Analysis of Plant Layout Design for Operational Efficiency with Craft Algorithms

Olusegun Kazeem Lekan[1], Olaoye Ismail Kayode[2], Abdulrahaman Abdulrazaq Morenikeji[3]

Abstract: This paper presents an exhaustive analysis of a pulley factory layout design for operational efficiency and effective production. Focusing exclusively on the pulley factory layout problem in a Thai factory, this study applies Craft algorithm to analyse the layout and arrive at an effective design. The analyses reveal that CRAFT algorithms ease free flow of materials and personnel at the least cost, minimize distance travelled and improve the original layout by twenty percent (32%). For this reason, the new layout design witnesses flexible operations, effective functionality, and meet cost savings objectives. Therefore, it is recommended that operation managers should adopt the Craft algorithm program to overcome material flow obstruction and ineffective operations resulting from ineffective layout designs.

Keywords: Pulley Factory Layout Design; Operational Efficiency; Material Handling Cost; Distance Travel; Craft Algorithm

JEL Classification: C12; C18; C52; C55

1. Introduction

Plant or facility layout design refers to a plan of an optimum arrangement of facilities including personnel, operating equipment, storage space, material handling equipment and all other supporting services along with the design of the best structure to contain all these facilities (Moore,1962; Telsang, 2007). It is one of the most significant current discussions in production and operations management. A good layout design well suited to the manufacturing philosophy is a sine qua non for

[1] Department of Business Management, Faculty of Management Sciences, Federal University, Dutsinma, Katsina, Address: P.M.B. 5001, Katsina State, Tel.: 0803 511 8202, Corresponding author: kolusegun@fudutsinma.edu.ng.

[2] Department of Business Management, Faculty of Management Sciences, Federal University, Dutsinma, Katsina, Address: P.M.B. 5001, Katsina State, Tel.: 0803 637 0779, E-mail: iolaoye@fudutsinma.edu.ng.

[3] Department of Business Management, Faculty of Management Sciences, Federal University Dutsinma, Katsina, P.M.B. 5001, Katsina State, Tel.: 0803 621 3294, E-mail: aabudulrahaman@fudutsinma.edu.ng.

effective production and efficient operations in any organization. The objective being to have quick and easy flow of material at the lowest cost and with the least amount of handling in processing the product from the receipt of material to the shipment of the finished product (Singh & Sharma, 2006; Tompkins, 2003), increase output and facilitate the control of information and material flows (Fu & Kaku, 1997; Parveen & Ravi, 2013), and decrease the work in process (WIP) and the throughput times (TT) (Asking & Standridge, 1993).

However, many organizations especially manufacturing firms suffer from a number of operational constraints owing to poor layout design. For example, a poorly conceived layout can also result in congestion, prohibitive material handling cost, increased accidents, decreased inventory space (Banjoko, 1998; Vaidya, 2013) or it can lead to accumulation of work in process inventory, overloading of material handling system, inefficient setups and material flow obstruction (Anucha, Phichit, Patcharee & Wisitsree, 2011). The implication is that 20% to 50% of total operating manufacturing costs related to material handling activities could be increased by 10% to 30% annually with inefficient facility layout design (Filippo, Maria, Orlando & Mario, 2013).

A number of study have attempted to explore the influence of facility layout design on operational efficiency in some manufacturing firms (Anucha et al, 2011; Drira, Pierreval & Gadony, 2007; Pinto & Shayan, 2007; Tao, Wang, Oioao & Tang, 2012; Telsang, 2007; Vaidya, 2013; Yifei, 2012). This study is an extension of the work carried out by Anucha et al, (2011) with emphasis on quantitative analyses of facility layout design. Anucha et al's work was descriptive in nature lacking quantitative support and largely based on intution. This paper is presented in five sections. Initial introduction is followed by review of relevant literature on facility layout design and operational efficiency. Section three explains the methodology of the research while section four analyses the original layout with Craft algorithm. Section five discusses the results and concludes the paper.

2. Literature Review

The subject of plant layout design and organisation operational efficiency has aroused the interest of many research scholars. In 1991, Francis & White surmised that proper analysis of the layout design is a vital prerequisite for running an efficient and cost effective business. They concluded that effective layout design is the result of an improvement in any production line. This necessitates sufficient evidence in the literature to suggest that optimising plant layout can improve safety and quality of products, ease free flow of materials and personnel, and thereby enhance organisations operational efficiency (Apple, 1977; Banjoko, 1998; Hassan & Hogg, 1991; Muther, 1995; Pinto & Shayan, 2007).

