LEAN MANUFACTURING BASED SPACE UTILIZATION AND MOTION WASTE REDUCTION FOR EFFICIENCY ENHANCEMENT IN A MACHINING SHOP: A CASE STUDY

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Abstract:
Lean manufacturing is a corporate strategy that focuses on continually improving all processes in the production environment by reducing waste and costs. The implementation of lean manufacturing systems will always begin within the existing facility layout. Therefore, the arrangement of the facility has a tremendous impact on the company's development and space utilization. This research addresses possible research gaps related to the industry's requirement for successful lean manufacturing and space utilization. In this research, an integration of lean techniques and facility layout planning has been used to optimize the workshop operation by implementing 5S and Systematic Layout Planning to rearrange machines, which eliminated waste caused by unnecessary motion. As a result, out of two alternatives of facility layout proposed, the process efficiency is improved from 53% to 66%. An efficient facility layout helps production schedules run more smoothly while minimizing costs and enhancing space utilization. It has contributed to create a safe and healthy work environment. The research is limited to optimizing space utilization and attempts to eliminate excessive motion of employees and equipment in the machining shop of a mechanical workshop. The need to close the implementation gap for lean and space utilization will make a substantial contribution to long-term industrial sustainability.

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1. INTRODUCTION

Lean manufacturing is developed by Taiichi Ohno Toyota in the 1960s [1]. It consists of a set of techniques that are implemented by manufacturing companies to assist in the adaptation of mass production whereby workers and workstations utilize lean tools to identify and eliminate all types of waste, reduce costs, optimization of systems, processes, and organizations [2]. Lean manufacturing ensures continuous improvement in all processes involved in the manufacturing environment [3]. The philosophy can be applied in automobiles, chemical engineering, logistics, or any other type of manufacturing. As stated, waste elimination is the essence of the entire lean manufacturing.

Manufacturers are adopting new methods and techniques to make products in the current global environment and to increase their competitiveness in the market. Currently, industries face significant challenges in adjusting to the changes that come with the fourth industrial revolution [4]. As a result of this issue, industries have been gradually growing, focusing on product and service quality in order to maximize productivity and profit [5]. A waste is defined as all non-value-adding activity in the production system. There are eight types of waste that must be eliminated in the manufacturing chain, which are transportation, over-processing,

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inventory, overproduction, motion, waiting, defects, and talent [4]. Waste occurs in all activities of not only manufacturing, but also in all business processes, and tertiary industries.

Motion waste is the unnecessary movement within the workspace and is considered a silent killer of the workshop or plant productivity. It is basically caused by incorrect facility layout, inefficient use of human resources, excess of other wastes in the workspace, etc. [6]. Hence, it is very important to identify the actual cause of the motion waste followed by developing standard operating procedures and improving the workspace layout and organization.

The overall system improvement is determined by the structure of the plant or organization, the type of product or service, and the intensity of the manufacturing process or operations. One of the issues that have an influence on system performance is determining the layout of the facility, which is referred to as the plant layout problem [7]. The application of lean manufacturing principles to plant and facility design improves the organization's flexibility as well as its competitiveness by eliminating or reducing waste (s) and improving efficiency and productivity [5]. This research is novel in the sense that it intends to close the possible gaps related to the industry's requirement for successful integration of lean manufacturing and space utilization targeting motion-related waste.

2. LITERATURE REVIEW

There are various past studies available on the implementation of lean manufacturing conducted by researchers and engineers to eliminate waste, improve workplace organization, enhance efficiency and productivity, etc. This section provides an overview of some selected past works.

Lean manufacturing is derived from a variety of techniques that were developed by the Toyota Production System (TPS) to adapt to mass production. Workers and work cells are made more adaptable and efficient by acquiring methods that assist in identifying and eliminating waste [8]. Lean philosophy is centered on prioritizing the customer’s demands. It is important to understand customers’ values because they allow companies to understand the type of waste, and how to eliminate it using lean techniques and tools. Lean manufacturing has improved to a management approach driven by continuous improvement. Organizations began to utilize lean tools to improve shop floor control. Lean is a method of management based on human factors that encourages workers to put their mindset towards reducing costs and waste [9]. Many companies fail to understand the positive effect on productivity when a lean system is simultaneously implemented with ergonomic principles. The human element is a vital aspect of continuous improvement and sustainability, according to the lean manufacturing technique. From a Lean viewpoint, ergonomics increases productivity, improves quality, and optimizes safe human performance. The integration of lean and ergonomics can assist in reducing waste and safety risks associated with ergonomics.

