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ORIGINAL RESEARCH ARTICLE

SYSTEMATIC LAYOUT PLANNING APPROACH IN PROCESS LAYOUT DESIGN FOR PROCESSING DEHYDRATED TOMATOES

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ABSTRACT

This study was conducted to determine an effective design for the processing of dehydrated tomatoes. The study proffer solutions to huge losses Nigeria encounters as a result of poor postharvest handling across the fruits and vegetables value chain. Despite the huge contributions of agriculture (vegetables) to Nigeria's economic growth, postharvest losses stands at $9 million with 50% losses in fruits and vegetables as a result of their perishable nature. Systematic layout planning (SLP) approach was used in designing the process layout for dehydrated tomatoes. The design approach was used to serve as an improvement layout and also as a new design for processing of dehydrated tomato plant, with estimated 5% material losses during processing, average temperature for dehydration as 65°C, plant production time of 748.99 minutes/day, a throughput capacity of 10 tons/day is achievable. Additionally, the design was validated using computer simulation and the results obtained from the simulation analysis indicated that the method can be used to optimize process planning for several production processes of dehydrated fruit and vegetables

1.0 Introduction

The performance and efficiency of industrial production system depends to a great extent on the quality of machineries, employees, as well as how facilities are positioned in a plant. Poorly designed facility, therefore, may result in loss in production time, efficiency and wastage of raw materials, while a well-designed production facility improves on the efficiency of production with fewer costs and time wastage (Tak and Yadav, 2012). Among the main goal of manufacturing system is to maximize productivity with regards to the complexity of the processes involved in manufacturing from raw materials to finished products and workstations (Carlo et al., 2013).

Agricultural products are processed to among other things improve the shelf-life of the produce and acceptability for final consumption as food or ingredients for industrial production. The output of processing result is varieties of by-products. Vegetables such as onions, tomatoes and pepper are the major vegetables produced in Nigeria, and they play a significant role in health and nutrition due to their constituents that regulate digestion. Onions are processed to produce dehydrated onions, onions powder and puree. Despite the enormous economic potentials of onions, the processing of onions for national growth and development has little to no existence in Nigeria Ibeawuchi et al. (2015). According to Ugonna et al. (2017), Nigeria's vegetable processing industries need to be developed to reduce postharvest losses and enhance food nutrition security. The establishment of these industries will boost the nation's economy thereby creating employment, wealth, reduced rate of malnutrition and increased standards of living for the rural populace.

According to Food and Agriculture Organization (FAO) Statistics FAO (2019) it estimated that Nigeria's tomatoes production is around 4.5 tons/ha with annual production of 3.8 million tonnes, while onions production is around 2.3tons/ha, with annual production of 1.3 million tonnes in the year 2019. Despite the huge contributions of agriculture (vegetables) to Nigeria's economic growth, about 50% of fruits and vegetables produced are lost as a result of their perishable nature, poor postharvest handling and mismanagement leading to a staggering 360 million USD losses annually

(GEMS, 2016., Elemo, 2017., Abdulhakeem et al., 2020). Nigeria is the 14th largest producer of tomatoes in the world, 2nd largest producer in Africa and the 3rd largest importer of processed tomato commodities (PWC, 2018; Sahel, 2017; Ugonna et al., 2017).

Available literature indicated that plant layout as described by Jain et al. (2013) refers to the arrangement of physical facilities such as equipment, machineries in a way to achieve the fastest flow of materials with lowest handling and costs within a factory building for efficient processing of products. Systematic layout planning (SLP) is a step-by-step approach to planning procedure that allows designers to identify, visualize, classify activities, relationships and alternatives in a plant layout design (Richard and Lee, 2015). SLP serves as organized way of layout planning and a tool used to arrange workstations in a plant, which offers fastest material flow in processing or products at the lowest possible handling and costs (Shubham and Prasad, 2016).

The aim of this study was to design an effective layout for processing of dehydrated tomatoes using systematic layout planning approach due to the absence of such plant in Nigeria.

2. Materials and Methodology

2.1. Basic Principles of SLP

The initial task in using SLP approach is to understand and input design data such as machine capacity, analyse the material flow and establish relationship between each workstation and sequence of production, develop a relationship diagram; relate the space requirements and available area to enable for space relationship diagram; identify, modify the factors of production, then evaluate and develop the best layout design (Hosseini et al., 2013). SLP approach is the recording of data that involve product, quantity, routing, support and time (P, Q, R, S, T) as the basic elements, with tables serving as analytical tools to conduct plant design (Zhu and Wang, 2009., Wiyaratn and Watanapa, 2010).

