DESIGN AND ANALYSIS OF A LEAN MANUFACTURING LABORATORY LAYOUT

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by

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Currently, there is a need for lean laboratory spaces in educational institutes. Applying lean principles contributes positively to the enhancement of educational institutes’ adaptability and comfort. The purpose of this research is to develop a lean laboratory layout concept design for future use. The focus is on the manufacturing laboratories. The goal is to understand limitations and deficiencies of existing layouts. This involves wastes, space, and workflow analysis in educational laboratories. Therefore, a case study of an existing manufacturing laboratory is presented for analysis. The case study indicates that there is room for improvement in order to have efficient, organized, and flexible work in laboratories. In order to design a lean laboratory layout, several techniques based on lean principles are used in this research such as the analysis of the current layout limitations, the analysis of the existing wastes, and the analysis of space utilization. Based on these analyses, a new lean-based layout is proposed that can be used as a template by manufacturing programs in educational institutes.
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Chapter 1: Introduction

1.1 Problem Statement

Currently, there is strong competition among the US educational institutes in terms of recruiting students and providing them with a high-quality education. Laboratory infrastructure is a critical component of quality education in science and technology programs. The problem with such programs is that the laboratory facilities design is considered in many cases as an afterthought, and not properly planned and implemented with a holistic perspective. This is especially true among the manufacturing centers, where different units are not integrated properly. Various laboratories within these centers, such as CAD labs, CNC labs, and Robotics labs are managed independently. In industry, these various stages of manufacturing need to work together in a concurrent manner.

The goal of this research is to study an existing manufacturing center at an educational institute as a case study in order to understand limitations and deficiencies, and then recommend a generic layout based on lean principles, which addresses the deficiencies of the current facilities design. Lean principles and technique such as Waste Reduction and the Five (5) S’s as well as analysis of several factors will be used in the improvement of the educational laboratories.
1.2 Scope of the Thesis

The goal of lean-based manufacturing laboratory layout is to improve the student experience at school by addressing existing issues, such as the improper processes design, the lack of standard work methods, and the inappropriate workplace design and layout. Because the existing manufacturing system laboratories do not meet the lean standards, there is a need for improvement. Applying lean principles is one of the most effective ways of ensuring efficiency and effectiveness in the educational environment. This research will analyze the limitations in the existing laboratory layout and present lean methods in order to overcome these limitations. Lean techniques such as Waste Reduction and Five (5) S’s Principles are addressed in this research. Eventually, this research develops a lean laboratory layout concept design for future use.

The waste reduction approach plays a crucial role in industrial and educational organizations that strive to achieve perfection in providing products or services. Therefore this approach adopted in this research provides a better understanding about existing wastes in educational institutes. This research classifies, determines wastes that occur in educational environments and suggests the methods to eliminate them. This arranges the floor and supports the process of enhancing lean concepts.

The five fundamental principles, also known as the Five (5) S’s elements, are one of the most important methods in Lean. Therefore, this research addresses these principles as they are consolidated to produce a single, yet powerful tool for effectively and efficiently overseeing, managing, and administering a successful work framework. Additionally, the Five S’s components provide constant value creation to students, staff, and research as well as help in bringing the entire system together and in making complex operations simple and smooth in their
running. By presenting the Five S’s Principles, this research offers an approach that results in a clean workstation, reduced waiting time, improved shop floor, reduced accidents/incident rate, improved storage system, reduced transport and movement time, and improved equipment reliability and usability. Moreover, the utilization of the Lean Five S’s maximizes chances to meet lean standards.

Applications of lean manufacturing in other fields, such as healthcare, construction, automation, food industry, and electronics, are also presented in this research. It demonstrates the importance of lean in any organization and gives more understanding of lean methods since it describes how other fields use lean techniques and methods in order to maximize benefits for an organization or a workplace environment.

Furthermore, this research presents an analysis of a manufacturing systems laboratory in an educational institute. The analysis focuses on the limitations of the current layout, space utilization, and existing wastes. Observations of wastes are collected and analyzed to determine the main causes. Laboratory technicians’ perspectives are included in the research.

