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Optimizing Plant Layout Design to Enhance Operational Efficiency: A Case Study of the Yemeni Company for Engineering Industries (YCEI)

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Abstract

This study focuses on enhancing the efficiency of industrial plant layouts, which are often suboptimal in traditional designs, leading to issues like reduced productivity, longer lead times, and higher maintenance costs. The research applies a flexible layout design to improve operations at General Industries, transitioning into the Yemeni Company for Engineering Industries (YCIE). Through a comprehensive literature review and case study analysis of the Hayel Saeed Anam Group's central workshop, the study develops a new layout tailored to the company's needs. Key findings emphasize the importance of flexibility, safety, and efficient material flow in optimizing plant operations.

Keywords
Fixable plant Layout design, Production Operations, and operation improvement.

1. Introduction

The internal layout of an industrial plant is a critical factor that directly impacts its operational efficiency and productivity. A well-designed plant layout can significantly enhance production processes by reducing material handling time, minimizing worker movement, and optimizing space utilization. On the other hand, poor layout design can lead to longer lead times, increased operational costs, and reduced productivity. This study focuses on the design and implementation of a flexible plant layout at the Yemeni Company for Engineering Industries (YCEI), aiming to improve its operational efficiency. The existing layout was found to be suboptimal, resulting in inefficiencies such as excessive material handling and longer process times. The research applies industrial engineering techniques, including flow analysis and Rank Order Clustering (ROC), to develop a new layout tailored to the specific needs of YCEI. The proposed layout is expected to enhance productivity, reduce waste, and support the company's vision of continuous improvement and operational excellence.

The application of a flexible and optimized plant layout is essential for YCEI as it transitions to meet the growing demand for its products. By focusing on key factors such as material flow, safety, and adaptability, the study aims to demonstrate how strategic layout design can lead to significant improvements in manufacturing efficiency.

Objectives
The primary goal of the study is to optimize the plant layout using industrial engineering techniques to increase efficiency and flexibility. The general objectives include enhancing layout effectiveness, minimizing production waste, increasing productivity, and reducing part travel distances. Specific objectives focus on supporting the organization's vision through better material handling, optimizing the use of resources, minimizing capital investment, and ensuring the layout is adaptable and easy to maintain. The project's primary goal is to optimize the plant layout using industrial engineering techniques to increase efficiency and flexibility. The general objectives include enhancing layout effectiveness, minimizing production waste, increasing productivity, and reducing part travel distances. Specific objectives focus on supporting the organization's vision through better material handling, optimizing the use of resources, minimizing capital investment, and ensuring the layout is adaptable and easy to maintain.

2. Literature Review
Optimal designing of manufacturing layouts is one of the most important determinants of operational efficiency, productivity, and overall competitiveness in production settings. A myriad of layout combinations has been conceived to maximize the efficiency of workflow, reduce waste, and improve space economy. A correct assessment of the comparative effectiveness of different layouts is necessary for choosing the layout best suited to particular manufacturing circumstances. To pinpoint the shortcomings of the comparative effectiveness of Group Technology (GT) in improving layout efficiency, this study assesses some previous research on these layouts.

Process Layouts
Process layouts, also called functional layouts, are those organized by similar resources or processes and done in a structured manner. This is even so in job shops and service industries, which apply the most flexible and customized priority. As posited by Slack et al. (2010), process architectures are significantly flexible in managing various products and less challenging in supervision. However, Groover (2016) observes that more often than not, they experience ineffective material flow, longer handling times, and high levels of work-in-progress inventory for the sole reason that operations are not sequenced in any reasonable order. Also, Stevenson (2018) believes that it is quite complicated to make a well-balanced process that minimizes the number of bottlenecks to ensure better throughput.