The efficiency of operations and production depends on how well the various machines, services production facilities and employee's amenities are located in a plant. Parveen & Ravi (2013) established this evidence in their study on a review of metaheuristic approaches to solve facility layout problem, that Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Tabu Search (TS) are used to optimize the multi-objective layout problem. They added that facility layout directly depends on safe movement of personnel and machine between and within departments. The study affirmed that intelligent optimization approaches enhance minimization of material handling cost, ease free flow of materials at the least cost, and minimise total closeness between machines/departmental and total distance travelled. In another study, Yifei (2012) analysed facility layout design with random demand and capacitated machines in a stochastic environment where demand is uncertain. The study reveals that distributed layout minimized the total expected material handling cost subject to arrangement of production facilities within a plant.

Some scholars have argued that efficient material flow and closeness rating factors are two common variables necessary for optimum design of manufacturing cell layout in any organization whose management philosophies are productive and efficient operations. For instance, Ghosh & Dan (2012) addressed the problem of manufacturing cell formation using simulated annealing metaheustic approach. The findings showed that metaheuristic approach is extremely effective and efficient in term of solution quality for designing effective layout. Corroborating this view, Vaidya (2013) in a study of plant layout design asserted that a good facility layout is essential to efficient production and complete success in an organisation. The study showed that the most important factors for effective plant layout were the location, materials flow and the machinery or capital investment. The reason is because capital investment requires huge amount of money. If layout planning is done poorly, the company would incur losses which would affect growth. Even if the correct machineries were bought, maintenance cost could be high.

Aligned with the foregoing, Anucha et al (2011) presented analysis of plant layout for effective production in a pulley factory in Thailand. They observed obstruction in material flow caused by poor layout design. The plant layout, operation process of each section and the materials flow of each operation were identified. Theoretically, the result showed that disassembly surface, finishing and inspection sections should be arranged to enhance free flow of materials, minimize accidents and distance travelled of materials, and thereby increase productivity. Consequently, the piece that seems to be missing from the work of Anucha et al (2011) is the quantitative support for the subject matter. This is the basis of this study and the gap this research intends to fill.

3. Research Methodology

3.1. Modelling Approach

The main objective of this study is to provide a quantitative analysis of the pulley factory layout design for effective production and operations. Specifically, the study examines how material handling system, material flow and distance travel of material improve productivity and operational efficiency. The study employs the computer-based Craft algorithm to analyse the secondary data adapted from the work of Anucha et al (2011). The main objectives of the Craft program is the minimization of the total cost of distance travelled between facilities. Stated mathematically, we have

$$\text{Min C} = \sum_{i=1}^{m} \sum_{j=1}^{n} \text{fij dij}$$

Where f_{ij} is the number of flows / loads or movements between facilities i and j

dij is the distance covered between facilities i and j (i=1,2, n) (j= 1,2, m).

3.2. The Craft Algorithm: Requirements and Basic Assumptions.

The Craft Program requires the following:

- The initial layout;
- The flow matrix;
- The cost matrix; and
- The number, sizes and locations of departments.

While basic assumptions of the Craft Program assumed in this study include:

- The flow and distance matrices are symmetrical;
- A move from one department to the other costs 1Thai Bayt (Thailand currency);
- No restriction exist as to where a particular department should be sited;
- And movement costs have linear relationship with distance.

4. Analysis of Original Layout with Craft Algorithm

This research focuses on factory layout design and operational efficiency with particular reference to the Thai pulley factory layout problem captured in the work of Anucha et al (2011). The factory adopts process layout design for the initial plant layout as shown in fig 1. Area of each department and the number of equipment/machine movement are presented in Table 1 while Table 2 represents flow of equipment. The operation is described as follows. Initially, metals from scrap yard were moved to furnace for melting, along with core making and store then followed the sand mold, disassembly and furnace finish. The pulleys are investigated by inspection section where work is inspected to know whether the work has defect or not. The work with defect identified will be sorted out while the work with no defect will be sent to warehouse to wait for delivery to customers (Anucha et al, 2011).