1.3 Organization of Thesis

The organization of the thesis is as follow: Chapter 1 contains the problem statement and the scope of the thesis. Chapter 2 presents reviews of literature in lean systems, applications of lean in various fields with a special focus on laboratories, and a literature review’s conclusion. Chapter 3 presents a case study, which is an analysis of an existing manufacturing laboratory layout. Chapter 4 presents lean laboratory layout concept designs, the comparison between various concepts, and a detailed design (CAD Layout) that can be used by different educational institutes. Chapter 5 contains conclusions and future research.
Chapter 2: Review of Literature

2.1 Definition of Lean

In manufacturing, the definition of lean is eloquently captured in the work of Womack, Jones, and Ross (1990) titled *The Machine That Changed the World*. In that volume, the authors focus on the process of the reconstruction in assembling as was the case in the Toyota Production System. That type of assembling is what is referred to as the 'lean system.' Basically, the lean system helps manufacturing companies to enhance value, improve value addition, and to ensure a smooth production process that minimizes waste and increases value for the customer (Womack; Jones; & Roos, 1990).

Thus, lean is a process that increases efficiency and effectiveness of the system by reducing interruptions, wastes, and other production problems. It is a network for binding the way an enterprise surveys design execution. It is also an information-based system and takes quite a long to perfection, as it requires commitment, readiness, and support from senior administration. Any other industry can apply lean principles provided it requires manufacturing and production of goods. Thus it is not only restricted in the automotive manufacturing industry. Besides the administration backing which is crucial in the lean system, adherence to policy and legal requirements is also crucial for enhancing the lean process (Womack, et al., 1990).

In lean manufacturing, the main goal is to engage in as many efforts as possible to utilize resources in the right and meaningful ways while trying as much as possible to minimize wastes, (muda-Japanese world), all these with the aim of adding value to the final product. At the end of the day, the lean system is focused on recognizing inefficiencies in the manufacturing process while attempting to increase the worth of the outcome. But that goal of attaining efficiency would not be reached without a method that the lean system uses, which is called customer-value
orientation that ensures that the final product is perfect and without any errors. According to Feld (2000), lean offers significance to basic and consistent improvements that will not just kill squanders, but also ensure value addition to final products (Feld, 2000).

2.2 Lean and Waste

The basic process of lean is to remove waste during the manufacturing process with an aim of achieving a high quality of product or service, customer satisfaction, and benefits. Therefore defining what waste in lean manufacturing, especially from a consumer point of view, is fundamental. Waste is recognized as an activity where non-value is added in a process (Emiliani; Stec; Grasso; & Stodder, 2013). At the end of the day, where there is waste, the customer does not get any value and hence, the process is viewed as waste. For instance, some of the processes that are regarded as waste include, revise, repair, and set-up time. Then again, Lean portrays the activity as value addition, non-value, and waste. While value addition activities change materials as per client desires, non-value addition is characterized by the waste that is supposed to be eliminated to ensure value addition for the purposes of customer satisfaction.

To better understand the process of the lean system and how to turn it for efficiency purposes, it is prudent to comprehend the value added, non-value-added activities. Moreover, there is little contrast between waste and non-value addition, which means that a careful knowledge of that is needed. For instance, a company perceives machine set-up time as a waste, even though it is fundamental to enhance value addition in the process. However, The set-up time is regarded as waste if it is not minimized.
2.3 Types of Waste

1. Overproduction

This is when a process produces more than is required by the consumers. In any case, overproduction is time-consuming and leads to wastage of materials and other resources (Kilpatrick 2003). Additionally, overproduction is when a product comes with many extra features that are not necessary (Emiliani, et al. 2013). That can be rectified by adopting the Just-in-time (JIT) or a pull system.

2. Waiting

According to Hicks (2007), waiting refers to the process of waiting for the trickling of upstream activities. Specifically, it is the period between when materials, tools, equipment, and data, among others, are ushered to the succeeding production stage. To minimize wastage in waiting the method of JIT is mainly adopted (Kilpatrick, 2003).