Product Layouts
Product layouts, sometimes called line layouts, involve the arrangement of workstations and equipment in a continuous sequence that corresponds to the manufacturing process for a particular product. Heizer and Render (2014) proposed that this layout is best for huge mass-production environments where large volumes of standardized products are produced. Advantages: streamline material flow, cut manual handling costs, increase manufacturing speed. However, Dodge et al. (2006) contend that product layouts are inflexible, thus making them unfavorable for those environments that need constant change or customization. A research work by Krajewski et al. (2015) has dwelled on the efficiency of product layouts as far as high output and low idle time is concerned, especially in the automotive and electronics industries.

Group Technology (GT) Layouts
Group Technology (GT) is a manufacturing paradigm that groups similar parts or products into families based on common characteristics, thus allowing the classification of the operations. Grosch (1961) introduced the concept of GT to optimize the efficiency of the system by reducing setup times, minimizing material movement, and improving the flow. Ohno (1988) had claimed that process optimization and the minimization of waste were never going to be achieved without GT in the Toyota Production System. Moreover, Abdollahi et al. (2009) relate GT to improved space utilization and better inventory handling. However, Rowe et al. (1992) caution that the effective implementation of GT requires careful study and detailed planning to optimally reap its rewards.

2.1 Hybrid Designs
The hybrid layouts thus incorporate some elements of both the process, product, and cellular layouts, with an aim to reap the benefits of the good features of each design, yet be limited by their individual disadvantages. Emmett (1983) also outlines the design of hybrid layouts, where the emphasis is on those layouts that will strike a good balance of flexibility with efficiency. Such layouts will thus accommodate a wide range of products while maximizing the flow of materials and the use of space. Rosenberg and Landay (1993) argue that hybrid layouts become increasingly favorable when production volumes fluctuate amidst organizations that manufacture a variety of product lines.

Research conducted by Shu et al. (2000) has, in contrast, established that hybrid layouts can provide significant operational performance improvement because they effectively control the trade-offs of pure layout configurations.

2.2 Comparison of Layout Configurations

While much research has been directed toward certain layout configurations, there is very little research that compares their relative effectiveness. Case studies or specific performance of some aspects of layouts are more often discussed in the previous literature than actual comparisons. For example, while Smith and Thomas (2004) made a comparison of material handling costs of different layouts, Johnson and Leenders (1998) looked at flexibility or throughput separately. However, these comparisons are in many cases limiting in their scope and do not provide an overall assessment of layout efficiency across numerous variables. Here, a noticeable information gap lies in the relative usefulness of group technology with other layouts of process, product, and hybrid in improving layout efficiency. Although group technology is known for improved workflow, minimization of fabricating time, etc., very few researchers have shown an interest in ascertaining how effective group technology would be in impacting layout effectiveness among other layouts. Therein lies the current knowledge gap: a lack of well-explored research about group technology and comparison of its material flow optimization, waste reduction, and space use optimization with alternative designing methods. Investigation into these factors could provide useful insights into the particular circumstances in which GT works better or complement other layout methodologies to make our understanding of layout design more comprehensive across different production settings.

3. Methodology

The methodology for designing an optimized plant layout for the Yemeni Company for Engineering Industries involved the following seven steps:

The case study

The Hayel Saeed Anam group is one of the biggest group in industrial filed in Yemen and middle east . Some of the spare parts for the group companies manufactured in central workshop for the group . Due to increase the demand on spare parts the group planned to consist new company it is called Yemeni Company for Engineering Industries.
The study will evaluate the current layout and operations in it and increase it is efficiency. The study involved the following steps: The research problem was identified and the previous studies related to the problem.

Collecting the data

The study conducted in the Central workshop for Hayel Saeed Anaam group is based on the available data for two years which contain the manufactured parts through that period and the another data is gathered by the observations and interviews through the study period. The table (1) shows the most parts manufactured and it is operation and sequence. This parts manufacturing operation will be used to evaluate the current layout and design the new layout .

