Optimizing Dairy Plant Layout Using CRAFT: Enhancing Space Utilization, Efficiency, and Productivity

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Abstract

Poor aisle configuration on the production floor results in congestion of men and machines, accidents that may lead to serious injury, and consequently, an overall loss in productivity. There is a need to prevent the incessant wastage of a huge number of resources, revenue, and production time as a result of the serial production shutdown, congestion on the floor, and poor space utilization. This research aims to improve the plant layout of a dairy company to ensure optimum space utilization, eliminate obstructions in material flow, and thus obtain maximum efficiency and productivity. Data such as the present layout of the production plant was obtained from the design section of the company Flow process chart of the production process was studied and analyzed using facility layout design concepts, and the proposed layout was developed using the Computerized Relative Allocation of Facilities Technique (CRAFT).

On the proposed layout, a free space of 1620m^2 which has the capacity for 997 jumbos, with a layout efficiency of 91%. Comparing the layouts, the proposed layout gives a better space utilization of 50.95% increase in storage capacity (from 489 jumbos to 997 jumbos), and the distance travelled was reduced from 457.24m to 172.20m. which is 62.36%, production time by 7.8% and the material handling cost by 6.2%. This improved space utilization gives room for future expansion and more space for a temporary storage point.

Keywords

Facility Layout Planning, Productivity, Efficiency, Space Utilization, Graph Theory, Computerized Relative Allocation of Facilities Technique (CRAFT)

1. Introduction

Facility planning is concerned with the design, layout, and accommodation of people, machines, and activities of a system or enterprise within a physical spatial environment. Facility planning is very important in a manufacturing process due to its effect on achieving an efficient product flow, better space utilization hence, enhancing higher productivity [1]. A good facility layout is necessary for efficient production and complete organizational performance. The study showed that the location, materials flow, and the machinery or capital expenditure were the most important factors for effective plant layout. On the other hand, improper facility layout design results in poor consumption of space, giving little space for the availability of a temporary storage point for resources, which results in congestion of the production floor [2]. Major transportation into and out of the production area using forklifts without well-programmed operations also leads to congestion on the production which often leads to accidents and sometimes serious injuries to the workers. It is estimated that between 20%-50% of the total costs in manufacturing are related to material handling, yet his cost can be reduced by 30% through effective facility planning [3]. Proper analysis of facility layout design could improve the performance of production lines, such as decreasing bottleneck rate, minimizing material handling cost, reducing idle time, raising the efficiency and utilization of labour, equipment, and space [4]. The mechanism of the design of facility planning is quite complex and broad, depending on the size of the plant and scale of operation. The hierarchy of the planning is presented in Figure 1.

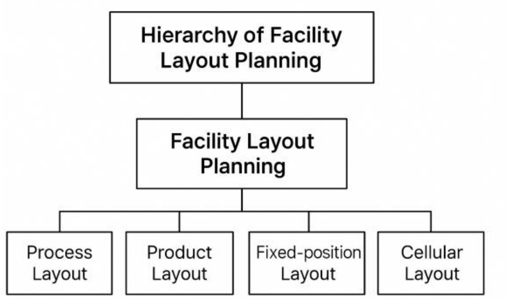

Figure 1. The hierarchy of facility Layout Planning.