In an important study, after implementing lean manufacturing, a reduction of 4.79% in lead time was achieved for a furniture industry case [10]. A recent study reports the importance of lean manufacturing in the label printing industry for improving efficiency and reducing wastage using value stream mapping as one of the powerful tools [11]. In a crankshaft manufacturing company, after implementing the lean strategy with value stream mapping, researchers have obtained approximately 70% reduction in inventory and lead time [12].

An important tool of lean manufacturing i.e. 5S is one of the extensively utilized techniques for workplace organization to reduce waste, enhance efficiency, and improve productivity [13]. In the metallurgical industry, research has been done on the difficulty experienced in the working cells when completing material cutting, welding, and shaping. To make it more efficient and safer, the 5S technique was applied. The implementation of the tool provides a concise problem-solving solution with reduced costs and a significant beneficial impact. Therefore, this indicates that implementing lean techniques and approaches results in several health and safety benefits [14]. The success of 5S implementation in the labs of a mechanical department at an international institution has recently been highlighted in research. The 5S concept was adopted in a university engineering laboratory to improve work and safety. As a result, a laboratory-wide organizational culture of all resources has emerged. University laboratories have evolved into industrial laboratories, conforming to the metallurgical industry's safety and organization requirements. The knowledge, control, and maintenance of the resources and activities involved may be completed in less time and for a lower cost. The amount of area available for resource placement has also increased [15].

The implementation of lean manufacturing systems will always begin within the existing facility layout. Therefore, the arrangement of the facility has a tremendous impact on the company's development and space utilization. Planning the layout of the facility is an important design element that has an impact on the system's productivity and efficiency [16]. There was an important program called "Systematic Layout Planning" developed that provides layout engineering standards and has been chosen to be effective in designing and formulating the requirements for the layout of the facility [17]. Production schedules run more smoothly with an effective facility plant architecture, which also reduces costs and unused floor space. The facility planner must make sure that the layout of the building allows for some flexibility and creates a safe and healthy work environment. In-effective design results in crowded areas, inefficient use of equipment, idle time, product degradation, and bottlenecks.

Lean Six Sigma is built on the widely used approach known as DMAIC. It is known that to improve performance, Lean Six Sigma is a team-oriented management strategy that removes waste, such as physical resources, time, efforts, and faults. The DMAIC technique, which was first employed in manufacturing processes, is now widely adopted in numerous service businesses, particularly in the financial and healthcare sectors. In DMAIC, the issues are Defined, variables affecting the process are Measured, sources of the problems are Analysed, improvements are designed and implemented, and variables are monitored until customer satisfaction is optimized, the DMAIC methodology can be used in the production to manage processes.

Based on the recent literature, it can be concluded that as one of the important industrial engineering tools, lean manufacturing, can be used in a variety of sectors and areas for waste reduction, safety, and organizational effectiveness. The need to close the implementation gap for lean and space utilization remains and seeks a substantial contribution to long-term industrial sustainability. In addition, there is no literature on the subject of Lean Manufacturing evaluation that uses a conventional facility planning approach. The research reported in this article fills that gap by conducting a preliminary benchmark analysis of a case organization to assess its lean implementation using the facility planning method.

The aim of this research work is to utilize the space of the considered machining shop by systematizing the layout of machines to reduce motion-related waste to eventually enhance efficiency.