2.2. Data Collection for Process Layout Design

Visits to existing tomato processing plant (Savanah Integrated Export Processing Farms Borno State) known as VEGFRU and traditional producers of sun dried tomatoes in Dadin-kowa, Gombe, Gombe State, Nigeria, were done to gain understanding on the steps being followed in processing of tomatoes to serve as a guide in designing of effective layout and recording of data on machine capacities, processing time, sequence of production, and space requirement. Savannah Integrated Export Processing Farms has a production capacity of 400 metric tons per day with a 24 hours' operation period with 12 hour shifts during harvest season and 16 hours' operation with 8 hours shift during off season, a summary of the company data is given in Table 1, while the process flow chart of the plant is given in Figure 1. The chart showcases the processes involved in the production of tomato paste; the data obtained aided in drafting the processing sequences of the dehydrated tomato plant. Flowcharts and Figures were designed using Microsoft Visio © software.

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Table 1: Summary of field data

Name of Firm	Savannah Integrated Export Processing Farms		
Machines and Sequence	Operation Type	Capacity	Nature or No of Operators
Elevator	Lifting of fruits from receiving pond		
Receiving tank	To wash, sort and grade the fruits from the elevator.	5 ton/h *2	12 operators six (6) on each production line.
Fruit meshing machine	To mesh the fruits.		1
Boiler	To heat the meshed fruits to 90 degrees Celsius		
Pulp machine	To pulp the fruits		1
Collecting tanks	Collect the pulped tomatoes for further processing		
Evaporators	To dry the excess moisture from the tomatoes	4 set of evaporators with 12 collecting tanks. 25 tons/set	8 operators 2 each
Feeding line			
Cold filling line			
Drum filler	To store processed tomatoes for later use when there's excess supply	2 sets to fill 200kg/ drum	2
Canning	To store processed tomato paste in cans of 70 gram each		1
Sterilizer A and B A: hot water tub (10-12mins) B: cold water tub (5-7mins)	Processed tin tomatoes pass through each compartment A and B for sterilization		
Blower or Dryer (3mins)	Dries the tomato cans coming from the sterilizer		
Packaging	To arrange the can tomatoes in cartons	100 cans per carton	10 Operators

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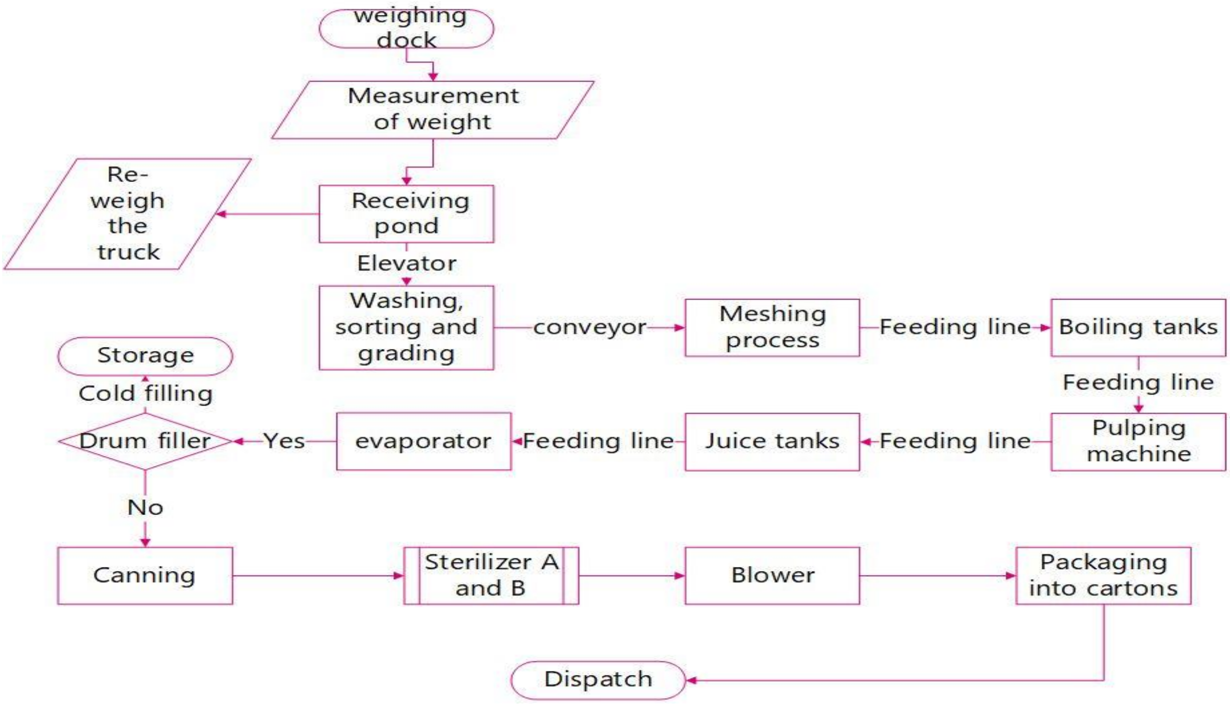