3. Transportation

Wastage in transportation is the pointless movement of materials from one point to another, such as during work in progress (WIP) or from the warehouse to the factory. Moreover, poor design of the workplace floor that require unnecessary movement from point A to point B is deemed a waste of transportation. This waste can be reduced by a careful plan of shop floor and the utilization of the process known as “point-of-use-storage” (Kilpatrick 2003).

4. Over-Processing

Whenever there is reprocessing, rework revamping and long inspections, this is what is termed as over-processing. At the end of the day, these activities do not increase any significant
value looking at it from the consumer perspective (Hicks 2007). In lean, there is a process referred to as “value stream mapping” which can be used to minimize over-processing (Emiliani, et al. 2013).

5. Excess Inventory

Excess inventory refers to an excess stock that cannot be utilized to meet the current client demands. These inventories, which include crude materials, work in progress (WIP) and finished products, take up space and require some maintenance; hence, they are considered as wastes if they cannot be used immediately. Excess inventory has been found to adversely impact on cash flow as well as the product worth (Licker 2007).

6. Defects

Any product or service that fails to meet client needs or fails the quality check is deemed a defect. Defects are wastes because they eat unnecessarily into resources and reduce customer satisfaction and eventually infringe on their loyalty. To reduce defects, revision or rework is necessary, but all the same, the waste will increase due to more use of resources, including labor, materials, and time, among others (Hicks, 2007; Kilpatrick, 2003).

7. Excess Motion

Excess motion is any superfluous movement, such as from one office to another, or frequent unnecessary visits to other departments due to poor planning of operations. To avoid this, carefully planned operations, such as the use of intranet, local area network, and a company database are important for reducing this excess motion waste (Emiliani, et al., 2013).
In addition to these seven waste types, Licker, 2007 included "Underutilized People" as the eighth classification of lean waste.

Table 2.1: Wastes in Educational Laboratories.

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overproduction</td>
<td>- Over use of resources and materials in a single process.</td>
</tr>
<tr>
<td></td>
<td>- Unnecessary duplication of activities.</td>
</tr>
<tr>
<td>Waiting</td>
<td>- Unnecessary time wastage while waiting for materials that need to arrive from other sections.</td>
</tr>
<tr>
<td></td>
<td>- A group of students queueing for another group to finish the lab activities.</td>
</tr>
<tr>
<td>Transportation</td>
<td>- Resources decentralized from point-of-use.</td>
</tr>
<tr>
<td></td>
<td>- Unnecessary Movements from one functional area to another.</td>
</tr>
<tr>
<td></td>
<td>- Students and employees need to walk to a different facility to complete a step of a process.</td>
</tr>
<tr>
<td>Over-processing</td>
<td>- Use of extra resources such as space, energy, and people.</td>
</tr>
</tbody>
</table>
Redundancy, such as having extra-unused features.

Excess inventory
- Having materials or stock, not for immediate use.
- Waste of space and impact on workflow.

Defects
- Rework, imperfection, wrong parts, missing parts, and wrong methods
- Repetitions
- Poor planning

Excess Motion
- Time-consuming while searching, reaching, walking, choosing, turning, arranging, and moving items from one point to another (Parminder and Lawrence, 2014)

2.4 Five Principals of Lean

Lean depends on five principals, which act as the foundation for the successful execution of the framework, see Table 2.2 below. A successful execution of these principles guarantees a smooth and hustle-free procedures with minimal waste, hence high-quality services that ensure customers are satisfied and that the organization maintains sustainability (Parminder and Lawrence, 2014).
Table 2.2: Five Principals of Lean

<table>
<thead>
<tr>
<th>Lean Principal</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify Value</td>
<td>The most important thing to do in lean is to identify what the value is. This entails determining the clients, what their needs are, at what price they are willing to pay and the place and time they want a product or a service. Additionally, it is vital to identify the right materials for use, and what activities to be engaged in to achieve the need. Everything else beyond that is to be considered as waste.</td>
</tr>
<tr>
<td>Map the Value Stream</td>
<td>Mapping the value stream guiding the production process to ensure that every process or activity falls within the boundaries of increasing value.</td>
</tr>
<tr>
<td>Create Flow</td>
<td>Creation of flow entails ensuring a stream of activities and processes such that there is minimum wastage from interruptions or any other kind of waste.</td>
</tr>
<tr>
<td></td>
<td>This entails taking time to understand what the customers need and setting up a system</td>
</tr>
</tbody>
</table>
Respond to Customer Pull for meeting those needs, such as offer one make one.