3. MATERIALS AND METHODS

In this case study, the metal cutting shop of the mechanical workshop of the university has been selected after identifying layout flaws. In other words, in the process of metal cutting, the arrangement or layout of machines is not according to the relativeness of machines, in the mechanical workshop. Due to such layout flaws, the operator was bound to skip certain closer machines to perform operations in the next machine, and when completed, the operator moved back to another machine. The movement between machines results in waste called motion which can be eliminated. This type of waste shares most similar causes with transportation [18]. This is the waste contributed by operators who move around the workshop without doing any productive work. The workshop's limited space makes it difficult to allow certain movements. This type of waste can be eliminated by integrating lean facility layout and 5S to improve the workplace organization and arrange the facility equipment, and machines in the most effective manner which will reduce motions that do not add value to the workshop operation. According to Fig. 1, a cause-and-effect diagram (also called a fishbone diagram) is used to determine the primary and secondary causes of unnecessary motions.

There were machines in the workshop which were not operational due to poor maintenance and/or breakdown. Maintenance of machines is a significant need as it prevents machine breakdowns and improves the accuracy of machines thus reducing the chances of producing defective finished products. Most of the breakdown of machines in the workshop is found to be the result of an inexperienced operator. There exists a 5 why (nonoperating machines, machine breakdown, poor maintenance and unskilled operators, lack of training, unutilized talent) root cause analysis which requires solving the last 3 why root causes in order to improve the whole system. There are technicians around the working area to assist students who are the first operators.

A key tool for identifying and problem-solving is data collection and analysis. With the appropriate data analysis, the nature of the issue under investigation can be easily revealed. The data gathered and evaluated support this statement that the excessive distance people walk within the facility is a problem brought on by a poor facility layout in this research. Fig. 2 shows the work breakdown structure of how the collected data was analyzed and used to develop improvements using DMAIC. This research uses a quantitative approach to analyze the data. Data in numerical form is collected as part of the procedure using observations, literature, and discussion with the facility stakeholders. A detailed discussion of the stepwise methodology adopted in this research is given here as under.

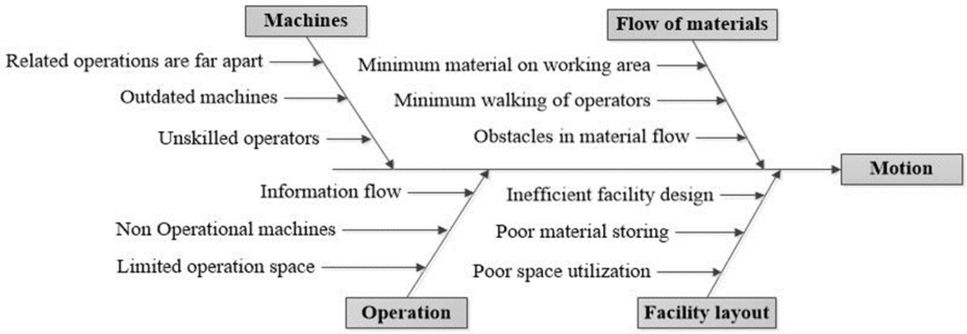

Fig. 1. Cause and effect diagram for the present study

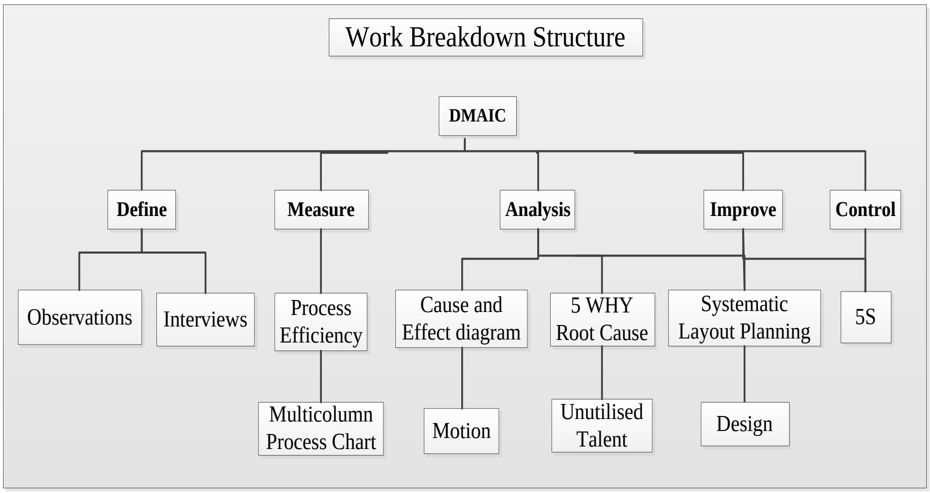

Fig. 2. Work breakdown structure (WBS) for DMAIC implementation in the present research

