that model, visualize, simulate and monitor flow processes and systems dynamically aided with animations in 2D, 3D, and virtual reality, over three levels; compiler, developer, and Application products (Nordgren, 2003; Abdulhakeem et al., 2020; Wu et al., 2018). Discrete event simulation is regarded as the most suitable for modelling manufacturing systems as it offers both design and operations stages of manufacturing facilities, improvement and optimization, scheduling, performance analysis, production planning and control (Lidberg et al., 2020; Song et al., 2016; Zúñiga et al., 2022).

2.2 Establishment of the Process in FlexSim Simulation Environment

The establishment of the process layout used in the FlexSim software environment was reported by Wu et al. (2018) and Abdulhakeem et al. (2020).

2.3 Building the Simulation Model in FlexSim Environment

The simulation elements were added to the FlexSim environment, parameters were set for each entity (See Table).

Table 1
Summary of model and System elements used

S/N	MODEL ELEMENTS	SYSTEM ELEMENTS	DESCRIPTION
1.	Source	Raw material arrival point	Material source point
2.	Flow items	Shea nuts	Products to be processed
3.	Fixed resources	Processing and transporting of flow items	Workstations
4.	Fluid elements	Processing and transporting fluid materials	For converting solid material to fluid, processing of fluids.
5.	Sink	Collection point	Serves as a dispatch point
6.	culls	Waste bin	Collection of waste products as they move across workstations

3. Results and discussion

3.1 Proposed Product Layout Flow Chart

The proposed product layout was drafted after visitations to traditional shea butter processing plants as reported by some researchers Gana et al. (2019) shown in Fig. 1 below. The figure showcased the processing sequences of shea nut into finished shea nut oil and butter; from arrival to dispatch, shea nuts are processed and refined to the desired products. Fig. 2 highlighted the Simplified Process Block Diagram of the processing sequences of the shea nut Plant, it is a breakdown of manufacturing operations, with each rectangular block representing a unit operation or group of operations and material and energy balances as raw materials flow between the workstation (Saravacos & Kostaropoulos, 2002), from the figure, it could be observed that workstations; sorting/grading estimated to have 10% losses (wastes) as the result of sorting and grading process involved in differentiating quality shea nut from defective nuts, while crushing (sheller), roaster, milling were expressed as 5% losses respectively as materials flow between workstations.