Figure 1: Process flow chart of tomato paste production at Savannah Integrated Export Processing Farms©

2.3. Flow of Materials

This procedure was followed to determine the most effective sequence(s) in which raw materials (tomatoes) move through stages of processing and the intensity of the movement, which involves relationship flow diagram, Process flowchart , multi-product chart and from-to-chart (Richard and Lee, 2015). Figure 2 highlight the product layout for dehydration of tomatoes, it showcased how raw materials flow from one workstation to another until the end of production.

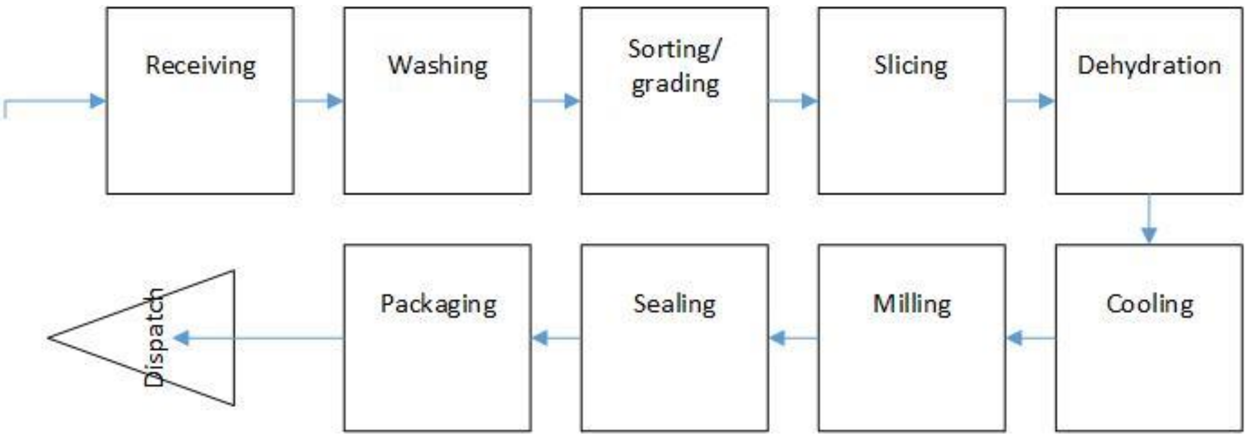

Figure 2: Product layout for dehydration of tomatoes

2.3.1. Activity Relationship Chart

The activity relationship chart was used to show the relationship between pairs of activities preceding in a process operation such as washing, sorting and grading of tomatoes, these processes are performed by separate machines. The chart showed the importance of the closeness between these machines based on their expected ratings as shown in Table 2 (Carlo et al., 2013; Richard and Lee, 2015).

Table 2: Activity relationship chart

Value	Relationship	No of Ratings
A	Absolutely important	4
E	Especially important	3
I	Important	2
O	Closeness ok	1
U	Unimportant	0
X	Not desired	-1

2.4. Mass and Energy Balance

The calculation quantifies the mass and energy in the system or process governed by the law of conservation of mass. It was reported that there are typical losses encountered in processing steps of fruits and vegetables (Fellows, 2004). These includes: washing (0-10%), sorting (5-50%), peeling (5-60%), slicing (5-10%), drying (10-20%) packaging (5-10%) and rejected packs (2-5%). These figures were used to draft the Process Block Diagram, the diagram depict the estimated minimum losses of materials through processing workstations.