Workplace organization is one of the cornerstones of lean manufacturing. The tool is used as a method to improve the efficiency and productivity of the organization by organizing and maintaining the workplace [19]. 5S techniques ensure space organization and cleaning, systematic item storage, disciplined material flow, employee travel time reduction, process improvement, accident prevention, and safety enhancement. Refer to Fig. 3a which shows the status of the workshop before 5s implementation and the status after 5S implementation is shown in Fig. 3b. The meaning of all 'Ss' in 5S is as follows [20]:

1. Sort: The step focuses on removing an unnecessary object from the workplace. To ensure that it does not interfere with productivity or the available workspace.
2. Set in order: Organize and put everything in its proper position, with a place for everything.
3. Shine: To get rid of contamination, clean the workplace. Whenever the workplace is organized, it is simple to spot problems.
4. Standardize: Document the information.
5. Sustain: Ensure the standards are applied.

This stage makes sure the 5S system is applied constantly by training new operators.

A program called "Systematic Layout Planning" is very useful for planning and developing layout engineering standards. A layout process must go through a number of stages, including various procedures that have been regulated and organized into a foundation in accordance with SLP, as presented in Fig. 4.

(a)

(b)

Fig. 3. Workshop status before and after 5S implementation

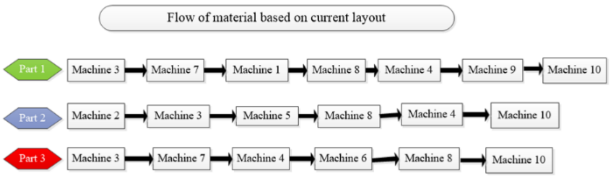

Fig. 4 Flow of material

Step 1: Input data and activities

Table 1 shows the number of machines that are available in the workshop. There are 10 machines available, according to the 5S, machines that are not working must be separated from the total operating machines. In the analyses of machines, the researcher will use numerical codes to refer to machines as illustrated in Table 1.

Step 2: Identify the flow of material

Planning out the steps of the material process begins with conducting a material flow analysis (MFA), also known as a process flow analysis. MFA is used in practically every step leading up to manufacturing. A thorough examination might reveal opportunities for workflow improvement across several manufacturing facilities.

In the case of the workshop, there are 3 parts processing in the facility which follow different routing sequences. Fig. 4 shows the processing sequence each part undergoes from raw material to finished product. The flow analysis will help to understand the relationship between machines and slightly provide the guideline for achieving effective machine arrangement.

Table 1. Status of workshop machines availability and conditions

Code	Description	Status
Machine 1	Lathe 1	Working
Machine 2	Larger saw cutting	Working
Machine 3	Bench saw cutting	Working
Machine 4	Grindstone	Working
Machine 5	CNC 1	Working
Machine 6	Station Table	Working
Machine 7	Press machine	Working
Machine 8	Drilling machine	Working
Machine 9	Belt sander	Working
Storage 10	Storage	Working
Machine 11	CNC 2	Not working
Machine 12	Buffer	Not working
Machine 13	Drilling machine 2	Not working
Machine 14	Grinding	Not working

Step 3: Activity Relationship Chart (ARC).

The activity relationship chart is the facility layout planning tool that is used to evaluate the need for the closeness of machines in the facility. ARC uses code letters A, E, I, O, and U to explain the closeness of each machine to other machines [21]. Furthermore, codes 1, 2, 3, 4, and 5 are used to justify the need for the closeness of machines, refer to Fig. 5.