The stakeholders [5] in the field of facility layout planning proposed a measurement model for the determination of any facility's layout's effectiveness using some factors that were considered significant. The three layout factors include facilities layout flexibility (FLF), closeness gap (CG), and productive area utilization (PAU). Many studies have been carried out by different authors based on Facility layout problems. Many of these studies have been directed to finding optimum facility design[5,6]. Heuristic methods for layout optimization are Tabu Search (TS), Simulated Annealing (SA), and Genetic Algorithms (GA). Besides the heuristic methods, the simulation technique is also recommended for optimizing facility design. Researchers [6] define in their review different types of facility layout problems (FLP) and discuss various problem formulation methods. They also discussed different facility problem-solving techniques with more emphasis on dynamic facility layout problems, derived a rough tree structure to present an idea of different considerations while developing a plant layout, and analyzed layout design of facilities with unpredictable demand and capacitated machines in stochastic environments where demand is unknown. Their study reveals that a distributed layout reduced the total expected cost of handling materials subject to manufacturing facilities arrangement within a plant. Another research work [7-9] provides a review of multi-criterion facility location problems and has categorized multi-criterion facility problems into three categories, which are bi-objective, multi-objective, and multi-attribute. They also discussed the methodology to be used to solve these categories of problems. Some researchers [10] discussed a new type of multi-stage, dynamic facility layout problem under a business environment that is considered dynamic, meaning that fresh machines may be added to and used/old machines may be removed from the plant. Presented recent advances in facility allocation using a dynamic modelling approach. They argued that in any organization, productivity, efficient material flow, and closeness rating factors are important variables required to optimize the design of the production cell layout. Researchers [11] researched the architecture of a plywood manufacturing company based on the Systematic Planning (SLP) theory for productivity increase. The results showed that the meta-heuristic approach to effective layout design is extremely successful and efficient in terms of the solution's performance. Scholars addressed FLP using many techniques; [12] proposed a bottom-up multi-objective optimisation approach to dynamic facility layout planning; [13] suggest a digital Facility Layout Planning to enhance a sustainable and productive working environment; [14] proposed a grouping matching approach using Genetic Algorithm for Dynamic Cell Layout Designs; [15] explore the use of . layout map in facility layout planning with a fuzzy methodology; [16] proposed an optimizing algorithm for facility layout planning for reconfigurable manufacturing systems based on chaos genetic algorithm; [17] suggest Deep Learning method for multi-facility location mechanism design; [18] proposed a MASS-Modified Assignment Algorithm in Facilities Layout Planning as an integrated approach that allows for even more detailed layout planning by analyzing network arrangements and routes or transport at the same time. These methods allow the mapping of unusual fixed machine types in detail, allowing a design for a dynamic demand environment for robust facility set-ups. They took costs that come along with the interruption of production into consideration alongside other general costs (total material handling cost and re-arrangement cost) to solve dynamic layout problems. This approach attempts to significantly reduce total material handling costs using a layout based on the assumption that production interruption and rearrangement costs are quite high, and hence, this approach tries to minimize the total material handling costs in all periods using a single layout.

The result, practically, showed that disassembly to allow free material movement, reduction in the distance traveled by men and materials, minimizes accidents, and increases productivity. One of the tools in FLP is the Computerized relative allocation of facilities technique (CRAFT) [19-21]. It is used for reallocation purposes, which starts with an initial layout and improves the layout by interchanging the department pair-wise so that the transportation cost is minimized. The algorithm continues until no further interchanges are possible to reduce transportation cost. CRAFT requirements are initial layout, flow data, cost per unit distance, and total number of departments, fixed departments, and areas of the departments. The various techniques and tools used in FLP are still evolving; all these efforts have revolutionized the field of facility layout design. This work is aimed at re-designing a diary manufacturing plant, is restricted to the evaluation and analysis of the existing layout of the production area, as well as the interaction between the warehouse and the production floor (material flow). The existing layout of the firm is presented in Figure 2:

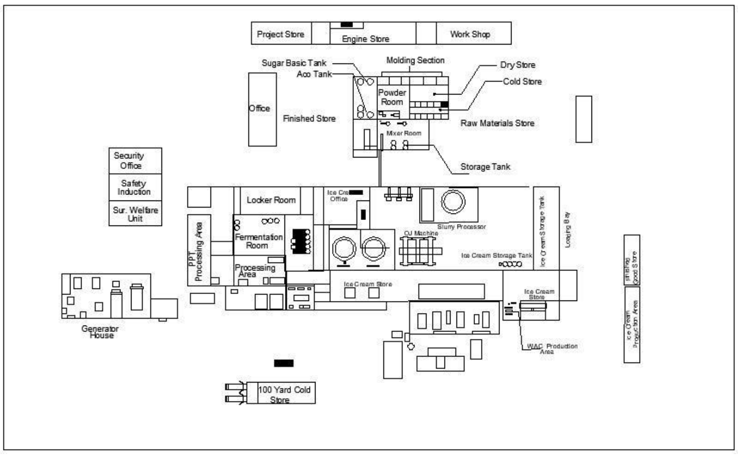

Figure 2. Diagram of the existing layout of the firm.