Pursue Perfection Perfection is a continuous cycle and therefore, producers are to improve their system by always and constantly adding new needs and eliminating new kinds of waste towards a hypothetical point of integrality (Parminder & Lawrence, 2014).

2.5 The five (5) Ss’

The 5 Ss’ components involve Sort, Set in Order, Shine, Standardize, and Sustain. Every one of these components consolidates to produce a single yet powerful tool for effectively and efficiently overseeing, managing, and administering a successful work framework. The 5S lean components are as follows;

Sort: Eradicating clutters and cleaning the workstation.

Set in Order: Cataloguing and grouping zones of work instruments.

Shine: Polishing and ensuring the workstation is spotless.

Standardize: Breaking down work into meaningful capacities, utilizing standard systems, and applying the best practices.

Sustain: Maintaining improvement, managing system approaches, and fusing the 5S's into the culture and entire system.
In the day-to-day operations of a company, the 5 Ss’ help in bringing the entire system together and in making complex operations simple and smooth in their running. A successful execution of these 5 Ss’ foster accountability and encourage high productivity while at the same time increasing efficiency, reducing interruptions and boosting cash flow (Al-Aomar, 2011). Additionally, a successful implementation of the 5 Ss’ would necessitate high improvement in inventory management as well as shop floor management hence minimizing waste. Moreover, it would help in the administration of best practice methods, such as cataloging, and classification of items for easier storage and identification. Such approaches provide an opportunity to practice high-end practices applied in lean systems of successful manufacturing approaches, such as cellular manufacturing, TPM, and JIT.

Also, application of the 5 Ss’ improves several areas of production leading to a successful process that is enjoyed by both the organization and the customers, including: clean workstation, accountability, reduced set-up time, reduced waiting time, improved shop floor, reduced accidents/incident rate, improved storage system, reduced transport and movement time, and improved equipment reliability and usability (Al-Aomar, 2011).

2.6 Spaghetti Diagram

Spaghetti diagram, also known as plot or spaghetti chart, is defined as a drawing that portrays a route or a flow of several things which include but are not limited to: a factory or workshop’s raw material flow, the steps followed by a hospital staff e.g. a nurse or that of a patient in the hospital, the process that transfers a file across several offices and even a human service employee within their working environs. The drawing explains how intense the route is and it creates a shape that looks like spaghetti on a plate and therefore the reason why it is named so. It is used to show the amount of distance that has been covered in a back and forth journey
and the time that has been misused. Part of the reason that this is done is people do not really know distances that they walk in a day in organizations, management is also not aware of the time that is used in movement and the time that is wasted in the process. A spaghetti chart, therefore, can be used by an organization to change the layout of the office and make movement less so that they can increase productivity and fatigue through saving time that was being wasted. In other instances, the order that the steps are in is what will change so that efficiency can be met. A spaghetti diagram will, therefore, show the process and the theoretical route while the spaghetti chart will show the future and the actual process. They can be drawn through observations; there is an already laid out structure of the environments or facilities and all the observer has to do is draw the lines to show the route. To draw an effective diagram, there are several tricks and tips that can be used and they include: drawing to the best scale so that the calculations of things like the total distance can be easy. If there is a back and forth trail, they should be drawn differently so that they can be differentiated and calculated in the right way. The drawing should depict the real route and it is therefore not advised to draw straight lines but the real route; if there is no information on the scale, steps can be counted and an average calculated to be used in the overall calculations (Hohmann, 2016).