Table 1. Area of department and material handling

S/N	Department	Total working area (M^2)	Material handling
1	Scrap yard	33	-
2	Core making	29.4	-
3	Melting casting (furnace)	106.2	6
4	Core store	25.92	-
5	Sand plant	212.4	2
6	Sand mold by machine	386.56	-
7	Disassembly surface	19.47	1
8	Inspection	98.15	-
9	Sand warehouse (packaging)	35	1
10	Raw Material	48.01	-
11	Inventory	2.25	1
12	Sand mold by hand	53.1	-

Source: Anucha et al (2011)

Table 2. Number of equipment and machine movement between departments

To/From	1	2	3	4	5	6	7	8	9
1	-	-	1	-	-	-	-	-	-
2	-	-	-	10	-	-	-	-	-
3	-	-	-	-	-	2	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	2	-	-	-
6	-	-	-	-	-	-	16	-	-
7	-	-	-	-	-	-	-	2	-
8	-		-	-	-	-	-	-	1
9	-		-	-	-	-	-	-	-

Source: Anucha et al (2011)

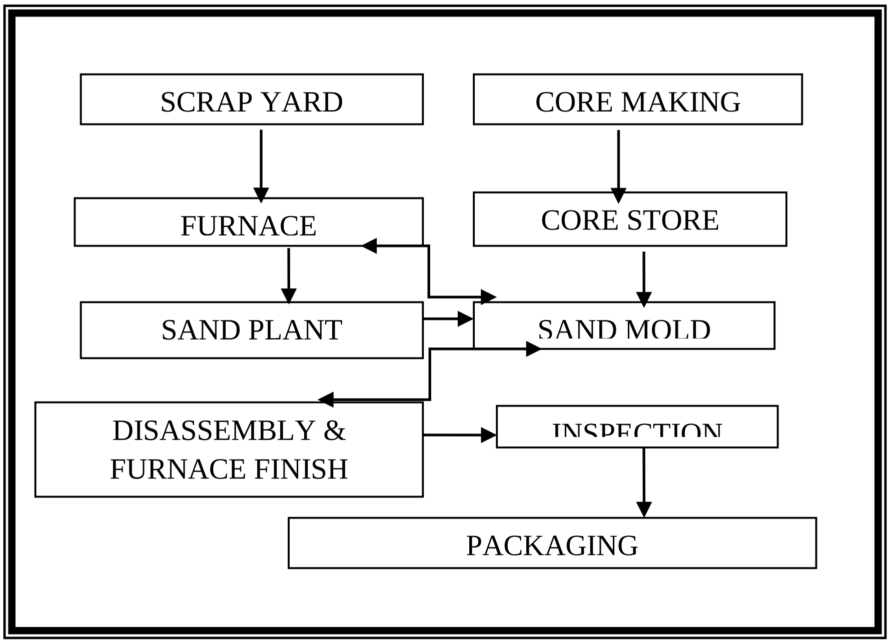

Figure 1. Process layout design (Anucha et al, 2011)

Table 3. Distance matrix of the initial layout

To/From	1	2	3	4	5	6	7	8	9
1	-	1	1	1	2	2	3	3	4
2	-	-	1	1	2	2	3	3	4
3	-	-	-	1	1	1	2	2	3
4	-	-	-	-	1	1	2	2	3
5	-	-	-	-	-	1	1	1	2
6	-	-	-	-	-	-	2	1	2
7	-	-	-	-	-	-	-	1	1
8	-		-	-	-	-	-	-	1
9	-		-	-	-	-	-	-	-

Source: Computed from initial layout presented by Anucha et al (2011)

The initial cost of the original process layout of the pulley factory is calculated first before analysis of craft algorithm is incorporated.

Table 4. Initial Cost Matrix

To/From	1	2	3	4	5	6	7	8	9	Total cost
1	-	0	1	0	0	0	0	0	0	1
2	-	-	0	10	0	0	0	0	0	10
3	-	-	-	0	0	2	0	0	0	2
4	-	-	-	-	0	0	0	0	0	0
5	-	-	-	-	-	2	0	0	0	2
6	-	-	-	-	-	-	32	0	0	32
7	-	-	-	-	-	-		2	0	2
8	-		-	-	-	-	-	0	1	1
9	-		-	-	-	-	-	-	0	0
										B50

The total cost of this initial layout is 50 Thai-Bayt. To improve on this initial layout cost, Craft algorithm is employed to rearrange the department. Departments with the highest cost from the initial cost matrix are relocated closer to each other. As a result, this rearrangement of departments is reflected in the improved layout shown in fig 2 and fig 3 and the corresponding improved layout cost are shown in table 6 and table 8 respectively.