Table 1. Operation sequence for parts

Part	Routing(operation sequence)
Shaft	R-C-T-M-D-H-G-O-S
Basic	R-C-T-M-G-P-O-S
Gear	R-C-T-M-P-G-O-S
Ben	R-C-T-G-O-S
Roll	R-C-T-M-G-O-S
Flinch	R-C-T-P-O-S
Knife	R-C-M-P-H-G-O-S
Bush	R-C-T-G-O-S
Gaud	R-C-T-G-H-O-S
Sabrocat	R-C-T-M-D-O-S

Table 2. From -To Chart

To

	R	C	T	M	G	D	P	H	O	S	Total	P.P
R		744 <u>**744**</u>									744	744
C			709 <u>**709**</u>	35 <u>**70**</u>							744	779
T				443 <u>**443**</u>	210 <u>**420**</u>		56 <u>**224**</u>				709	1087
M					289 <u>**289**</u>	112 <u>**224**</u>	77 <u>**231**</u>				478	744
G							49 <u>**98**</u>	76 <u>**228**</u>	533 <u>**2132**</u>		658	2518
D								82 <u>**164**</u>	30 <u>**90**</u>		112	254
P					42 <u>**168**</u>			35 <u>**35**</u>	105 <u>**210**</u>		182	413
H					117 <u>**702**</u>				76 <u>**76**</u>		193	778
O										744 <u>**744**</u>	744	744
S											4564	8061

$$EFFICIENCY = \frac{4564}{8061} = 56.62\ \%$$

3.1 Flow Analysis

Flow analysis assist the manufacturing facilities designer in the selection of the most effective arrangement of machines, facilities, workstations and departments. When designing the flow pattern, keep in mind that the employee walking time is a nonproductive time .If an operation with perfect flow could be established, it will nearly eliminate all waste associated with: Inventory, Storage space, Transportation, Waiting. The from to chart is the most exact technique in evaluating the flow analysis .Designers can develop an efficiency that considers the importance of the parts .Up until now .we have considered each part as equal in importance ,the techaniqe applied and the final result shows in the Table(2)

3.2 Process Desigen

To group machines, part routings must be known. This section present a method for clustering part operations onto specific machines to provide this routing information. This technique called Rank order clustering (ROC) .This method is based on sorting the rows and columns of machine part incidence matrix. The rank order clustering was developed by King (1980). The steps of this algorithm is given below

Step 1. For each row of the machine part incidence matrix, assign binary weight and calculate the decimal equivalent

Step 2. Sort rows of the binary matrix in decreasing order of the corresponding decimal weights.

Step 3. Repeat the preceding two steps for each column.

Step 4. Repeat the preceding steps until the position of each element in each row and column does not change.

Table 3. Final Machine-Part Matrix of ROC

M/P	shaft	base	Gear	roll	ben	bush	guad	knife	sabrocat	slinch	Binary numbers (value)	Order
Grinding	1	1	1	1	1	1	1	1	0	0	**1020**	**1**
Turning	1	1	1	1	1	1	1	0	1	1	**1019**	**2**
Milling	1	1	1	1	0	0	0	1	1	0	**966**	**3**
Drilling	1	0	0	0	0	0	0	0	1	0	**514**	**4**
planer	0	1	1	0	0	0	0	1	0	1	**389**	**5**
binary numbers(value)	**30**	**29**	**29**	**24**	**28**	**21**	**9**					
Order	**1**	**2**	**3**	**4**	**5**	**6**	**7**					

A weight for each row i and column j are calculated as follows:

$$\text{Row i}: \; W_i = \sum_{k=1}^{n} a_{ik} 2^{n-k}$$

$$\text{Column j}: \; W_j = \sum_{k=1}^{m} a_{kj} 2^{n-k}$$

In the final matrix generated by the ROC algorithm, clusters are identified visually in our case study we have many machines to produce a lot of parts. the algorithm was applied and the final result is shown in table(3) :

The results show that three groups can be formed**:-**

Group 1: parts {base, gear, knife, slinch }, machines {grinding ,turning ,milling ,shaper}
Group 2: parts { shaft ,roll ,sabrocat}, machines { grinding ,turning ,milling ,drilling}
group 3: parts {bush, ben ,gaud}, machines { turning ,planner}

3.3 Evaluating the new layout

The from to chart used to evaluate the efficiency of every cell and the total layout efficiency. the following tables show the results in tables (4,5,6):

