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Improvement of Facility Layout Using Systematic Layout Planning

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Abstract: The facilities layout problem is an integral part of facilities planning that aims to systematically arrange and locate all production units within a facility with an objective of improving the production operations of a company. The work reported in this paper aims to study and improve the facility layout of a manufacturing company using Muther's systematic layout planning procedure (SLP) for increased productivity and space utilization. In this case study, the existing layout is studied and the amount of equipment identified. Data on the production processes is investigated and flow analysis conducted. An activity relationship chart is formed, studied and new layout alternatives developed.A multi-criteria decision making tool is then proposed and used to evaluate the developed alternatives which are compared with the existing layout. The SLP method derives an improved layout that improves flow of materials, utilizes space effectively, and is flexible.

Keywords: Facilities planning, Facility Layout Problem, Systematic Layout Planning, Material Handling, Multi-criteria Decision Making

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I. INTRODUCTION

Today, there is a rapid change in corporate environments and manufacturing facilities are going through periods of expansion and decline due to ever-changing strategic goals. Many companies are fast switching from one product line to another and discontinuing the existing production lines. To keep up with the pace, the facility layout, a key element of facilities planning, has to be adaptable to changes (Chen, 2013). A facilities layout strategy emerges from the overall strategic plan of a firm and its success is dependent on having an efficient production system, therefore, it is essential that the product design, the process selection, and the schedule design be mutually flexible and supportive (Tompkins, 2010).

More often, companies forget to consider strategic planning for their facilities. Instead, they focus on other factors such as maintenance, quality assurance, and marketing. In the recent times, facilities planning has become more and more important and researchers have proposed several new layout design strategies to improve the performance of manufacturing systems. The facility designers select these layouts based on the degree of uncertainty in the production mix, the volume data for future needs and revision of layout costs (Maryam Hamedi, 2012). Facilities planning has thus gone from simple planning or no plan at all to complex mathematical modeling solutions (Tompkins, 2003).

The facilities layout problem (FLP) is an integral part of facilities design and it aims to locate all the production units within a facility. Traditionally, FLP features two approaches; qualitative or quantitative (Sahin, 2010). The qualitative approach aims to maximize closeness rating scores between work centres or departments based on a closeness function derived from a relationship chart while the quantitative approach aims to minimize the total material handling costs between departments based on a distance function (Jia Zhenyuan, 2011). According to Keragu, (1999), a facility designer attempts either to maximize the adjacency measure, minimize the total cost of material handling or optimize a combination of the two. Therefore, FLP can be formulated differently but it is usually considered as an optimization problem (Poormostafa, 2011).

A crucial element during the FLP design process is the design of an effective material handling system. Material handling decisions have a significant impact on the effectiveness of a facility layout. In this regard, the layout design and the handling system should be considered simultaneously (Tompkins, 2010). Many researchers try to address material handling cost reduction as an important aspect because it is estimated that material handling cost contributes to 20-50% of the manufacturing cost of a product. Furthermore, it is generally agreed that effective facilities planning can reduce these costs by at least 10 to 30% (Tompkins, 2003). When the location of the workstations or machines changes, a reduction in material handling cost can be achieved by minimizing the distance traveled by the material handling equipment between the facilities.

From literature, there are many approaches aimed at creating facility layouts. Many of these approaches are advanced algorithmic techniques such as genetic algorithm technique (Resende, 2015), and ant colony optimization algorithm (Chen, 2013). Algorithm approaches usually involve only quantitative input data and they are complex, thus requiring advanced training in mathematical models (Chien, 2004). However, procedural approaches, such as Systematic Layout Planning(SLP), can be used to link both qualitative and quantitative factors together in the facility design process (Apple, 1977). Furthermore, according to Sharp, (1999), much research effort has been on the facility layout design process and there is a lack of solutions in the evaluation stage.

According to Tompkins, (2010), there is an organized systematic approach to the facility layout problem which applies the traditional engineering design process. This approach can be used to either design a new layout or improve an existing one. Developing a new layout involves constructing one from 'scatch' while improving a layout involves generating alternatives based on an existing layout. Even though a majority of the existing literature focuses more on designing a new layout, more work still involves improving the layout of existing facilities (Tompkins, 2003). The Pairwise Exchange Method (PEM) technique can be used for evaluating alternative facility layouts generated from the improvement type category. This technique seeks to minimize the total cost of transporting materials between workstations. It uses a distance matrix and is based on a rectilinear distance from the centroid of one workstation to the centroid of another workstation.