2.7 Applications of Lean in Various Fields

Lean is not only limited to manufacturing, but it has been beneficial to other fields such as Health Care, Automation, Food Industry, Construction, and Electronics.

2.7.1 Lean in Health Care Laboratories

Healthcare falls in the service sector due to the fact that most of the deliverables of the industry are intangible and include healing, recovering, and better health. However, healthcare also engages in some form of production such as in pharmacy. In this regard, the laboratory
layout may be designed in a lean fashion to capture the essence of waste minimization in the sector. Unlike traditional approaches where a few key sections of a facility could be optimized for lean production, overhauling the entire value stream yields superior production results (Joseph, 2006). For a laboratory design, the key to lean design lies in a layout that eliminates waste and encourages the cheap use of resources. Optimizing the layout directly solves the problems that workers deal with when handling materials in the medical premises.

One of the most important goals is reducing the weighted workflow by achieving the operational efficiency. Lean medical laboratory layouts require one to plan for growth and projections emanating from various activities. This entails thinking about space in the long-term in order to ensure that there are minimal chances of unnecessary part demolitions in future. Another key technique is developing the requirements of the space with a focus on functional areas (Joseph, 2006). For instance, the automated and manual key processes need critical components in terms of space and accessibility. Lastly, the lean laboratory design is sensitive to workflows meaning that it is necessary to develop high-level layouts via optimization. The weights, matrices, and quantities of workflow need to be optimized as much as necessary.

2.7.2 Lean in Automation

Unlike other production disciplines, automation and lean manufacturing are both modern work concepts. Some economists have hinted that there is the likelihood that these two techniques cannot co-exist. This is not entirely true as there are several work areas where one may be able to automate and employ lean production (Manufacturing Engineering, 2017). Automation can make use of lean technology in applications that employ flexible automation solutions such as vision-equipped and intelligent robots that boost efficiency in lean production in factories.
Lean technology in automation addresses the critical question of whether technology actually solves a problem or merely covers it up with more hurdles (Manufacturing Engineering, 2017). Automation allows technologists to save activity time and resources in various industrial activities. However, it introduces some problems such as wastage. This is where lean technologies come in. They separate technology for the sake of change from technology that allows industrial progression.

2.7.3 Lean in Food industry

The food industry fundamentally lies outside the production environment and can be said to occupy the agricultural and processing sphere. This does not mean that the food industry is immune to common processes that waste time and resources. In fact, the food industry has some of the greatest wastes on various levels of the supply chain (Borges; Freitas; Sousa, 2015). Some of the factors that have been identified as potential areas of interest when applying lean technology to food production include standardization, operations, workforce, and tools’ availability.

Applying lean technology in the food industry will require a framework that sets the appropriate standards. This can take the format of documentation that would detail changeovers and critical processes among other key issues. Poorly trained workers have been costing the food industry a lot in terms of waste (Cox and Chicksand, 2005). Setting up flexible regional training workshops can aid in passing critical knowledge to workers in the industry. Lastly, availing tools and opening working opportunities in the industry can ensure that lack of resources does not lead to unnecessary waste.
2.7.4 Lean in Construction

The construction industry can be defined as a production sector to the extent that it supplies buildings and roads to the society. Perhaps, the major difference between construction and other forms of production is the nature of the product. The deliverables in construction are usually produced in singular units, as mass production of houses is largely unimplemented. Construction is one of the most wasteful industries in the society. This is especially true for inexperienced contractors (Johansen and Walter, 2007). Broken construction materials, malformed concrete, irregular ends of reinforcement bars, and unused materials are a common sight in many construction sites.

Researchers have suggested that applying lean technologies to construction will require a thorough knowledge of the building process (Johansen and Walter, 2007). They have suggested that proper planning can solve the problem, especially with advanced construction planning. This would work by forcing the builders to utilize the waste construction materials in other sections of the project. Therefore, the planning would have to forecast the production and utilization of various waste materials.