2. Materials and Methods

2.1 Data Collection

The data from a diary firm in Ibadan, southwest Nigeria, is used in this work. Data such as the present layout of the production plant was obtained from the design section of the company. The distance between the departments was measured. The area of different departments was measured. The cost of transporting the material from one department to another was obtained. Data concerning the volume of materials handled and the degree of paperwork between departments was also obtained. The tools used are the from-to-chart, from-between chart, activity relationship chart, and activity relationship diagram.

2.2 Layout Design

The existing layout design is such that the facilities are arranged according to the sequence of operation in which the products are made. This implies that the layout is of the Product type design layout. Changes were made in the positioning of the workstations, and the proposed layout was also of the product type. The changes were aided by the activity relationship chart. These changes were made to improve material flow, working conditions, resulting in better performance and arrangement of facilities.

2.3 Computerized Relative Allocation of Facility Technique (CRAFT)

CRAFT involves the implementation of layout evaluation to compare the existing layout and the designed layout using the layout efficiency rating (LER). LER is the ratio of the adjacency score and the maximum possible adjacency score. Adjacency means that they share a border, not corners. The higher the efficiency rating, the better the layout

3. Methodology

3.1 Flow Matrix Analysis

This phase aggregates all the flow of material between departments to decide the flow intensities. The materials transferred among the departments are of different sizes and shapes. There are different types of materials which are: sugar, milk, the mixed product, pasteurized product, packaging materials (jumbo bags, rolls e t c), and finished product (scanico, ppf1, ppf2).

Table 1. Generated total flow matrix for the production floor.

	Raw Material Store	Mixer	Pasteurizer	Storage Tank	Packaging Material Store	Packaging Machine	Scaniko	PP F1	PP F2	LR Storage
Raw Material Store	---	145	0	0	0	0	0	0	0	0
Mixer		------	137	0	0	0	0	0	0	0
Pasteurizer	0	0	------	137	0	0	0	0	0	0
Storage Tank	0	0	0	------	0	137	0	0	0	0
Packaging Material Store	0	0	0	0	------	480	0	0	0	0
Packaging Machine	0	0	0	0	0	------	356	1477	1395	0
Scaniko	0	0	0	0	0	0	------			356
PPF1	0	0	0	0	0	0	0	----		1477
PPF2	0	0	0	0	0	0	0	0	-----	1395
LR Storage	0	0	0	0	0	0	0	0	0	------

3.2 Area of Each Department

When the necessary space is determined by the position of the departments, additional space should be provided for the movement of the workers, material handling, loading and unloading of goods, maintenance requirements, etc., in addition to the area needed for installing machines in that department. Growing department's length and width are derived from current formats and specifications, as shown in Table 2.

Table 2. The space allocation for each department.

S/N	Department	Area (m2)
1	Raw material store	864
2	Mixer	540
3	Pasteurizer	432
4	Storage tank	72
5	Packaging machine	180
6	Packaging material store	288
7	Scanico freezer	216
8	Ppf1 freezer	144
9	Ppf2 freezer	144
10	LR freezer	1360
11	Production floor	4240
12	whole building	5860

3.3 Activity Relationship Analysis

Activity relationship analysis latches onto the relationship among departments to arrive at a closeness rating. The values from the between-charts are converted into a closeness rating. To draw the chart, the highest value in Table 2 was divided by 4 to give 4 ranges. The ranges are attributed to five alphabets, which are A, E, I, O, and U. The alphabets denote the closeness rating of the relationship among the departments. The activity relationship chart is presented below in Figure 3. The closeness rating means:

1.A-Necessary: 1477-1109 2. E-Especially important: 1108-739
3.I-Important: 738-369 4. O-Ordinary closeness: 368-1
5.U-Unimportant: 0