Evaluation of facility layout alternatives is a difficult affair as multiple objectives, both qualitative and quantitative, are usually involved (Taho Yang, 2000), and considering that these objectives are subjective in nature, their optimization can, therefore, be used to bridge the gap between theory and practice. According to Keragu, (1999), any alteration of an existing layout introduces two types of costs: downtime costs incurred due to the loss in production time and the cost of physically moving equipment from their existing location to the new location. The benefits of the new layout should be greater than the costs of rearrangement of an existing layout.

This study proposes to use Systematic Layout Planning (SLP) as a procedural tool for layout improvement of a machining and fabrication manufacturing company. Flow analysis shall be investigated and new layouts developed. Material handling costs of the developed layouts are then calculated using the Pairwise exchange Method and rearrangement costs estimated. A multi-criteria decision-making tool is finally proposed and used to evaluate the developed alternatives.with an aim of selecting a suitable one that is compared with the existing layout. This paper aims to demonstrate that SLP procedure can be used to improve an existing layout for better productivity.

II. FACILITIES PLANNING

The facilities planning subject continues to be a popular topic among researchers for many years now. It is one of the most popular published areas in the academic field. According to Tompkins, (2003), facilities' planning seeks to determine how an activity's tangible fixed assets best support achieving the activity's objective and in a manufacturing context, it involves determining how a manufacturing facility best supports production. The main objective of facilities planning is to utilize a company's available resources in the most effective way in order to maximize the return on investment on all capital.

It is crucial for business executives to understand the importance of effective facilities planning and to effectively plan for change in the design of existing products, the processing sequences for existing products, quantities of production and associated schedules and the structure of organization and management philosophies. These variables affect the facility layout and as such, it should be flexible to accommodate them (Adil Baykasoglu, 2006). Standridge, (1993) states that there are four types of layouts in manufacturing systems: process, product, group technology and fixed. According to Tompkins, (2010), there is a relationship between the different types of layouts in terms of production volume and product variety, with product layout being characterized by high production volume and low product variety and process layout being characterized by low volume production and high product variety.