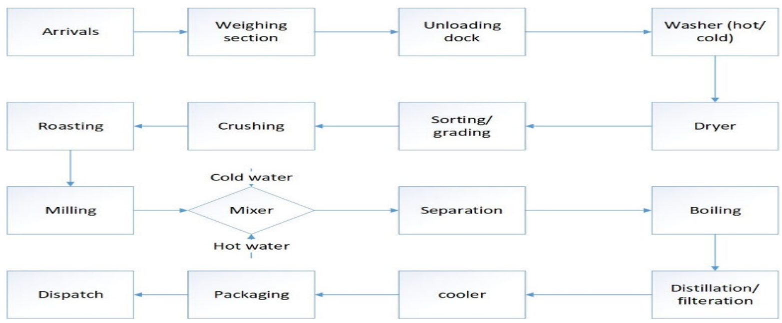

Fig. 1. Product layout of shea nut processing plant

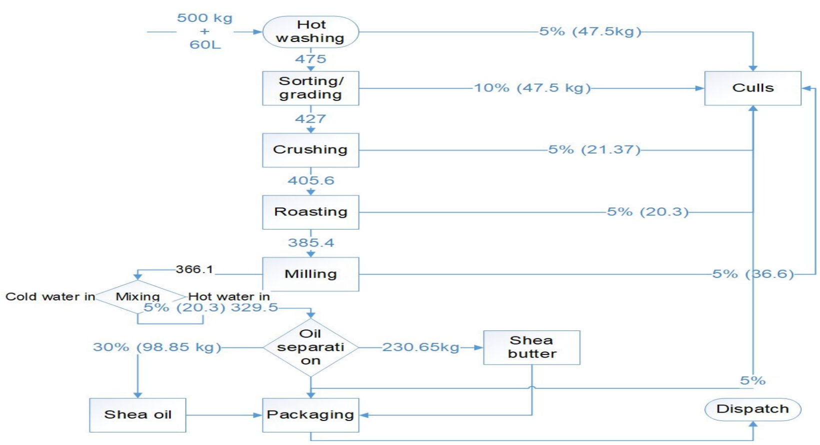

Fig. 2. Shea nut Simplified Process Block Diagram

Table 2
Simulation Working Data

WORKING PROCESS	DESCRIPTION	MACHINE CAPACITY
1. Washers	Washing of shea nuts	8.33 kg/min
2. Sorters/graders	Sorting and grading of shea nuts	8.33 kg/min
3. Dryers	For drying washed shea nuts	
4. Sheller	For crushing the nuts	8.33 kg/min
5. Roasters	For roasted shea nuts	2.5 kg/min
6. Milling	For grinding the shea nuts	2.5 kg/min
7. Fluid ticker	Send and receive the material at set intervals	
8. Item-to-fluid	Converts objects to fluids	
9. Fluid-to-item	Convert fluid to items	
10. Fluid tank	Collection tank for fluids	
11. Fluid generators	Generate fluids (hot and cold water)	
12. Fluid mixer	Mixes the fluids	
13. Fluid processor	Processes the fluids	
14. Fluid pipe, splitter	Transportation of fluids and separation	
15. Separator	Distinguish between butter and oil	
16. Packaging	Packages the butter and the oil into cartons	

3.2 Fluid data model

Table 3
Fluid model data used in the simulation exercise

FLUID OBJECT	DATA	SIMULATION DATA
Fluid-to-item	10.00 units per flow item, max. port rate 2.00	1.00 flow item per kg
Item-to-fluid	Max. 20.00 units	1.00 flow item per kg
Pipe loading to tank	Max. 20.00 units, transfer rate	1.00L/s
Pipe loading to the mixer	Max. 10 units, transfer rate	1.00 L/s
Fluid Tank	Low mark: 1.00 Liter High mark: 200 Liters	200.00 L
Fluid Mixer	Object rate 4.00, port rate 2.00 units	Port rate 1.00
Converter	Fluid per discrete Unit 35.00, 10.00 units per flow items	1.00 flow item per kg
Fluid Generator	Max. content 200L, Refill rate 100L	Output object rate 2L,
Fluid splitter	Max. object rate 20.00, port rate 10.00	By percentage 70/30 for shea butter and shea oil

Table 2 presents the simulation data used in the FlexSim© environment and machine capacities from the Table, it could be observed that workstations (Washer, sorter/grader, sheller) have the capacity to process 8.33 Kg/min of raw shea nuts, (Roaster and Milling) have a capacity of 2.5Kg/min respectively. The variation in machine capacity was due to the generated culls which were shown in Fig. 2. while Table 3 highlights the fluid model data used in converting raw shea nut into fluid as part of state changes in the processing of shea nut into shea butter and oil.

3.3 Simulation Results and Analyses of The Initial Model Layout

Simulation operation: The simulation time was set to 50,000 seconds according to the traditional time of production at the plant and the results were elaborated in Table 4 below, the Table displayed the throughput of each workstation, maximum content stay-times (cycle time) for each batch process and the percentage utilization of each workstation. Workstations (Hot_wash, Roaster, Milling, fluid-to-item 1&2) were observed to have the highest percentage of idle times (92.80, 99.09, 99.15,99.87, 99.72%) this was because the cycle time for these workstations was shorter because of the batched processes involved in cleaning, roasting, milling of shea nuts into paste, and for extraction of butter and oil. The initial model layout entailed a lot of manual labor, improper worker utilization, poor hygiene, and poor plant safety as materials flow between workstations.