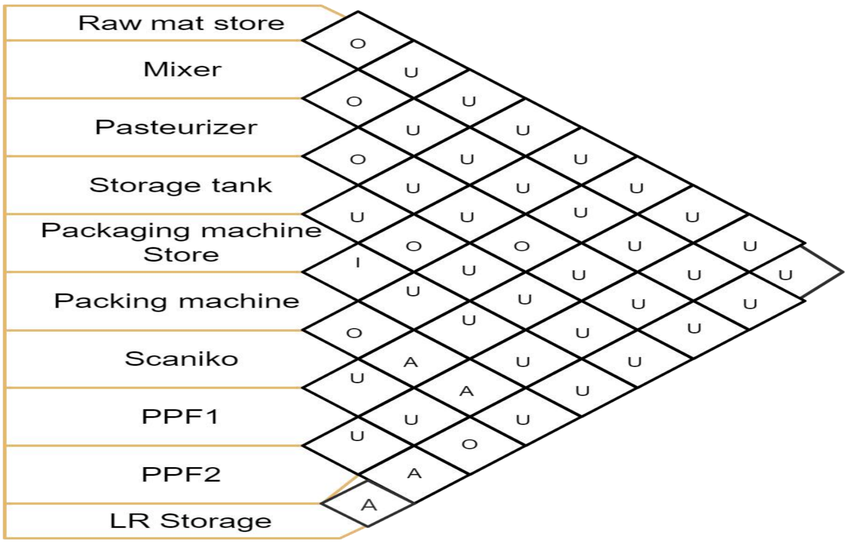

Figure 3. The activity relationship chart.

3.4 Activity Relationship Diagram

The operation relationship in the activity relationship chart (Figure 3) shows the strength of the information flow between the departments. It facilitates position decision-making. Departments that have high material flow intensity should be located near each other, while departments with no material flow should be sited far from each other. In Figure 4, the activity relationship diagram consists of numbered boxes and lines. The lines represent the material flow intensity, and the boxes represent the department. The activity relationship diagram is derived from the activity relationship chart that was drawn previously in Figure 3. The closeness ratings are represented by lines. They are represented as follows:

A= Four lines, E= Three lines, I= Two lines, O= One line, U= No line.

Figure 4 shows the activity relationship diagram of the initial layout. In this diagram, it can be deduced that departments 6 (packaging machine) and 8 (ppf1) intensely interact, likewise departments 9 (ppf2) and 10 (LR storage). It can also be seen that there is a break in the trend of interaction between departments 4 and 5. This is because department 5 starts another production line (packaging), which does not interact with the first. After iterating the layout, another activity relationship diagram, all activities with a high closeness rating are moved close to one another.

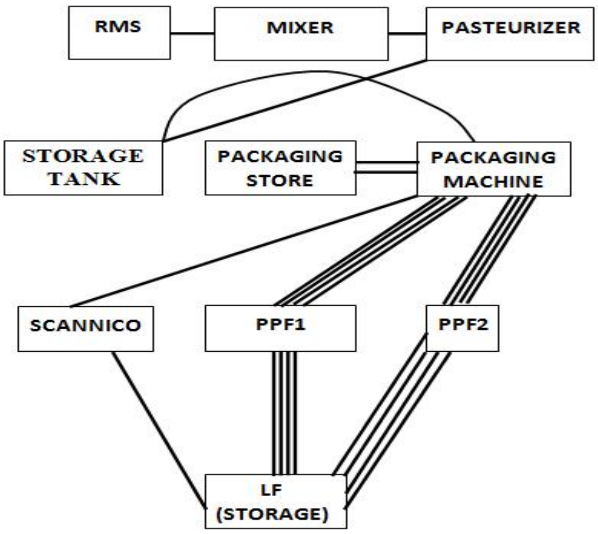

Figure 4. Initial activity relationship diagram.

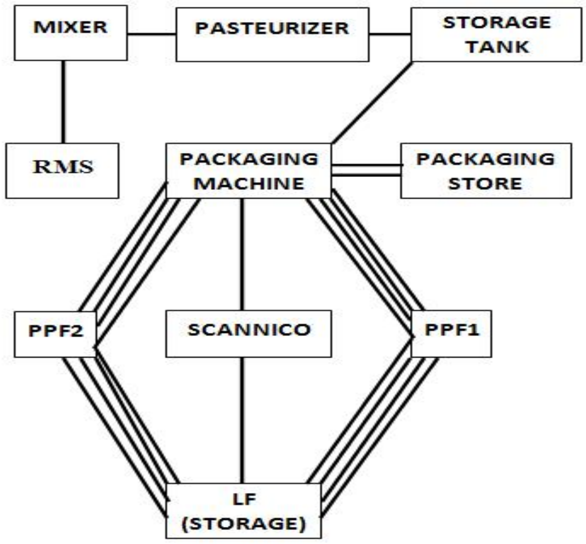

Figure 5. Final activity relationship diagram.