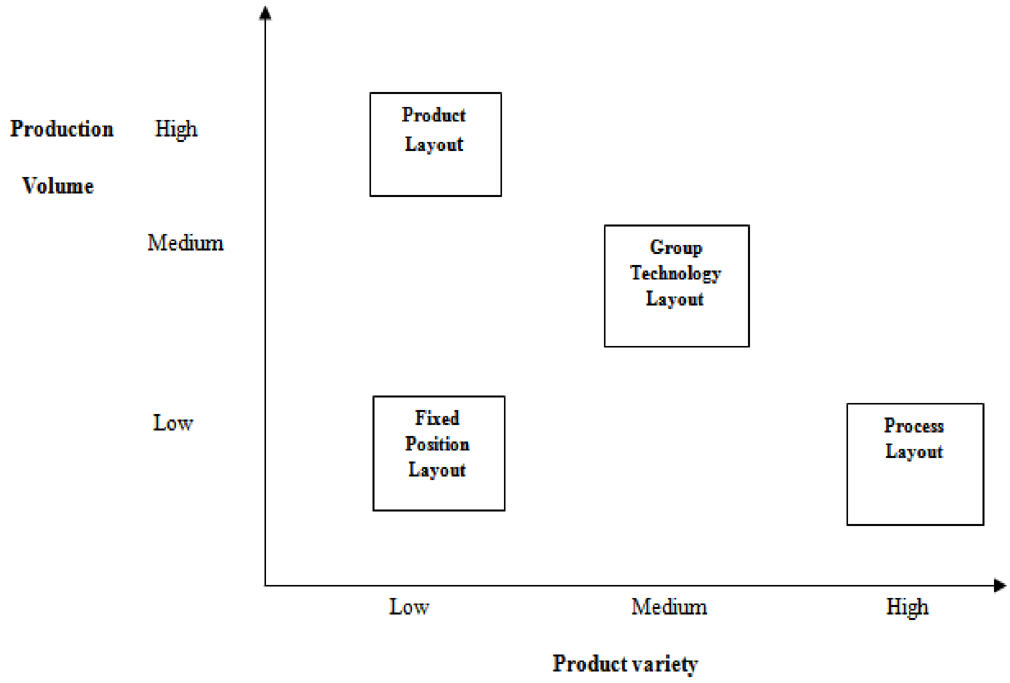


Figure 1: Types of layouts based on volume-variety

III. SYSTEMATIC LAYOUT PLANNING (SLP) PROCEDURE

Systematic layout planning (SLP), illustrated in figure 2, is a procedural layout design approach developed by Muther in 1961. It's a proven powerful tool that is widely used by researchers for academic and practical purposes and it uses the activity relationship chart as its foundation (Tompkins, 2003). An activity relationship chart results from the analysis of the different activities and how they relate to each other. It is performed based on the input data such as the product, quantity, route, support, time and an understanding of the roles and relationships between activities. The input data helps generate a material flow analysis chart normally referred to as a From-to-Chart. From the analysis of the from-to-chart and activity relationship chart, a relationship diagram is developed (Tompkins, 2010). After determining the amount of space required by each activity and assigning each activity the available space, space templates are made for each department in order to obtain the space relationship diagram. The next step involves developing and evaluating a number of layout alternatives based on modification considerations and practical limitations. The developed alternatives are then evaluated based on a facility designers' criteria with an objective of selecting a suitable one. Readers are referred to Muther's (1973) book for extensive details.

IV. ANALYSIS OF THE EXISTING FACILITY LAYOUT

In this study, a machining and fabrication company engages in the design and manufacture of industrial and automotive parts. It is planning to enhance production of its manufacturing operations by expanding the number of machines operating in its machining workshop. The company is looking to improve the performance of the existing workshop in terms of efficiency, productivity, and space utilization. It seeks to adapt a layout strategy that is flexible, able to accommodate future production needs and one that can adopt to productivity improvement in the flow of people and materials. The machining workshop is a process type layout with several machines, designed as workstations, arranged according to the functions they perform. They mainly perform milling and gear hobbing operations. The existing layout has three non-operational machines that have exhausted all repair strategies.

There are three types of material handling equipment that are used to transport materials across different workstations in the workshop. They include two bridge cranes, one forklift, two trolleys, and one hydraulic fork trolley. It is important to mention that any workpiece that gets into the workshop for machining originates either from the storage area (as a customer order or, from the foundry section of the company) or from a raw piece of metal cut by the band saw. The relationship between the workstation size and area is tabulated in Table 1.

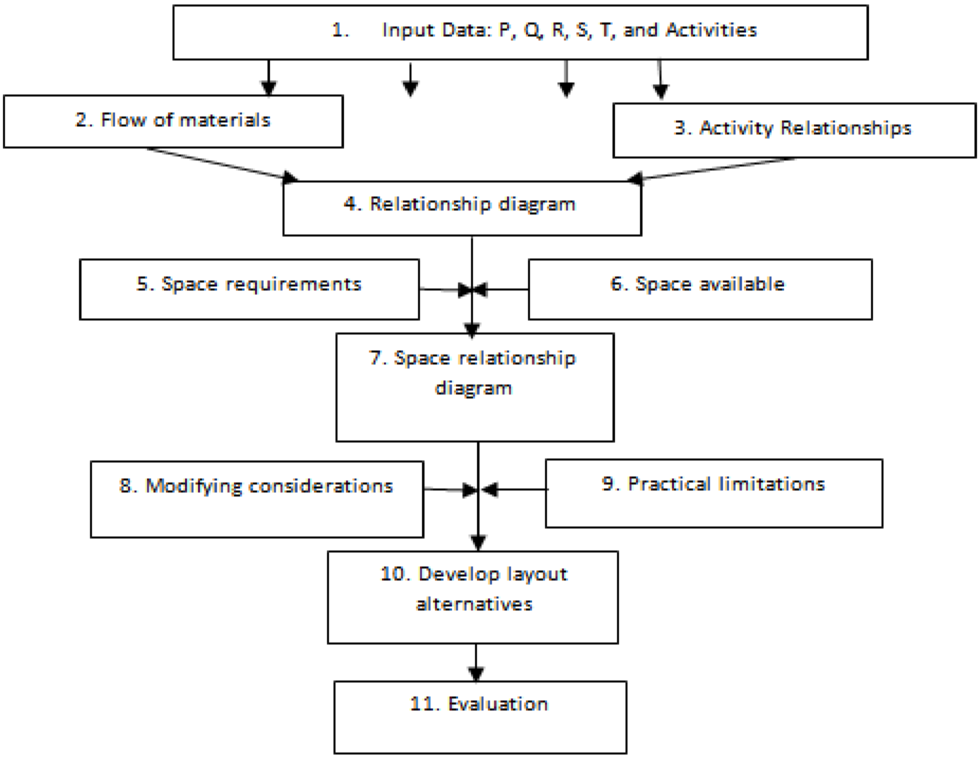


Figure 2: Systematic layout planning (SLP) procedure. Tompkins, (2010)

Table 1: Relationship between Equipment/Section size and area.