Group one(cell one)

Table 4. From-To chart for cell one

	R	C	T	M	D	H	G	S	Total	P.P
R										
C			85.33 85.33						85.33	85.33
T				85.33 85.33					85.33	85.33
M					60.22 60.22		25.11 75.33		85.33	135.55
D						35.11 35.11			35.11	35.11
H							35.11 35.11		35.11	35.11
G										
S									326.21	376.43

$$EFFICIENCY = \frac{326.21}{376.43} = 86.7\ \%$$

1. Group two (cell two)

Table 5. From-To chart for cell two

	R	C	M	P	G	H	S	Total	P.P
R									
C			33.111 33.111					33.111	33.111
M				60.22 60.22	25.111 56.222			88.333	116.5
P					28.111 28.111	32.111 64.222		60.222	92.333
G				28.14 56.28				28.14	56.28
H					32.111 64.222			32.111	64.222
S								241.917	362.446

$$EFFICIENCY = \frac{241.917}{362.446} = 66.75\ \%$$

2. Group three (cell three)

Table 6. From-To chart for cell three

	R	C	T	G	H	S	Total	P.P
R								
C			71.35 71.35				71.35	71.35
T				71.35 71.35			71.35	71.35
G					27.111 27.111		27.111	27.111
H								
S							169.811	169.811

$$EFFICIENCY = \frac{169.811}{169.811} = 100\ \%$$

$$\text{The Total average efficiency} = \frac{86.7+66.75+100}{3} = 84.48\ \%$$

Evaluating the operations required

The operation that required to manufacture the ten spare parts in the current layout is shown in (Figure 1.) and for the GT layout in (Figure 2.)

Graph(1) . Operation in the current layout

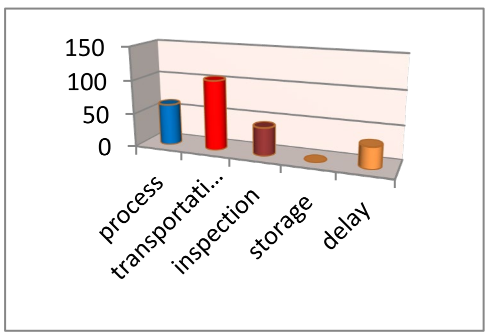

Figure 1. Operation in the current layout

Graph(2) Operation in the GT layout

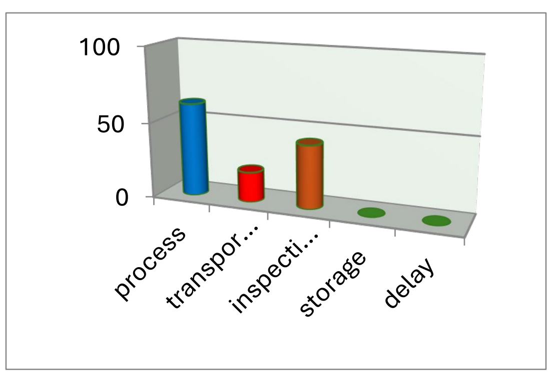

Figure 2. Operation in the GT layout

4. Result and Discussion

The comparative analysis between the existing layout and the newly proposed group technology (GT) layout has been discussed in this chapter. The objective of the study was to analyze the effectiveness of the existing layout in the central workshop of the Hayel Saeed Anam Group and propose a more effective layout based on the group technology approach.

4.1. Current Layout Efficiency

The present layout was analyzed for flow, with the support of a From-To chart giving a total number of parts movement between machines. The analysis showed that the existing layout was not optimized. A large number of inefficiencies were experienced due to long distances traveled by the parts and high materials handling. The total efficiency of the current layout was 56.62%. This relatively low efficiency indicated that the current layout was not effectively supporting the increasing demand for spare parts manufacturing. Dispersed machine arrangement led to unnecessary delays and increased nonproductive time for material handling and transportation.