$$mass\ in = mass\ out + mass\ stored \quad (1)$$

$$Energy\ in = Energy\ out + Energy\ Stored \quad (2)$$

$$\Delta HT + \Delta Hdt + \Delta Het + \Delta Hdry + \Delta Hct = 0$$

Specific heat capacity of tomatoes was given by Dickerson's Equation in Ikegwu and Ekwu (2009) as:

$$Cp = 1.675 + 0.025\, W \quad (3)$$

Where W= moisture content

The wet-basis moisture content of sliced tomatoes (W_{in}) and dehydrated tomatoes (W_{out}) is given by (Green and Perry, 2008):

$$Win = \frac{F_{water}}{(F_{water} + F_{rt\,in})} \text{ -} \quad (4)$$

$$W_{out} = \frac{F_{dry}}{F_{dry} + F_{rt\,out}} \quad (5)$$

$$\Delta HT = F_{rt}\, C_{P\,rt}(T_{in} - T_{out}) \quad (6)$$

$$\Delta Hdt = F_m C_{pw}(T_{in} - T_{out}) \quad (7)$$

$$\Delta Het = -G_{evaporated} * \Lambda_{vapourization} \quad (8)$$

$$\Delta Hdry = F_{wout} * C_{p\,rt}(T_{in} - T_{out}) \quad (9)$$

$$\Delta Hct = F_{dt} * C_{p\,rt}(T_{in} - T_{out}) \quad (10)$$

Where: $\Delta HT = Change\ in\ enthalpy\ of\ raw\ tomatoes$

$\Delta Hdt = change\ in\ enthalpy\ of\ tomatoes\ in\ the\ dryer$

$\Delta Het = change\ in\ enthalpy\ of\ evaporation$

$\Delta Hdry = change\ in\ enthalpy\ of\ dehydrated\ tomatoes$

$\Delta Hct = change\ in\ enthalpy\ of\ cooled\ tomatoes$

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3. Results and Discussion

3.1. Process Flowchart

Figure 3 showed the proposed flowchart for the dehydrated tomato plant. The process flowchart showed a chronological sequence of processing dehydration of fruits and vegetables with a classification into pre-dehydration and post-dehydration. Pre-dehydration involves sorting, washing, and shredding/slicing then dehydration, while post-dehydration includes milling/grinding, mixture for soups, inspection and packaging (Adegbola et al., 2012).

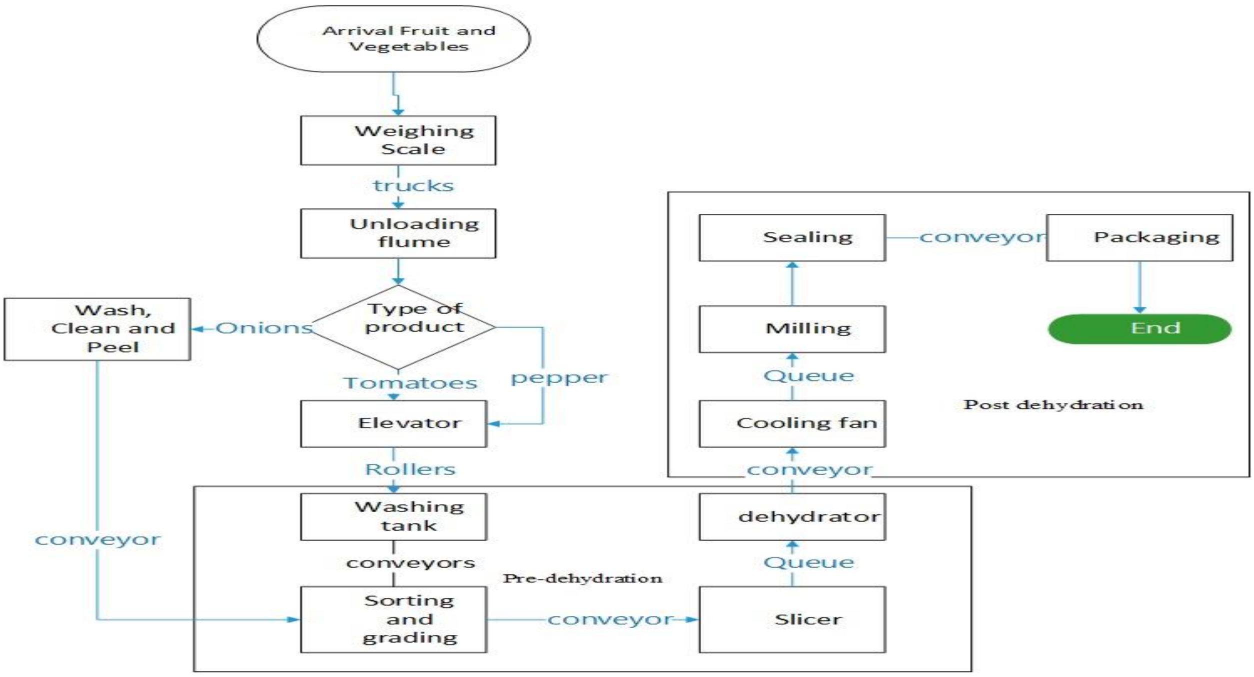

Figure 3: Proposed process flowchart for dehydration of fruit and vegetables processing plant.