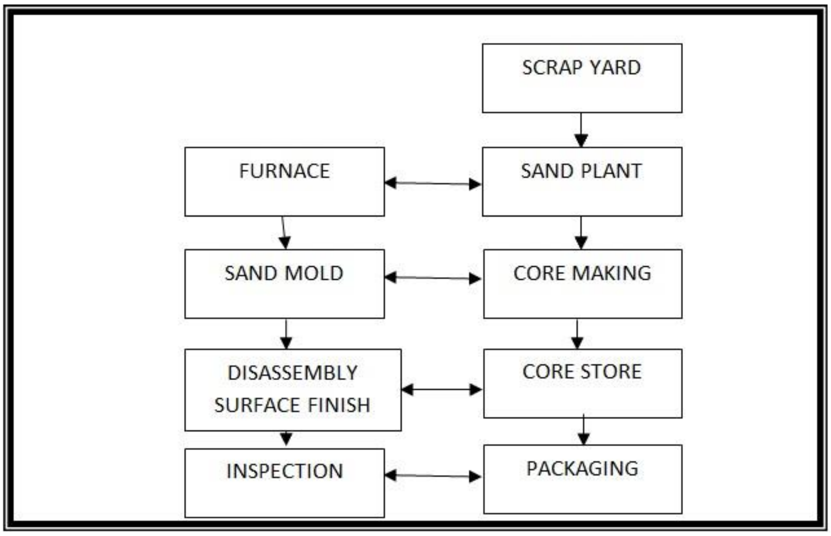

Figura 2. First improved layout

Table 5. Distance of the first improved layout

To/From	1	2	3	4	5	6	7	8	9
1. 1	-	2	1	3	1	2	3	4	4
2. 2		-	1	1	1	1	1	2	2
3. 3			-	2	1	1	2	3	3
4. 4				-	2	1	1	1	1
5. 5					-	1	2	3	3
6. 6						-	1	2	2
7. 7							-	1	1
8. 8								-	1
9. 9									-

Source: Computed from the first improved layout

Table 6. First improved cost matrix

From/To	1	2	3	4	5	6	7	8	9	Total Cost
1. 1	-	0	1	0	0	0	0	0	0	1
2. 2		-	0	10	0	0	0	0	0	10
3. 3			-	0	0	2	0	0	0	2
4. 4				-	0	0	0	0	0	0
5. 5					-	2	0	0	0	2
6. 6						-	16	0	0	16
7. 7							-	2	0	2
8. 8								-	1	1
9. 9								-	0	0
										34 Thai-Bayt

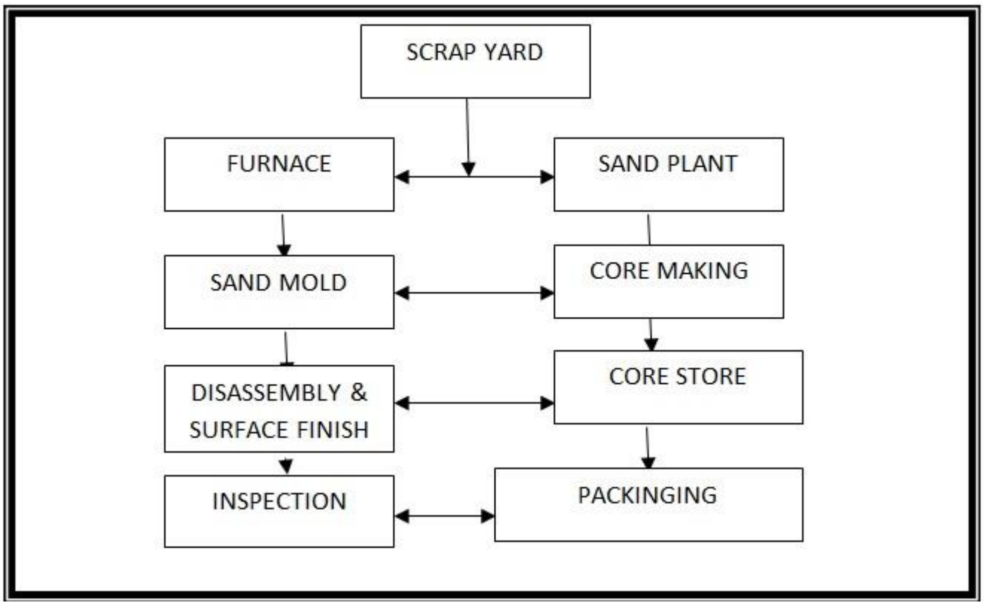

Figura 3. Second improved layout

Table 7. Distance of the second improved layout

To/From	1	2	3	4	5	6	7	8	9
1. 1	-	2	1	3	1	2	3	4	4
2. 2		-	1	1	1	1	1	2	2
3. 3			-	2	1	1	2	3	3
4. 4				-	2	1	1	1	1
5. 5					-	2	2	3	3
6. 6						-	1	2	2
7. 7							-	1	1
8. 8							-	-	1
9. 9								-	-

Table 8. Second improved cost matrix

To/From	1	2	3	4	5	6	7	8	9	Total cost
1. 1	-	0	1	0	0	0	0	0	0	1
2. 2		-	0	10	0	0	0	0	0	10
3. 3			-	0	0	2	0	0	0	2
4. 4				-		0	0	0	0	0
5. 5						4	0	0	0	4
6. 6						-	16	0	0	16
7. 7							-	2	0	2
8. 8								-	1	1
9. 9								-	0	0
									-	36 Thai-Bayt

There is no feasible way of reducing further the material handling cost (34 Thai-Bayt) obtained in table 6. Any attempt to improve further would result in the outcome obtained in table 8 (36 Thai-Bayt). Consequently, the best layout of departments in terms of the material handling cost is 34 Thai-Bayt shown in table 6 by layout design in fig 2.