Serial No.	Equipment/ Section	Equipment capacity	Number of Equipment	Equipment and working area (m2) (L*W)
1.	Band saw	High/Low capacity	1	14.0
2.	Storage section	High/moderate capacity	1	80.0
3.	Universal Machine centre (UMC)	High capacity	1	120
4	Universal Machine centre (UMC)	Low capacity	1	100
5.	Universal Machine centre (UMC)	Low capacity	1	68.25
6.	Universal Machine centre (UMC)	Low capacity	1	55.0
7,8.	Horizontal Machine Centre (HMC)	4 Axis, High capacity	2	118
9.	Horizontal Machine Centre (HMC)	5 Axis, High capacity	1	78.0
10.	Horizontal Machine Centre (HMC)	Low capacity	1	65.0
11.	Turning Machine Centre (TMC)	High capacity	1	87.75
12.	Turning Machine Centre (TMC)	High capacity	1	97.5
13.	Turning Machine Centre (TMC) - Bar feeder	High capacity	1	87.7
14.	Turn-mill Centre	High capacity	1	74.1
15.	CNC Lathe Machine	Low capacity	1	65.0
16, 17	Gear Hobbing Machine	Helical and spur	2	88.5

		gears		
18.	Surface Grinders	Cylindrical type	1	55.0
19.	Surface Grinders	Flat type	1	58.5
20.	Conventional Lathe Machine	Low capacity	1	45.0
21.	Finishing Section	Low/Moderate capacity	1	20.0
22.	Heat Treatment Section	Moderate capacity	1	220.0
23.	Maintenance cabinets	Moderate capacity	10	56.25
24.	Workshop store for spare parts	High/moderate capacity	1	114.7
25.	Crankshaft and assorted parts	Assorted parts	Many parts	81.0
26.	Conventional drilling machine	Low capacity	1	20.0
27.	Conventional lathe and shaping machine	Low capacity	3	50.0
28.	Research and development section	Low capacity	1	28.0
29.	Light fabrication section	Low capacity	1	120
30.	Turning machine centre (TMC)	Non-operational	1	87.75
31.	Turning machine and horizontal machine	Non-operational	2	72.0
32	GANGWAY 1, 2, 3			3*73.5
33	GANGWAY 4			6*20

V. ANALYSIS OF THE FACILITY LAYOUT BASED ON SLP

Data on the production processes between workstations was collected and flow analysis conducted with an aim of understanding the flow of materials. The selected data was for a period of eighteen months. A from-to-chart, shown in Table 2, representing all the flow volumes between activities across the workstations was constructed. An activity relationship chart, shown in figure 3, was then created. This chart shows the relationship between the workstations in the process design. A Pareto analysis was conducted and a closeness rating assigned depending on the importance of the relationship between workstations. The closeness values are defined as A = Absolutely necessary, E = Especially important, I = Important and O = Ordinary

Table 2: From-to-chart

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		-	135	102	102	96	364	364	300	382	267	267	267	680	155	-	-	-	-	18	-	-
2			80	59	68	60	443	443	196	196	10	5	5	-	-	-	-	16	16	-	-	185
3				-	-	-	-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
4					-	-	-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
5						-	-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
6							-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
7								-	-	-	-	-	-	-	-	4	3	7	7	-	17	22
8									-	-	-	-	-	-	-	4	3	7	7	-	17	22
9										-	-	-	-	-	-	4	3	7	7	-	17	22
10											-	-	-	-	-	4	3	7	7	-	17	22
11												-	-	-	-	20	16	-	-	-	-	13
12													-	-	-	20	16	-	-	-	-	13
13														-	-	20	16	-	-	-	-	13
14															-	-	-	-	-	-	-	2000
15																20	12	-	-	-	-	10
16																	-	-	-	-	-	48
17																		-	-	-	-	48
18																			-	-	-	-
19																				-	-	-
20																					-	-
21																						-
22																						

A relationship diagram was then created from the relationship chart where the workstations were placed spatially, with those with the highest closeness rating being placed close to each other. Relationship lines were drawn to represent the closeness rating. The main purpose of the relationship diagram is to indicate the relationship between workstations and it helps in positioning workstations during improvement. The relationship diagram that resulted is shown in figure 4.