3.5 CRAFT Implementation

After a thorough assessment and evaluation of the existing layout at the plant, it became immediately apparent that a huge amount of revenue and production time had been wasted and lost as a result of the serial production shutdown, congestion on the floor, and poor space utilization. These problems grossly affect production efficiency. The activity relationship diagram in Figure 5 is derived from the activity relationship chart that was drawn previously in Figure 4. The closeness ratings are represented by lines. They are represented as follows;

A= Four lines, E= Three lines, I= Two lines, O= One line, U= No line.

Figure 4 shows the activity relationship diagram of the initial layout. In this diagram, it can be deduced that departments 6 (packaging machine) and 8 (ppf1) intensely interact, likewise departments 9(ppf2) and 10 (LR storage). It can also be seen that there is a break in the trend of interaction between departments 4 and 5. This is because department 5 starts another production line (packaging), which does not interact with the first. After iterating the layout, another activity relationship diagram is drawn, and all activities with a high closeness rating are moved close to one another.

Table 3. Departments notation.

Departments	S/N
Raw Store	1
Mixer	2
Pasteurizer	3
Store Tank	4
Packaging Machine	5
Packaging Material Store	6
Scanico	7
PPF1	8
PPF2	9
LR Store	10

3.7 The Calculation of Layout Efficiency

Layout efficiency is calculated by using equation 1 to determine the evaluation for both the designed and existing layouts. The layout efficiency ratio is calculated using equation 2.

$$\sum_{j}^{m} f \sum_{j}^{m} \sum_{j} P(i,j) x_{ij} \quad (1)$$

$$\text{LER} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} x_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij}} \quad (2)$$

$x_{ij} = 1$ if the departments are adjacent.

$x_{ij} = 0$ if the departments are not adjacent.

LER: layout efficiency rating.

4. Result and Discussion

4.1 Data Analysis and Presentation

The flow data is shown in a from-to chart in Table 4.1 below. The numbers shown in the cells indicate the average number of unit loads transported from the departments in the vertical column to the departments in the horizontal row for a month. For example, 145-unit loads are transported from the raw material store to the mixer every month. The data is taken from materials movements between departments, averaged over a period of 12 months. The layout efficiency rating computed, the proposed layout has a higher efficiency of 0.909 compared to 0.727 of the existing layouts. The proposed layout shows that there are still enough spaces left out in the building to cater to other facilities and, if possible, expansion of certain departments to provide ease for supervision and quality check. The proposed layout enhances a space utilization of 27.64% instead of 13.8% of the existing layout. The final optimized layout diagram, the optimized layout with minimal cost generated through CRAFT, is presented in Figures 6 and 7.