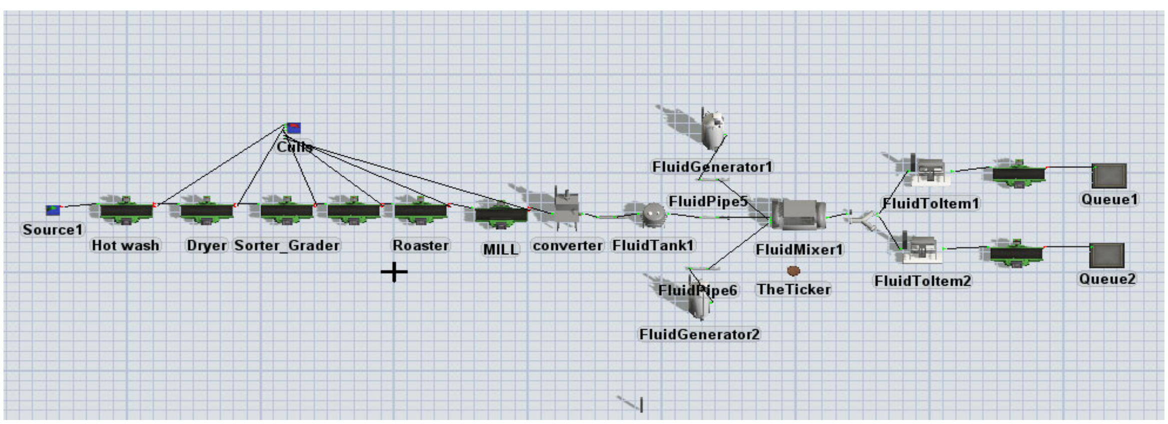

Fig. 3. A simulation Model of the Initial Layout

Table 4
Results of Simulation Analysis on Initial Model

Elements	System Throughput (Kg)	Maximum Content Stay times (seconds)	Processing time (%)		
			Blocked	Processing	Idle
Hot wash	500	3600.00	0.00	7.20	92.80
Dryer	469	5832.98	0.00	11.67	88.34
Sorter_Grader	439	3605.95	0.00	35.93	63.94
Sheller	408	3605.00	0.00	35.92	63.94
Roaster	350	5445.18	0.00	0.76	99.09
Milling	326	900.00	0.00	0.85	99.15
Fluid-to-item1	228	79.97	0.00	0.16	99.84
Fluid-to-item2	350	138.43	0.00	0.28	99.72
Shea oil packager	228	5593.83	0.00	11.19	88.81
Shea butter packager	350	5608.75	0.00	11.22	88.78

3.4 Improvement Model Results and Analysis

Simulation Operation: raw material arrival schedule was set to 120 seconds interval with each batch process consisting of 100Kg raw shea nuts, then sent to the hot_washer section for cleaning and removal of debris. The simulation parameters were set according to the data highlighted in Table 2. The simulation clock was set to 21600 seconds and elements were connected as shown in Fig. 4. Agricultural commodities when processed, change from solid to liquids, semi-solids or semi-liquid and granules, in the case of shea nut processing this change of state was possible in FlexSim © Environment using the Fluid library components; converter, mixer, fluid tank, fluid generator, pipes, fluid processor, fluid-to-item, item-to-fluid (fluid-to-item1) as shown in Table 3. The improvement layout offered greater machine utilization, fewer idle times and overall plant efficiency, Table 5 showcases the results of the simulation analysis on the improvement layout, from the Table, workstations (Dryer, Sorter_Grader, Sheller, Roaster and Milling) recorded a decrease in the idle times during operations (62.78, 44.18, 27.30, 28.98, 29.93% respectively which was an indication of the effective machine and worker utilization. The results showed that the bottlenecks experienced in the initial model were mitigated. The content stay times and throughput of the workstations were in tandem with the simplified process block diagram in Fig. 2.

Table 5
Results of Simulation Analysis on the Improved Model

Elements	Throughput (Kg)	Maximum Content Stay times (seconds)	Processing time (%) Blocked	Processing	Idle
Hot wash	500.00	92.66	0.00	1.35	71.03
Dryer	469.00	8039.31	0.00	37.22	62.78
Sorter_Grader	439.00	3598.95	28.12	27.76	44.18
Sheller	408.00	3605.00	0.00	72.89	27.30
Roaster	349.00	5445.18	0.00	71.20	28.94
Milling	348.00	900.00	0.00	70.23	29.93
Fluid-to- item1(item-to-fluid)	120.00	211.21	0.00	0.97	99.21
Fluid-to-item2	280.00	574.78	0.00	2.66	97.34
Shea butter packager	280.00	5608.78	0.00	25.96	74.04
Shea oil packager	120.00	5593.81	0.00	25.90	74.10