2.7.5 Lean in Electronics

The electronics industry is also wasteful especially with respect to hardware. The industry has undergone rapid advancements in the past few decades that electronic products are getting obsolete extremely fast. Electronic companies are always rushing to implement better features on nearly a monthly basis. Consumers are participating in the destructive processes as they waste monetary resources to own the latest and newest. Lean technology is being implemented in this industry via reuse of old electronic parts and recycling (Jeyaraman and Kee Teo, 2010). The two processes will generally get rid of waste by lowering the price of many
electronic products, as customers will have an opportunity to simply update instead of upgrading their electronic possessions.

2.8 Conclusion

This chapter addresses the definition of lean, lean principles, the lean five S’s, and waste reduction methods. Additionally, the chapter illustrated how the implementation of lean can achieve the maximum benefits for organizations in various fields. Although there are many past research works on lean projects in various fields, there is still a gap in the literature as there are rare research initiatives on lean projects in laboratories, particularly manufacturing laboratories in educational institutes. This thesis contributes to filling this gap by focusing on the application of lean principles to the manufacturing laboratories layout in educational institutes.
Chapter 3: Analysis of an Existing Manufacturing Laboratory Layout: A case study

This case study is conducted in a small university in the U.S. that has a well-established manufacturing systems center. The engineering school in the university offers lean manufacturing principles in some courses, but one would ask: Do the students practice their experience in a lean laboratory? Or does the current laboratory meet the lean standards? The following analysis steps answer many questions, and forms a basis for lean laboratory layout design:

- Outline the limitations of the current laboratory layout.
- Analyze space utilization.
- Analyze the existing wastes.

3.1 Limitation and Distance Analysis of the Current Layout

The current manufacturing systems laboratory, which includes Computer Aided Design (CAD), Material Testing, and Manufacturing Automation labs, is improperly designed since its sections are located and managed within two different buildings. Figures 3.1, 3.2, and 3.3 below illustrate the facilities layouts respectively, which were provided by the university. Additionally, Figures 3.4, 3.5, and 3.6 show pictures of the current manufacturing systems laboratory. It has been noticed that the biggest drawback is that the laboratory sections are located on the first floor rather than being located on the ground floor. Heavy equipment, tools, machines, and materials would affect the building structure and the safety rating.
Figure 3.1: An Architectural Layout of the Manufacturing and Automation Section
Figure 3.2: An Architectural Layout of the Materials Testing Section

Figure 3.3: An Architectural Layout of the CAD Section
Figure 3.4: CAD Laboratory Section
Figure 3.5: Materials Testing Laboratory Section

Figure 3.6: Manufacturing and Automation Laboratory Section
Lean manufacturing techniques strongly recommend that each component in the laboratory should be at the point of use. One of the disadvantages of the current manufacturing laboratories is that there is the undesirable distance between laboratory sections. The walking time between the Manufacturing and Automation and the CAD sections is more than a minute. This improper design of location causes several wastes (Wastes in Lean) categorized under waiting, transportation, and motion wastes. These wastes will be determined later in this chapter. In addition, there is a street located between the two laboratory buildings, which results in great wastes. When students or staff want to move heavy equipment, tools, and materials between the two sections, they have to use stairs in each facility as well as they have to cross the street through the pedestrian lane. Moving heavy items between different laboratory sections, while a small vehicle or bus is passing the street, maximizes the wastes of time and waiting. In this case, the travel time between the two different laboratory sections will be much more than a minute.

3.2 Space Utilization Analysis

Space determination is part and parcel of laboratory layout. An optimal utilization of space contributes positively to the quality of the product or service provided by any organization or facility. However, it appears that the current manufacturing systems laboratory’s space does not meet the lean criteria. Additionally, the improper allocation of space affects the workplace negatively and add no value to students, staff, and research. Figures 3.7, 3.8, and 3.9 illustrate the unused areas in the current layout. These areas include a lot of scrap and rarely used items. It appears from figure 3.7 that the unused area is bigger than the CAD and Material Testing sections combined together.
Figure 3.7: The Total Area of the Manufacturing Laboratory

Figure 3.8: the Unnecessary Items in the Unused Area of the Manufacturing Laboratory
3.3 Analysis of the Existing Wastes