Based on considered improvements, new alternative layouts were created. Several factors were considered: the space requirements and availability, the safety of the equipment and workers, size and bulkiness of the equipment, material handling, and ease of access. The input of the workshop workforce was also considered. Due to practical and modifying considerations; the heat treatment section, research development section, the storage area and the workshop store could not be moved. Three alternatives were developed and they are represented as B, C and D. The existing layout is represented as A, as shown in figure 5. The improved layouts eliminate non-operational machines and introduces a material loading bay and a setting section that combines with the finishing section.

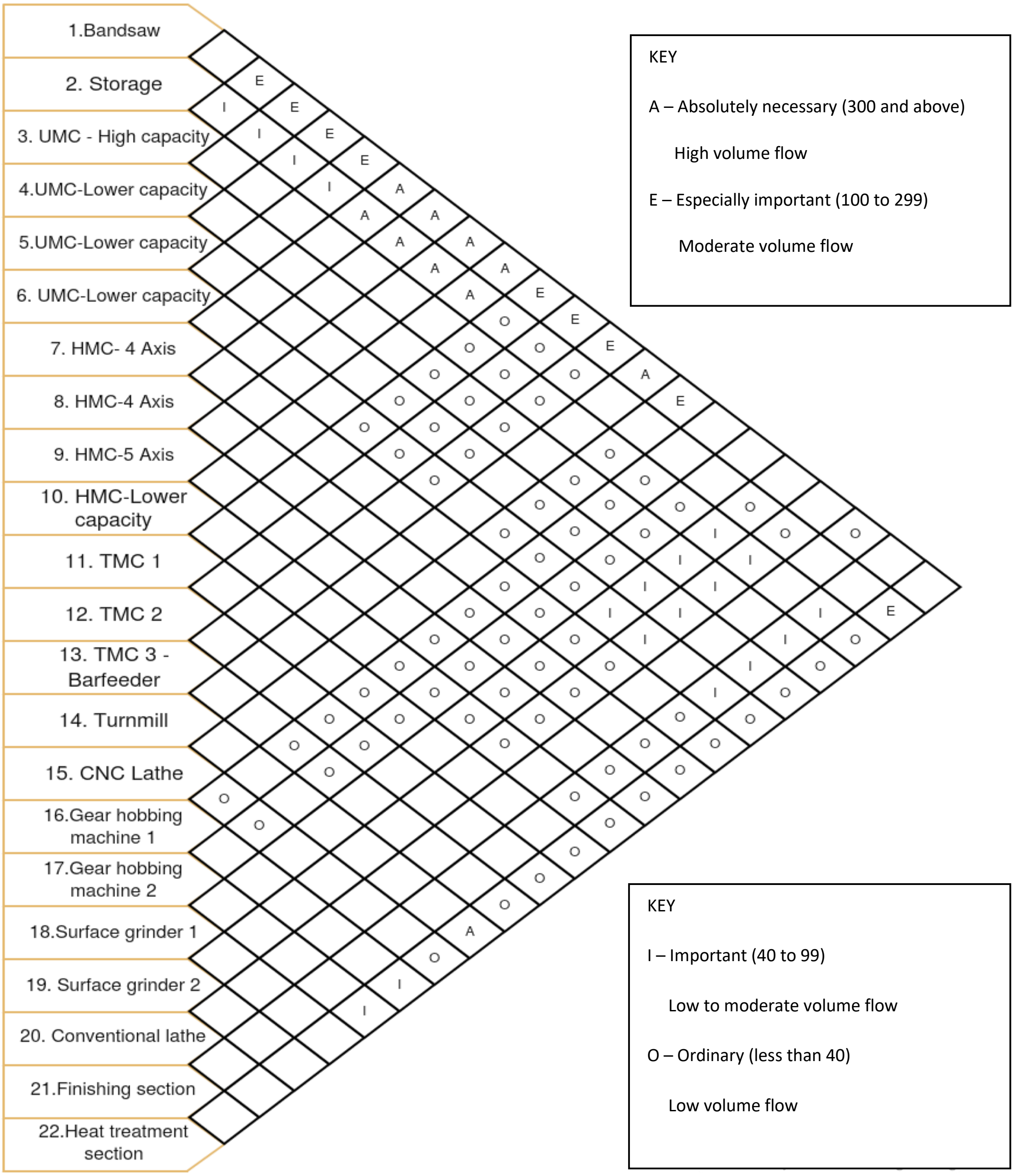


Figure 3: Activity relationship chart

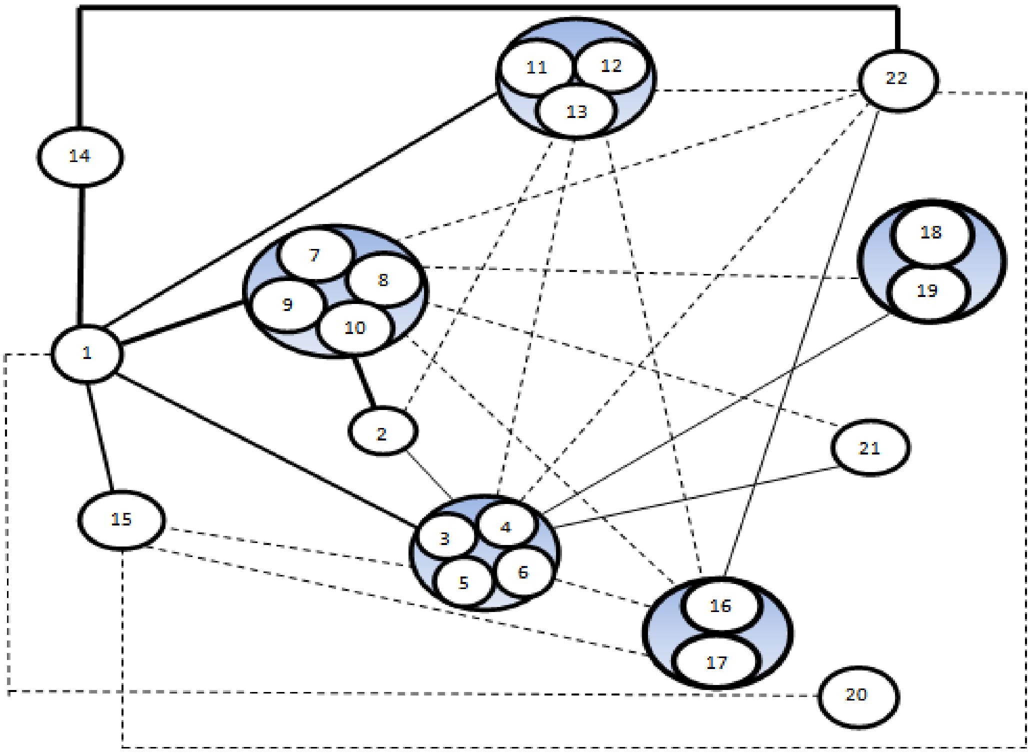
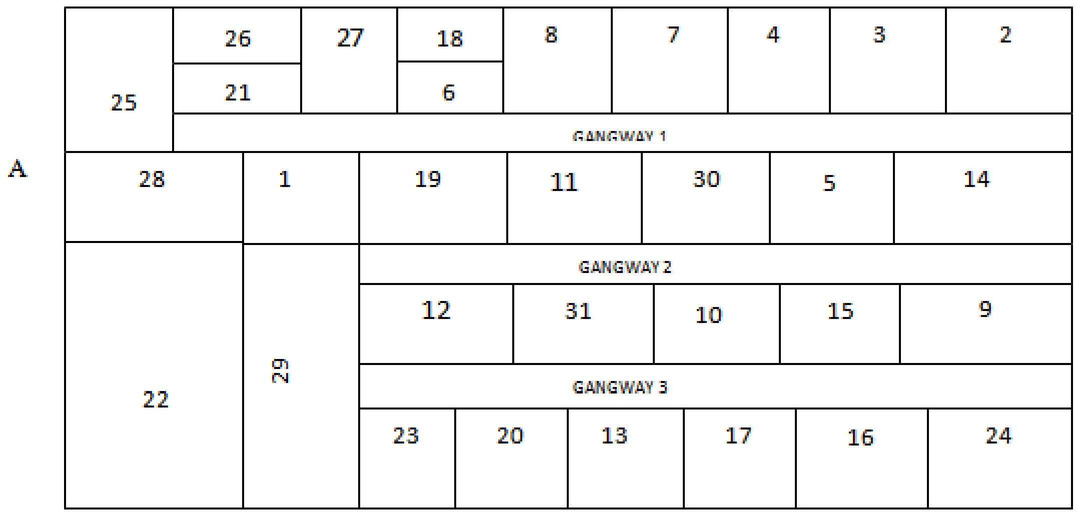


Figure 4: Relationship diagram

Line	Closeness ratio
(thick solid line)	A- Absolutely necessary
(solid line)	E-Especially important
(thin solid line)	I-Important
(dashed line)	O-Ordinary