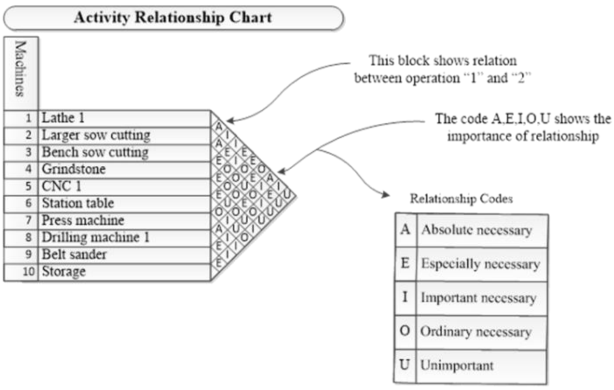

Fig. 5. Activity relationship chart (ARC)

The use of A code should be limited to the flow of materials and machines that perform an almost similar task. For example, larger sow cutting, and Bench sow cutting are absolutely necessary to be close because they perform almost similar tasks. The need for a close relationship between the press machine and the drilling machine is justified by the reason code 1, to ease the flow of material, refer to Table 2.

The use of A code should be limited to the flow of materials and machines that perform an almost similar task. For example, larger sow cutting, and Bench sow cutting are absolutely necessary to be close because they perform almost similar tasks. The need for a close relationship between the press machine and the drilling machine is justified by the reason code 1, to ease the flow of material, refer to Table 2.

Use E codes when the researcher is unsure if the link between two machines falls under an A code. The relationship between machines is assigned an E code when there are a lot of materials following between them but not often [22]. For example: the bench saw cutting and the grindstone machine need to be closer because most parts after cutting proceed to the grinding machine. The closeness of the belt sander and storage is justified by reasoning codes 1 and 2, refer to Table 2.

Using I and O codes when a certain level of importance is required; however, these proximity codes are less efficient than the others. Leaving these codes out of the first several layout suggestions is not a good strategy. For example: the bench saw cutting and the grindstone machine need to be closer because most parts after cutting proceed to the grinding machine. The closeness is justified by the reasoning codes 1 and 4, refer to Table 2. U codes are useful since they show when there is no need for an activity or an interface between two machines. The machines might be situated apart from one another.

Table 2. Relationship reasoning codes

Code	Description
1	Flow of material
2	Safety
3	Noise
4	Security purpose

4. RESULTS AND DISCUSSION

The primary layout and design plan will be built upon this layout in Fig. 6 even though it has no dimensions. Space will be allocated to each machine in accordance with the structure of the dimensionless block diagram once the facility's size has been determined [23].

Steps 4 and 5: Space requirements and availability

The space allocation for machines is given in Table 3. The facility space was obtained by measuring the space with the assistance of the workshop technician. The measurement will be used to fit the machines in an arrangement that will improve space utilization.

Table 3. Machine space allocation

No	Name of machine	Space required	Total area (m^2)
1	Lathe 1	1m x 3m	3
2	Larger saw cutting	1,5m x 0,5m	0.75
3	Bench saw cutting	1m x 1,5m	1.5
4	Grindstone	1,5m x 0,5m	0.75
5	CNC 1	1,5 x 3,5	5.25
6	Station Table	1m x 4m	4
7	Press machine	1m x 1.5m	1.5
8	Drill machine	0,5m x 0,5m	0.25
9	Belt sander	1m x 1,5m	1.5
10	Storage	2m x 4m	8
Total area required			26.5

Step 6: Modifying considerations and practical limitations

Facility layout limitations

When developing a proposed facility layout, there are certain restrictions that must be taken into consideration.

- Some machines within the arrangement are fixed in place, including the Lathe 1, CNC 1, Station Table, and Storage. The machines cannot be moved because they are big and heavy. Since moving or changing the facility's size won't be possible, this will be considered.
- The workshop's physical structure cannot be changed since the costs would be an unacceptable expenditure for the management. This covers both the facility's shape and the overall amount of space available.

Step 7: Design alternatives

Layout Alternative 1 was developed through the implementation of 5S.

The layout alternative was designed after the implementation of 5S and industrial tools with the aim of eliminating waste and optimizing space utilization. The layout has shown to have made improvements in the facility but has no effect on the process of production and offers a minimum space utilization improvement, refer to Fig. 7.

The layout Alternative 2 was developed through systematic layout planning.

The layout is developed by following systematic layout planning (SLP) steps. SLP is the tool used to construct a lean facility layout. The implementation and analyses of SLP were conducted following the procedure shown in Fig. 8. Practical limitations were considered when developing this proposed layout.