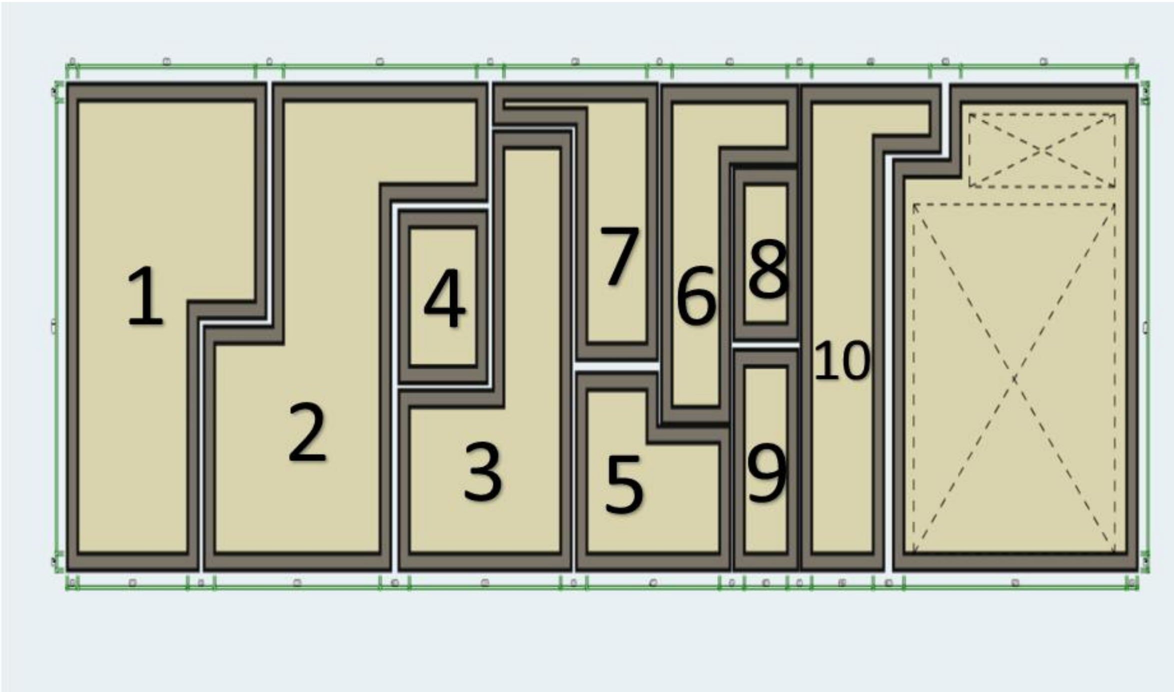

Figure 6. Optimized layout Diagram.

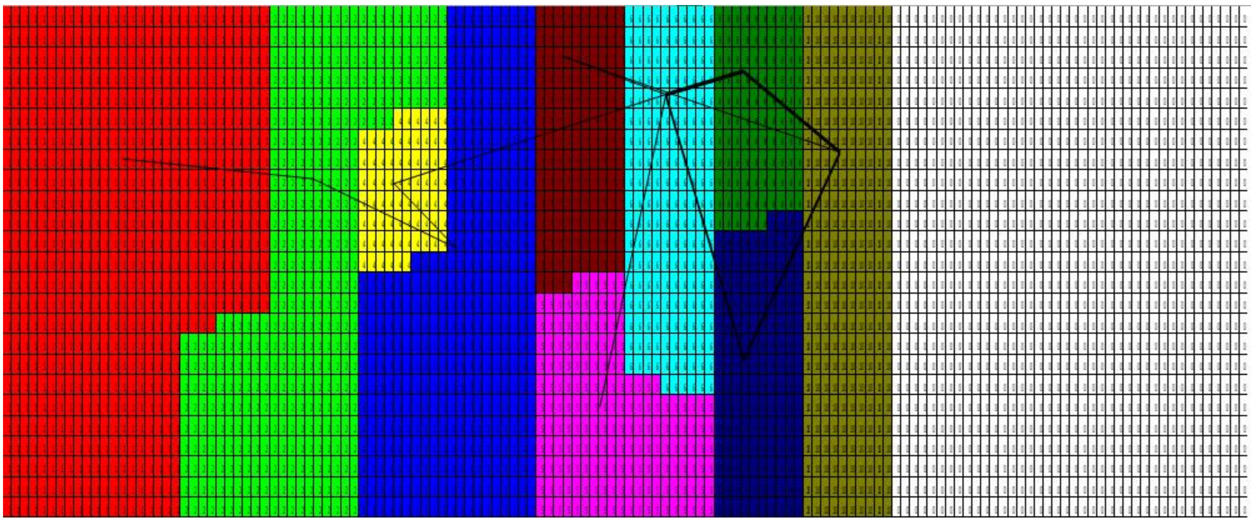

Figure 7. The optimized layout with minimal cost generated through CRAFT.

5. Conclusion

This paper has redesigned the layout of the dairy company. This was carried out using facility layout concepts. It was discovered from the analysis that some departments that have high material flow intensity are at far distances from one another, which leads to an increase in production time. The new proposed layout was developed to improve the existing layout according to the activity relationship optimized layout was developed using craft to improve the existing layout. This improved space utilization and gives room for future expansion and more space for a temporary storage point. On the proposed layout, a free space of 1620m^{2,} which has the capacity for 997 jumbos, with a layout efficiency of 91%. Comparing the layouts, the proposed layout gives the best properties and advantages: the highest space utilization of 27%, storage capacity (from 489 jumbos to 997 jumbos), and the distance travelled was reduced from 457.24m to 172.20m. This research only applied facility layout design concepts to solve a dairy production plant's problem. An in-depth discussion was not conducted to derive an optimum land size for establishing such a company. Therefore, further study should be conducted to get the optimum land size that can be used to establish a double production line, all things being equal.

6. Acknowledgement

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7. Conflict of Interest

There is no conflict of interest.

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