The process block diagram (PBD) in Figure 4 highlighted the sequentially breakdown of material losses from each workstation in a flowchart form indicating the minimum losses in each step of operations and expected product output (George and Athanasios, 2002).

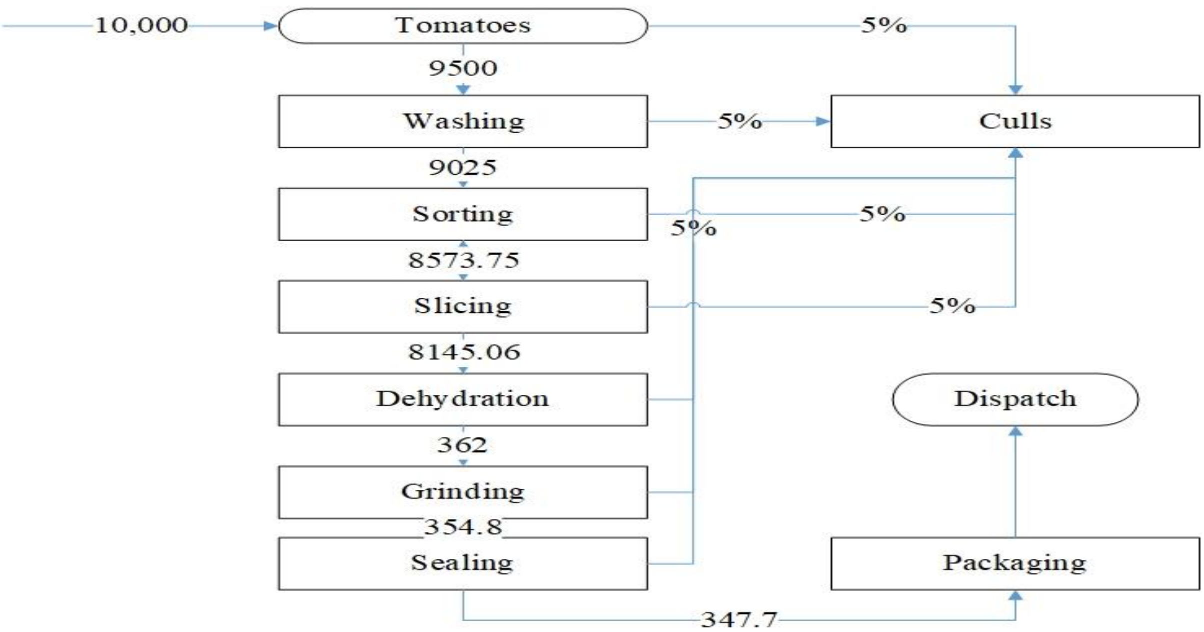

Figure 4: The simplified process block diagram (PBD) for dehydration of tomatoes

3.1.2. Activity Relationship Chart

Figures 5 and 6 highlight the workflow diagram of materials flow between workstations numbered sequentially and the relationship between pairs of activities preceding in a process operation, with intersections to two dividing lines showing a letter that symbolizes the importance of their closeness between each other as shown in Table 2. This enables the selection of optimal sequencing with the corresponding block layout (Carlo et al., 2013; Sutari and Sathish Rao, 2014).