The objectives of this design were to ensure that the layout should have the following:

1. Clean facility layout with the help of 5S implementation.
2. Less traveling distances between machines and less backtracking.
3. Improved space utilization.
4. Reduced waste.
5. Enhanced safety and efficiency.

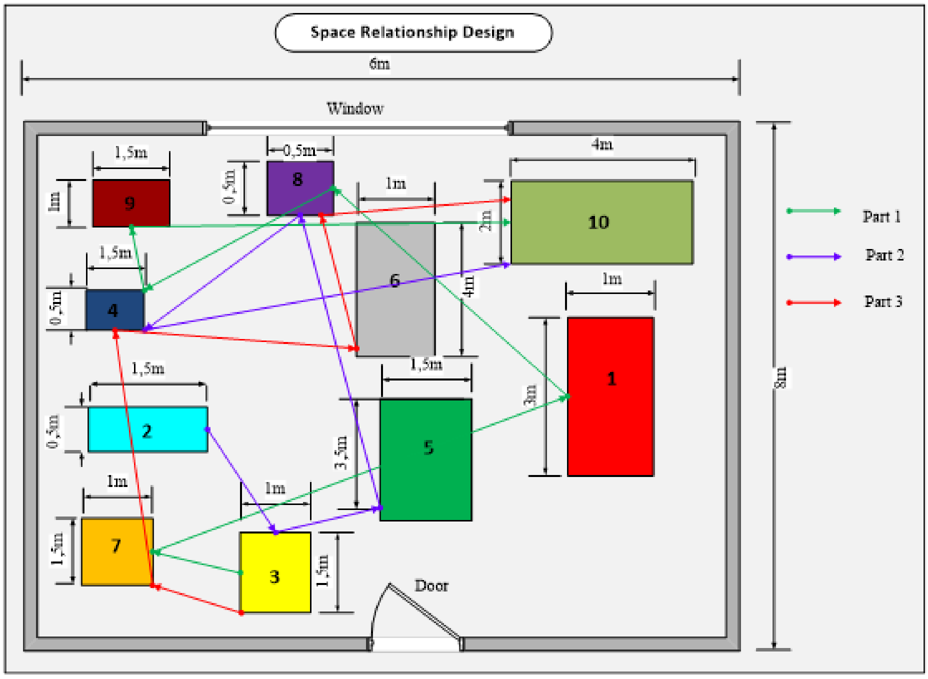

Fig. 6. Space relationship design

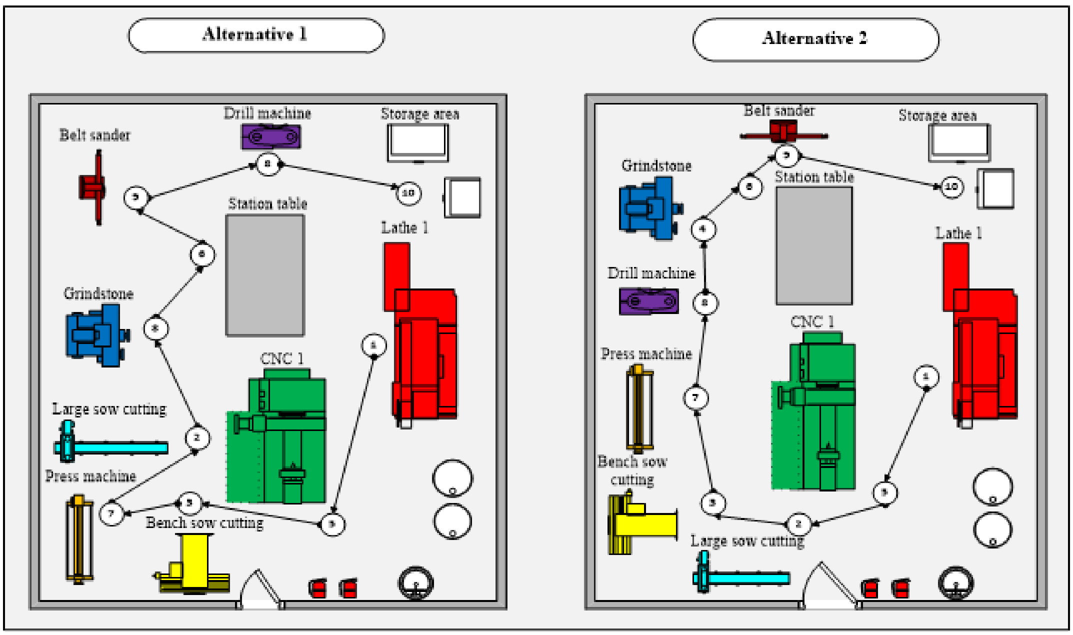

Fig. 7. Proposed alternative layout

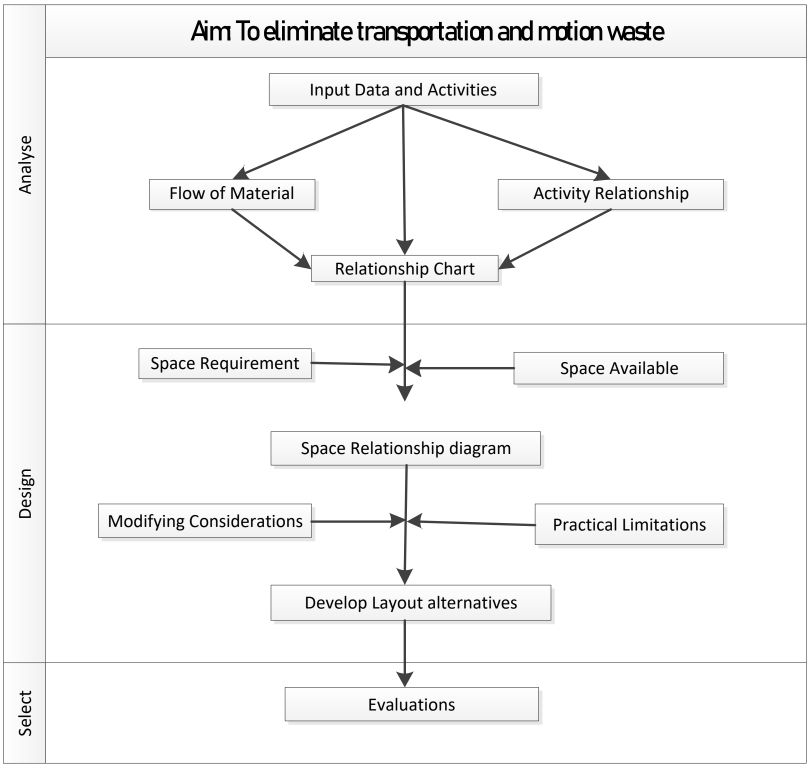

Fig. 8. Systematic layout planning

Step 8: Design evaluations and selection Flow analysis

The core of a plant's layout and the first step in a material handling strategy is flow analysis. The machine arrangement flow is the route it travels as it moves through the manufacturing facility. The designer of the production plant will benefit from flow analysis in determining the optimal arrangement of equipment, facilities, and workstations [24]. Improving flow analysis will eventually increase profitability. In general, the goals of flow analysis are to reduce the travel distance, backtracking, cross traffic, and motion waste; and to enhance safety, machine efficiency, and overall profitability. This work quantified cleanliness, improved space utilization, and achieved a reduction in travel distance and backtracking i.e., an overall reduction of motion waste, in terms of process efficiency. In other words, the reduction in motion waste, and improvement in space utilization, arrangement, and cleanliness, have led to the enhancement of the efficiency that is quantified as below.

Based on the workshop, there are 3 parts that can be prepared, and they go under various arrangement processes (routing sequence) as presented in Table 4. In this work, a multicolumn process chart is used to evaluate the flow analysis. Fig. 9 shows the flow analysis of layout alternative 1 and Fig. 10 shows the flow analysis of layout alternative 2.