Figure 4: Relationship diagram



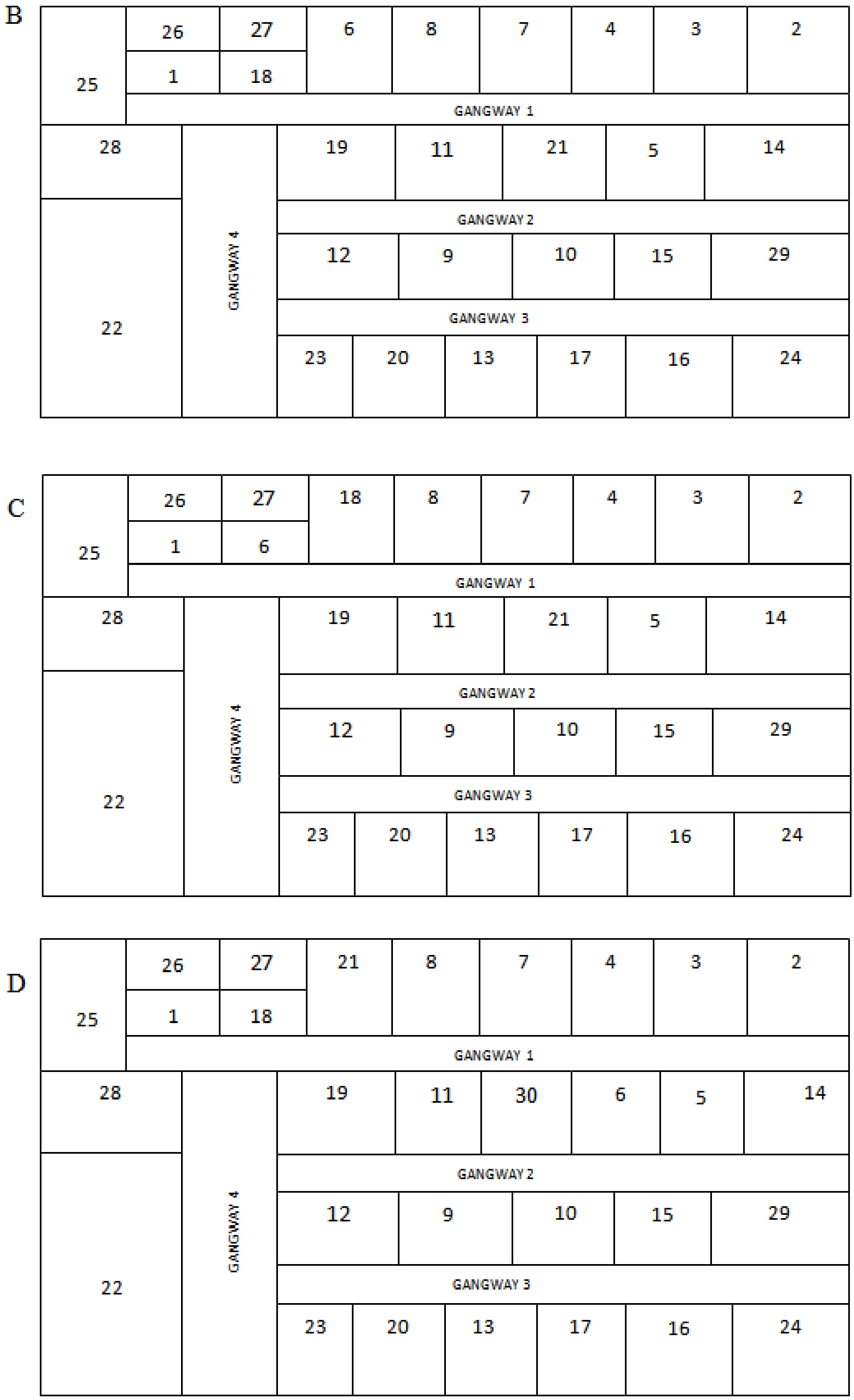


Figure 5: Facility layouts between existing and improvements (A, B, C & D)

VI. EVALUATION OF THE EXISTING LAYOUT AND ALTERNATIVES

Evaluation of facility layout alternatives is a difficult affair as multiple objectives, both qualitative and quantitative, are usually involved (Taho Yang, 2000). Most of these objectives are subjective in nature and their optimization can be used to bridge the gap between theory and practice. The developed alternatives were evaluated by calculating the material handling and rearrangement costs and comparing them with the existing layout.