4.2. **Use of Group Technology Layout**

To correct the inefficiencies found in the existing layout, a GT layout was proposed. A Group Technology Layout is ROC-designed and clusters machines around part families defined by the similarity of processes used on them. Parts would only have to move short distances with linked operations located closely together. The new layout was structured in three well-defined manufacturing cells:

- Cell 1: Base, Gear, Knife, Slinch; Operations - Grinding, Turning, Milling, Shaper.
- Cell 2: Shaft, Roll, Sabrocat; Machines: Grinding, Turning, Milling, Drilling.
- Cell 3: Bush, Ben, Gaud; Machines - Turning, Planer.

4.3. Comparative Layout Efficiencies

The present design was compared to the efficiency of the newly proposed GT layout. The results showed a drastic improvement in efficiency as follows:

- Cell 1 Efficiency: 86.7%
- Cell 2 Efficiency: 66.75%
- Cell 3 Efficiency: 100%
- New Layout Efficiency Rate: 84.48%

However, the total efficiency in the existing layout was very low at 56.62%. The observation is that the GT layout provides a more systematic production process that reduces nonproductive time related to handling, transportation, and waiting. Efficiency was enhanced in the GT layout due to less travel of parts; that is, machines closer to one another in one cell reduced the need for a part to travel over long distances. This not only reduces the level of delay but also makes the workflow effective as similar operations are grouped together.

5. Discussion

According to the findings, the GT layout is an effective approach to enhance the efficiency of the manufacturing layout. Improvement from 56.62% to 84.48% in layout efficiency is indicative of a big reduction in waste and nonproductive activities. Minimization of unnecessary movement and handling has shortened production times, thereby reducing operational costs associated with the GT layout. Therefore, comparing the present layout with the GT layout enforces the fact that layout design plays a critical role in determining manufacturing efficiency. In light of this fact, since the GT layout focuses more on lowering transportation and material handling costs, it is more efficient and effective for meeting increased production demand at Hayel Saeed Anam Group.

6. Conclusion

The project considered in this case was an optimization of a manufacturing layout for the Central Workshop of one of the biggest and most diversified industrial organizations in Yemen and the Middle East, Hayel Saeed Anam Group. The tremendous increase in the demand for spare parts prompted the group to want to form a new company by the name of Yemeni Company for Engineering Industries, and it hence knew that there was a dire need to increase the efficiency of the work done by it. A systematic approach using flow analysis and Rank Order Clustering (ROC) accurately identified inefficiencies with the present layout and suggested an alternative, more productive design. Analysis of the present layout indicated that the current layout is only 56.62% efficient, which demonstrates that a lot is left to be desired. A significant improvement to 84.48% efficiency was attained in the study by reconfiguring the layout into three cells that had been optimized for specific routings.

One of the major breakthroughs attained with the new layout was a tremendous reduction in non-value-added activities, such as excessive transportation, unnecessary delays, and idle operations. Shorter manufacturing lead time came as a direct benefit of the new layout; this shorter lead time would reduce the distance between consecutive operations and the flow of parts through the shop would be smooth. Shorter manufacturing time was also one of the factors behind lower operating costs, which occurred as a result of effective utilization of resources and minimization of wasteful activities. It reduced nonproductive time, making the productive process quicker and raising its cost-efficiency at the same time. This in effect enabled the workshop to produce the required spare parts within a reduced timeframe and at a lower cost than previously—since the growth in demand for them requires more and more production without drops in quality.

Such time and cost efficiency improvements genuinely play an extremely important role overall in keeping this workshop competitive in the market and reacting accordingly to an increase in production demand. It can therefore be concluded that strategic layout design is one of the prime essentials in manufacturing industries. In this study, a less efficient traditional layout of the system was transformed by very strict analysis tools into a highly optimized system where productivity was boosted very significantly. So, the success of this project just proves how important continuous improvement is in any industrial operation with respect to reducing nonproductive activities, and thereby shortening manufacturing times and costs. This is an operational framework and dictates that an effective layout design is crucial for achieving operational excellence in similar endeavors across various manufacturing settings.

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Biographies

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