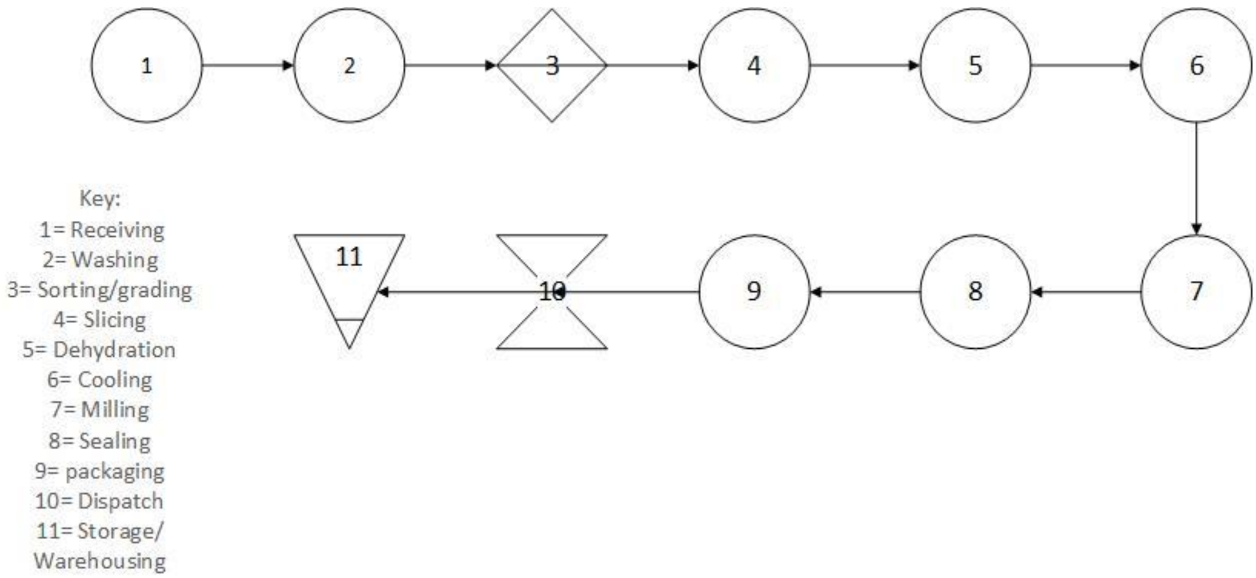

Figure 5: Workflow diagram

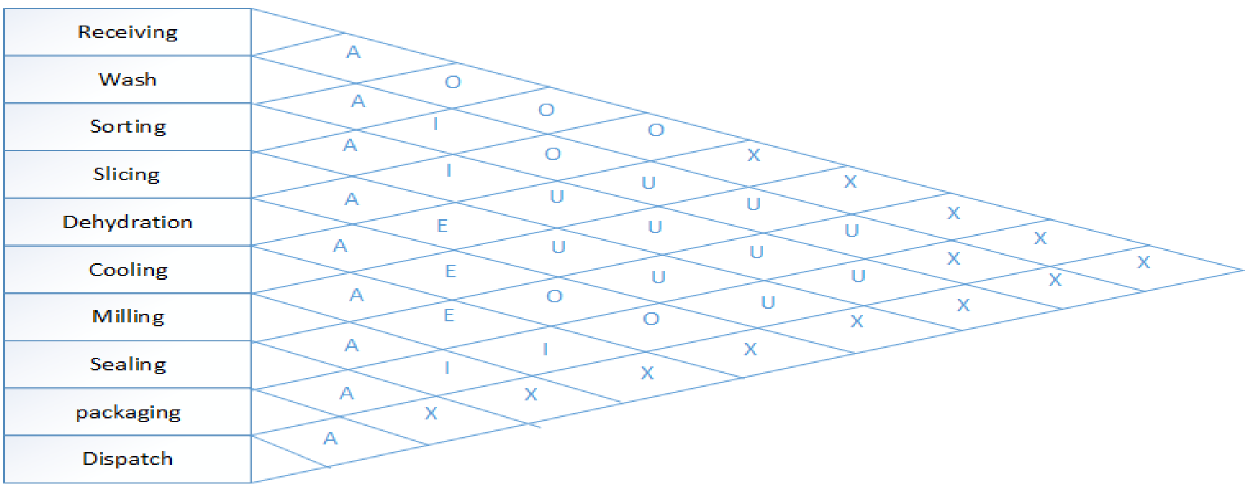

Figure 6: Activity relationship chart for tomato dehydration

3.3. Space Requirements

The data were compiled to obtain the distance of material flow between departments and then transformed these data into closeness ratings as seen from Table 3 presents the space requirement for each department in relation to equipment and space requirement by each machine. The data help in designing an effective layout (Sutari and Sathish Rao, 2014).