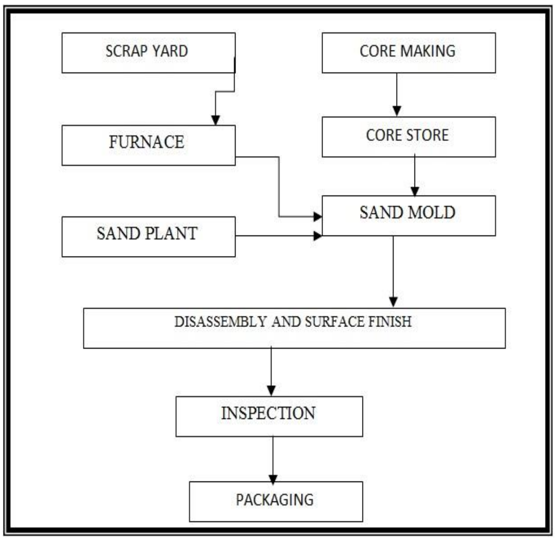

Figure 4. Improved layout (Anucha et al, 2011)

Table 9. Distance matrix layout (Anucha et al, 2011)

To/From	1	2	3	4	5	6	7	8	9
1. 1	-	1	1	1	2	2	3	4	5
2. 2		-	1	1	2	2	3	4	5
3. 3			-	1	1	1	2	3	4
4. 4				-	1	1	2	3	4
5. 5					-	1	1	2	3
6. 6						-	1	2	3
7. 7							-	1	2
8. 8								-	1
9. 9								-	-

Table 10. Cost matrix layout

To/From	1	2	3	4	5	6	7	8	9	Total cost
1	-	0	1	0	0	0	0	0	0	1
2		-	0	10	0	0	0	0	0	10
3			-	0	0	2	0	0	0	2
4				-		0	0	0	0	0
5						2	0	0	0	2
6						-	16	0	0	16
7							-	2	0	2
8								-	1	1
9									0	0
										34 Thai-Bayt

Source: Researchers' analysis

Anucha et al's (2011) layout design is also subjected to quantitative analysis. The study revealed material handling cost of 34 Thai-Bayt as shown in table 10. The implication is that Anucha's layout cost is similar to this study's improved layout cost which was obtained using the Craft method.

5. Results and Conclusions

In this study, analysis of factory layout design in the pulley factory in Thailand was conducted quantitatively in order to overcome material flow obstruction resulting from ineffective layout design. The study employed the Craft algorithm program to improve the initial layout of the pulley factory by minimization of material handling costs, material flow and distance travel for effective production and operations. Given the initial layout of the pulley factory, material flow matrix and the initial distance matrix, the initial cost of the pulley factory layout was 50 Thai Bayt and was obtained by multiplying the distance matrix by the number of flows between departments as showed in table 4. To improve on this initial layout, Craft algorithm was employed and the departments with highest cost from the initial cost matrix were relocated closer to each other. As a result of this, improved layout was designed and the total layout cost was 34 Thai Bayt. Thus, the original layout was improved by 32% resulting in efficient operations and effective production. In addition, attempt was made to evaluate the improved layout to determine whether further improvement is possible. The study revealed that such attempt could push total costs beyond the current amount of 34Thai-Bait because the minimum possible cost has been obtained as shown in Table 6. Consequently, the best layout for the departments in terms of material handling cost is the first improved layout obtained by Craft method as revealed in Table 6.

In addition, efforts were also made to subject Anucha et al's layout (2011) to quantitative analysis. The findings showed the same result with the result obtained by Craft algorithm. Although, Anucha et al (2011) have carried out an accurate analysis of the departmental pulley factory layout design descriptively, however, this study has been able to confirm this result quantitatively. Hence, it is concluded that Craft algorithm is an attractive improvement tool to minimize material handling cost, enhance free flow of materials, reduce distance travel for materials and to eliminate unnecessary obstruction of material flow through effective design of plant/factory layout for optimum production and efficient operation.

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