Table 4. Process routing sequences

Part number	Routing sequences
1	3 7 1 8 4 9 10
2	2 3 5 8 4 10
3	3 7 4 8 10
Alternative 1 machine arrangement	1 5 3 7 2 4 6 9 8 10
Alternative 2 machine arrangement	1 5 2 3 7 8 4 6 9 10

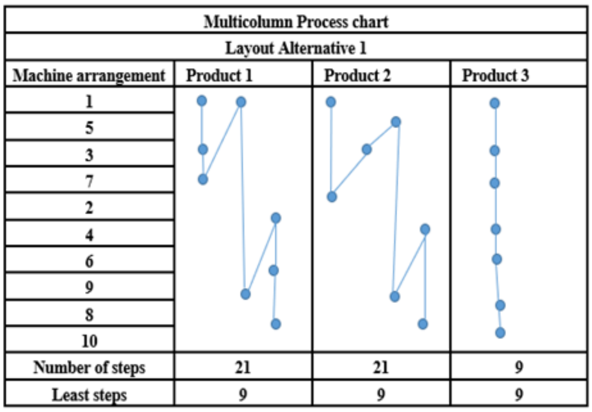

Fig. 9. Alternative 1 multicolumn flow analysis chart

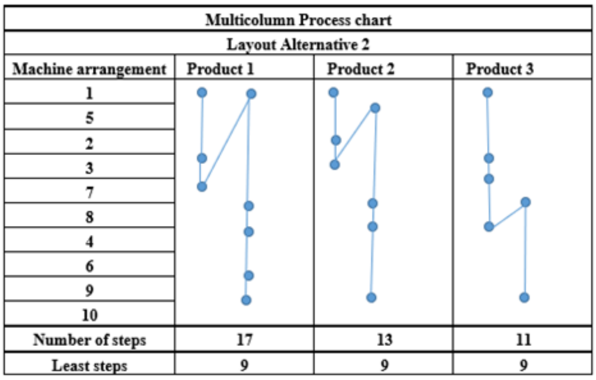

Fig. 10. Alternative 2 Multicolumn flow analysis chart

4.1 Calculation of process efficiency

The ratio of the total least steps to the total steps determines a process' overall efficiency. The workshop can achieve its intended profitability while ensuring smooth material processing and reducing costs by increasing process efficiency. An improved process efficiency shows an efficient arrangement of machines.

Alternative 1

$$E_1 = \frac{Total\ least\ steps}{Total\ number\ of\ steps} = \frac{27}{51} = 0.529 \approx 53\% \quad (1)$$

Alternative 2

$$E_2 = \frac{Total\ least\ steps}{Total\ number\ of\ steps} = \frac{27}{41} = 0.659 \approx 66\% \quad (2)$$

It is evident from the Equations 1 and 2 that Alternative 2 is the efficient alternative. According to equation 1, layout alternative 1 has 53%, and layout alternative 2 has increased to 66%. This arrangement may further offer shorter overall travel distances between the machines, lower implementation costs, and feasibility for cleaning, space enhancement, and utilization for effective motions. Each of the numerous spots shown on the plan will be taped off and labeled. Everything has a designated place where it belongs, and the movement of people, information, and materials is effectively considered. It is expected that this will lead to improved housekeeping and keep the layout safe for the workers.

The improvement of the design efficiency of a facility can reduce the time and effort needed by the production system while also offering important material handling benefits. Effective utilization of space is essential because it reduces waste creation. For an institution to have a productive and effective manufacturing workshop, special consideration must be given to facility layout. A facility design should consider the quantity of available space, the final product, the facility's safety, and the people using it.

5. CONCLUSION

In this research, the Systematic Layout Planning (SLP) technique along with other tools is implemented to fulfill the requirements of a lean facility layout related to the reduction of motion waste, improving organizational effectiveness, and efficiency enhancement. Following the DMAIC approach, an alternative facility layout is developed in the case of the machining shop of the central workshop, taking into consideration the safety of people, space utilization, machine operation efficiency, and offering operators training prior to using the machines. Machines are arranged to optimize the routing sequence that parts undergo from raw material to finished product which eliminates waste caused by unnecessary motions. As a result, the process efficiency is improved from 53% to 66%.

The results are noteworthy and motivate us to further implement lean manufacturing tools in other facilities of the institutional setup for waste reduction and organizational effectiveness. The methodology presented and outcomes of this research are useful to other scholars and researchers to further attempt the SLP technique, DMAIC, and combinations of other lean tools to reduce and eliminate various waste types from an organizational facility and setup.

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