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Table 3. The relationship between equipment size and work area

S/N	DPT	Size (m^2)	No of Equipment	Area (m^2)	Total Area Required (m^2)
1.	RP	1.20	2	2.40	10.80
2.	WN	1.93	2	3.86	9.86
3.	PL	2.20	2	4.40	10.40
4.	ST	1.77	2	3.54	9.54
5.	SL	1.16	2	2.32	8.32
6.	DH	7.23	3	21.69	25.69
7.	ML	1.20	2	2.40	8.40
8.	SE	3.30	1	3.30	7.30
9.	PK	1.32	1	1.33	5.33
				Total	95.64

DPT= Department, RP= Receiving pond, WN= Washing, PL= Peeling, ST= sorting, SL= Slicing, DH= Dehydration, ML= Milling, SE=Sealing, PK= Packaging

3.4. Dimensionless Block Diagram

Dimensionless block diagram in Figure 7 was designed from the Activity relationship chart. It ignores the space requirements and building limitations. The focus behind is to gives a better understanding in designing an effective layout, it elaborates the need for workstations to be arranged in a manner to maximize productivity and utilize space (Carlo et al., 2013). Figure 8 showcase the proposed floor plan of the plant, which is expected to have two production lines, with processing equipment

3.5. Mass and Energy Balances

The study showed approximately 8145.06 kg of tomatoes were sent to the three dehydrators each with a capacity of 3000 kg, with around 7783.06 kg mass of water removed. Dehydration process lowered the moisture content to a level were microbial activities will not easily affect the final product and further extend its shelf life, the estimated enthalpy changes of raw tomatoes, enthalpy of dehydrated tomatoes and specific heat capacity of tomatoes were 148162 kJ/h, -12229.2 kJ/h, and 1.6985 kJ/kg K these values signify the rate at which moisture is removed from the surface of tomatoes, it is affected by the setup temperature and pressure (Correia et al., 2015), the calculations done were at 65°C, as the temperature range was found to be effective temperature for dehydrating tomatoes (Rasool et al., 2013), higher or excessive temperatures increases the oxidative damages, affect ascorbic acid content, flovour, colour and nutrients of the final product (Zanoni et al., 1999., Correia et al.. 2015, Rasool et al., 2013). Work-study calculations were ommited because of limited number of pages, however, the production time was calculated as 748.99 minutes per day, the capacity and effectiveness of the dehydrated tomato plant was also validated using computer simulation software to address the issues of work-in-process, capacity utilization, effective design and throughput of the plant were reported in Abdulhakeem et al. (2020).