The Pairwise Exchange Method (PEM) was used to calculate the material handling costs and an efficiency ratio (ER) derived. PEM is a heuristic method for layout improvement that is based on minimizing the total cost of transporting materials among all workstations in a facility. It uses a distance objective between workstations and the distance is measured from the centroid of one department to the centroid of another. Distance measurement can either be rectilinear or Euclidean-based. In this case, rectilinear measurement was used. It uses the material flow matrix of a from-to-chart and for each layout alteration, all the material flow in the location of workstations are evaluated and the alteration with the largest reduction in the total cost is selected. The final outcome of any alteration is compared to the initial layout. Readers are referred to Tompkins, (2010) for extensive details. The material handling costs are listed in Table 3.

Rearrangement costs, as listed in Table 4, were estimated by the maintenance department and they included costs for dismantling and moving machines from their original location to the new desired location and also costs for moving machines that have broken down to the outside of the workshop. Installation, labour and overhead costs, such as electricity were also included.

An MCDM theory was also defined to aid in the evaluation of the alternatives. Several factors were considered in analyzing the characteristics of the layout. They include safety considerations, the flexibility of the layout, space utilization, material handling effectiveness and flow movement effectiveness. The Simple Additive Weighting (SAW) method was used where a weight was assigned to each of these factors based on the priority requirements. An MCDM evaluation of the existing layout and the alternatives is shown in Table 5. The final summary of the tabulated MCDM is listed in Table 6.

Table 3: Material handling costs

Layout type	**Material Handling Costs**	**Efficiency Ratio(ER) – percentage increase/decrease**
Existing Layout A	434494.32	Nil
Alternative B	448185.92	0.031511574
Alternative C	447418.62	0.029745613
Alternative D	453241.12	0.043146249

Table 4: Rearrangement costs

Alternatives	Movement costs for unutilized machines (KES)	Movement costs for operational machines (KES)	Overhead costs, such as electricity (KES)	Labour cost (KES)	Total cost (KES)
Alternative B	400,000	100,000	80,000	70,000	650,000
Alternative C	400,000	130,000	80,000	90,000	700,000
Alternative D	400,000	150,000	80,000	90,000	720,000

Table 5: MCDM Evaluation

		Requirement Priority Scores			
Criteria	Weight	Existing Layout	Alternative Layout B	Alternative Layout C	Alternative Layout D
Flexibility	25%	1	3	3	2
Safety considerations	25%	2	3	3	3
Material handling effectiveness	20%	2	3	3	3
Flow effectiveness	20%	2	3	2	2
Space utilization	10%	1	3	2	2
Weighted Scores	100%	1.65	3	2.7	2.45

Key: 1 – Poor, 2 – Fair, 3 – Good, 4 – Very Good

Table 6: Summary

Layout type	Material Handling Cost	Efficiency Ratio (ER)	Rearrangement costs (KES)	Requirement Priority Scores
Alternative B	448185.92	0.031511574	650,000	3
Alternative C	447418.62	0.029745613	700,000	2.7
Alternative D	453241.12	0.043146249	720,000	2.45

From the analysis, the preferable alternative selected by the authors is layout B. It has the highest priority score in the MCDM evaluation and the least rearrangement costs though it slightly increases material handling costs by 3.14 per cent. It improves the safety of the existing layout of the company, offers flexibility, improves the flow of materials and people, and utilizes space efficiently.

VII. CONCLUSIONS

In this paper, the authors have used Muther's SLP procedure to solve a facility layout problem. Despite SLP being a proven procedural tool for designing new facility layouts, it can be used for improving existing layouts. Unfortunately, many companies, as found out by (Williamson, 1996), are not aware of it as a technique for layout improvement and from our experience with the case study company, no interest has been shown to bridge this gap. Additionally, much research effort has been on the designing aspect of the SLP procedure, rather than on the evaluation one. Furthermore, an increase in the number of activities will complicate the plotting of relationship diagrams because of the unavailability of plotting facts. Any misrepresentation of facts at any stage in this procedure will result in ineffective decision making. Therefore, proper analysis of the existing layout design should be carried out by competent facility designers, and since the validity of the calculations and results is dependant on the input data, it is important to capture accurate input data to get reliable results. The authors present a simple and objective multi-criteria evaluation process as opposed to existing algorithmic procedures, to solve a qualitative objective problem. The case study illustrates that SLP is a viable procedure in solving a layout design and improvement problem.

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