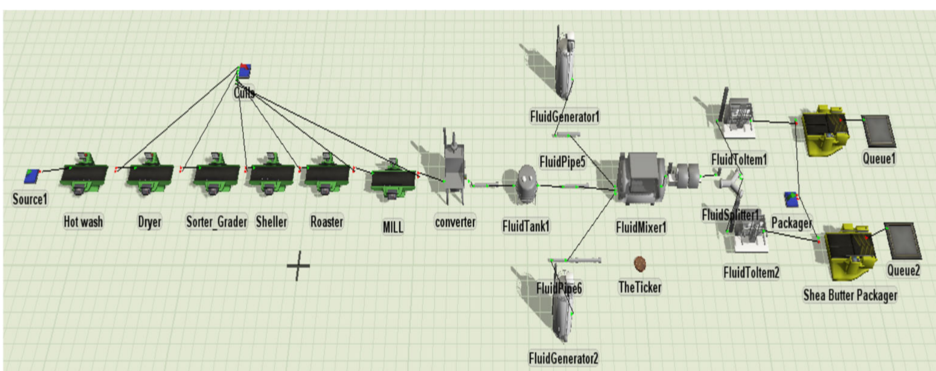

Fig. 4. Simulation Model of the Improved Plant

Comparison between Initial Model and Improved Layout Scheme: the comparison between the initial model layout and the improved model was based on the utilization of production equipment, system throughput and utilization of synthesizers as shown in Table 6 below.

Table 6
The results of the system throughput and utilization of synthesizers

Basis of Comparison	Workstations	Initial Model Layout	Improved Model Layout
Utilization of production equipment	Hot_washer	7.20%	1.35%
	Dryer	11.67%	37.22%
	Sorter_grader	35.93%	27.26%
	Sheller	35.92%	78.89%
	Roaster	0.76%	71.20%
	Milling	0.85%	70.23%
System Throughput	Milling	326 Kg	348 Kg
	Shear butter packager	228 Kg	280 Kg
	Shea oil packager	532 Kg	120 Kg
Utilization of Synthesizers	Fluid-to-item1(Item-to-fluid)	228 Kg	120 Kg
	Fluid-to-item2	350 Kg	280 Kg

From Table 6 above it could be seen that Production Equipment Utilization, and System Throughput were better in the Improved Model Layout, and the simulation results showed conformance with the Plant Layout Design than in the initial model. Fluid-to-item2 workstations were used for the synthesis of shea paste to shea butter, the Initial Model had 350 Kg which was higher than the initial shea paste content from the Milling machine as such makes the values from the Initial Model Layout questionable, however, the data obtained from the Improved Layout Model showed conformance with the throughput rate of the Milling workstation when the shea paste was synthesized to extract shea butter and oil with 280 Kg and 120 Kg respectively. The Improved Layout Model addressed the issues of bottlenecks that were encountered in the Initial Layout Model

4. Conclusion

This study was conducted to develop an optimum layout for a 500 Kg shea nuts processing Plant using simulation software (FlexSim©). This endeavor was aimed at improving the traditional shea nut processing clusters largely dominated by women in the rural areas of Nigeria, to introduce standardized machines, enhance worker utilization, reduced wastage, improve lead times, hygiene and safety of workers to increase return on investment and maximization of profits with reduced costs of production.

From the Initial Model, the bottlenecks were largely based on underutilization of machines due to manual labor involved in the production of shea butter and oil, workstations (Roster, Milling) had the highest idle times (99.15, and 99.84%) respectively due to the tedious nature of the process when done manually. The Plant production efficiency was 35.7%.

However, the Improvement Model Layout addressed the issues of bottlenecks by introducing standard processors for roasting and milling, easing the use of manual labour, improving cycle times, and lead times, improving utilization of resources and the design recorded a production efficiency of 83.3%. Consequently, the Improvement Model Layout was found to be more effective and offer realistic statistics to the proposed design than the Initial Model Layout.

The main suggestion for future work is the use of another simulation software to perform experiments to further validate the model and to effectively implement the design as an alternative to the traditional shea nut processing Plants.

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