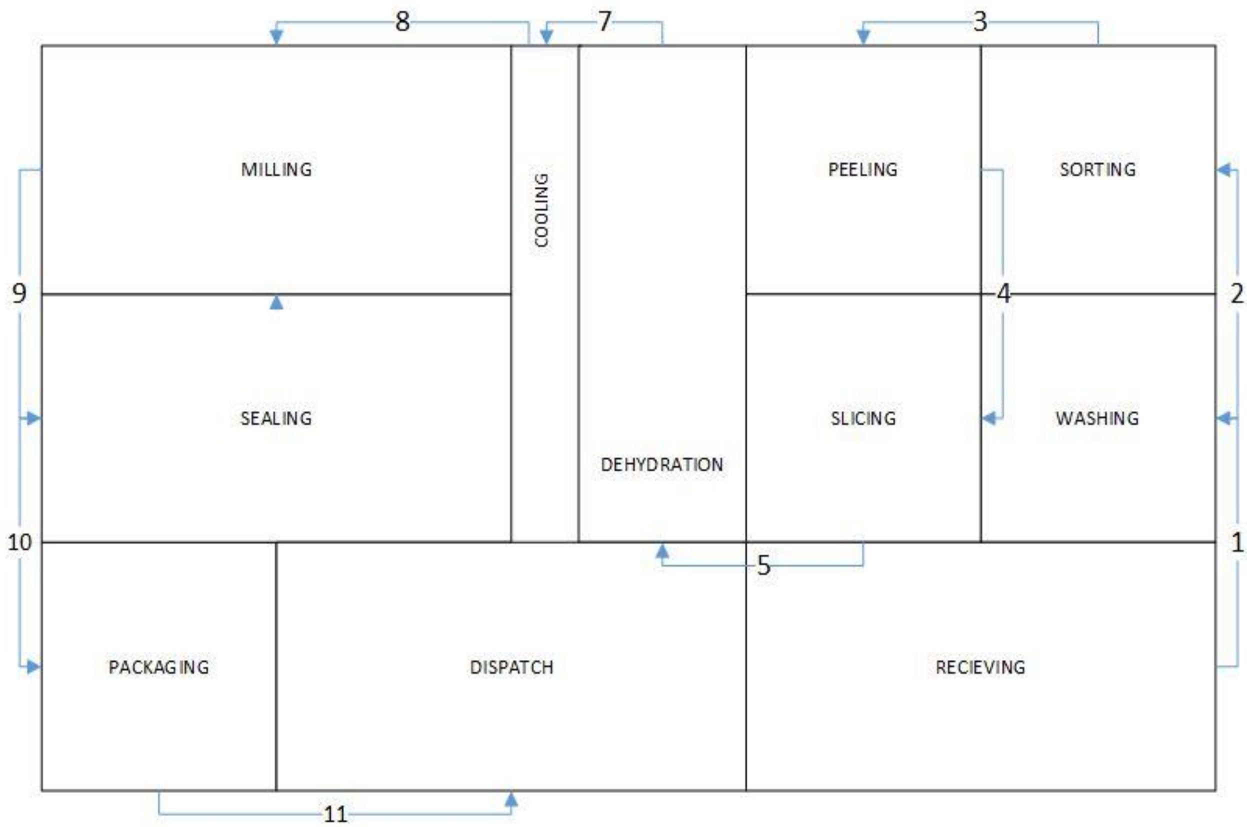

Figure 7: Dimensionless block diagram for the proposed process layout

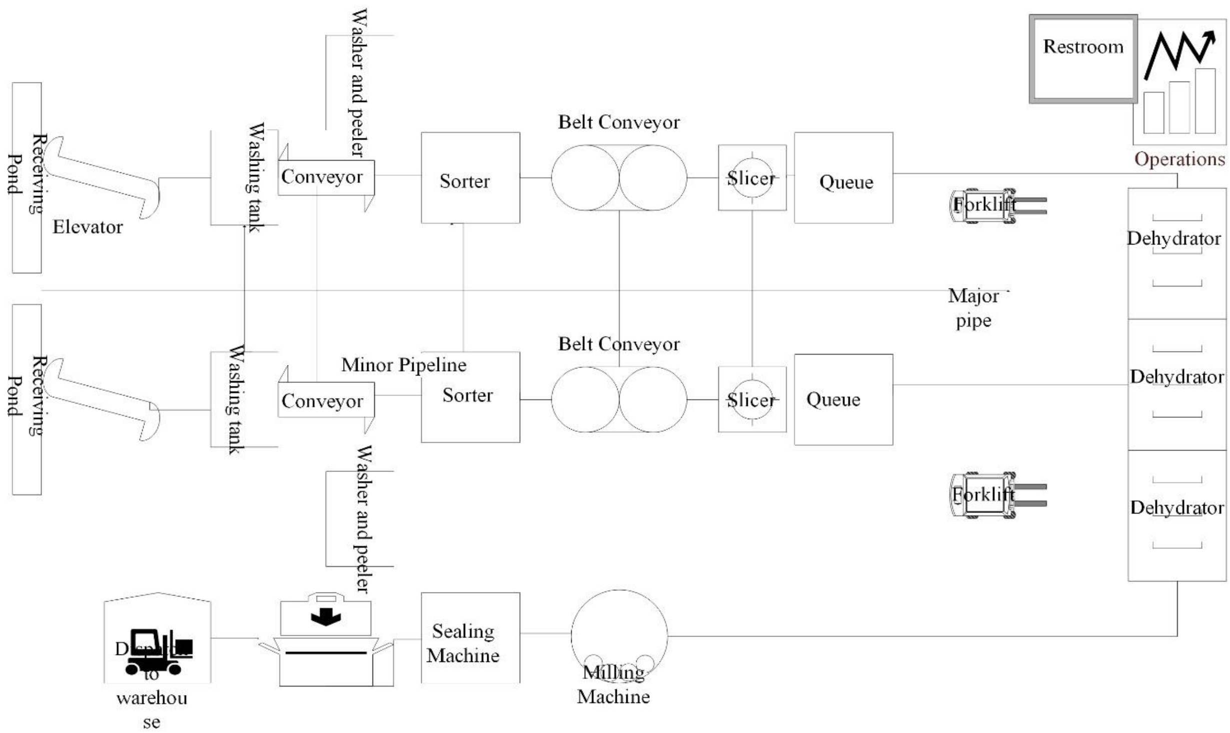

Figure 8: Floor plan for processing of dehydrated fruit and vegetables

4. Conclusions

Facilities are designed to improve the efficiency of production, reduced costs of handling and increased return on investments. The plant was designed to have two production lines, throughput capacity of 10,000 kg/day with an estimated operation time of 748.99 minutes (12hrs 48 minutes) of production cycle time. The design was validated using computer simulation to check for the effectiveness and productivity of the design.

If fully implemented in Nigeria, the design will provide means of improving the current postharvest handling challenges ravaging the fruits and vegetables value chain through production of dehydrated tomatoes with longer shelf life.

The plant should also be tested for processing of other fruits and vegetables such as mangoes, pepper and onions.

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