In order to design and improve a lean laboratory layout, several types of waste have to be analyzed. Wastes like processing, transportation, defects, waiting, and motion, should not be ignored. Otherwise, they might affect the workflow in any workplace or organization. However, Figure 3.10 below includes a waste observation sheet (adopted from Gemba Academy) that is designed in order to write down existed wastes in the current manufacturing laboratory on a continual basis.
3.3.1 Waste of Processing

It appears from figures 3.8 and 3.9 that the unused area in the manufacturing laboratory has a lot of excess items. Some of these items are rarely used or unneeded anymore for processes that being held inside the lab. Hence, these items unnecessarily take more space that can be used for other meaningful processes. This is called waste of processing since the unused items consume more resources than is required, such as space and handling equipment.

3.3.2 Waste of Transportation

The waste of transportation is the unnecessary movement of materials that does not add value to the provided services. This occurs when materials are stored away from the point of use, or students and staffs are moving materials between functional areas. It has been observed that the current design of the laboratory layout is an essential factor that maximizes the likelihood of transportation waste occurrence. Moreover, the location of the Material Testing section requires...
students and staff to consume more resources, such as energy and space, when they are moving materials from the manufacturing and automation lab section to other lab sections.

3.3.3 Waste of Defects

In educational laboratory, Waste of defects is the product or service that does not meet the student’s needs. Also, errors that results in resource wastage and students dissatisfaction are deemed a waste of defects. However, in the manufacturing and automation lab section, lack of proper work handling and improper sorting of tools are two signs that indicate to the waste of defects in student lab assignments.

3.3.4 Waste of Waiting

The time spent by people waiting for the arrival of materials, equipment, and information from other departments is a waste of waiting. Additionally, the time spent by people waiting for an equipment or a tool to be available is also considered a waste of waiting. There are many examples of waiting in the manufacturing systems laboratory such as when students and staff are not able to do their work because they are waiting for materials to arrive from other sections, or perhaps they are searching for missed tools in a disorganized spot. This occurs because of the inappropriate planning and sorting for tools, materials, and equipment.

3.3.5 Waste of Motion

The movement of students and staff between the lab sections is a waste of motion. In other words, unnecessary movement or excess work during processing due to unplanned operations are wastes of motion. Examples of motion in the manufacturing systems laboratory are searching for items that are not located in their customized spot, lifting items off the ground, reaching for tools, and choosing or arranging tools due to improper sorting. Figure 3.11 illustrates the movement of students, staff, and researchers between the laboratory sections. The
improper design for processes, the lack of standard work methods, and the inappropriate design of the workplace and the layout are essential causes of the waste of motion.

Figure 3.11: Movement of Students between the Laboratory Sections
It appears from Figure 3.11 that the product life-cycle design processes require students to repeat movement between the laboratory sections. First, the process starts from the Design & Modeling section, also known as Computer Aided Design (CAD), where students design products. Second, students walk to the Prototyping section to create and test the 3D prototypes before manufacturing them in large quantities. Third, students move to the Quality Control section where they can measure various parameters of a product by using the Coordinate Measurement Machine (CMM). Fourth, the first three steps of the process may require modifications in the design of the product so that students may need to move again to the CAD section. Fifth, students need to walk to the Manufacturing and Automation section, where they have access to CNC machines or other necessary equipment for the manufacturing process. Sixth, students need to walk to the Material Testing section in order to test the used materials of products. Seventh, students recognize that they need to check product parameters again so that they walk to the Quality Control section. Eighth, students walk again to the CAD section to make final changes in the design of the product. Finally, students walk back to the Manufacturing and Automation section to complete the last step, which is to manufacture final products in desirable quantities. To conclude, the total travel time is calculated when students are traveling without moving items with them. If students are moving heavy items, the total travel time will be much longer.
Chapter 4: Lean Laboratory Layout Design

4.1 Concept Designs

Three different concept designs, for a proposed manufacturing systems laboratory layout, have been created based on lean principles. These concept designs are explained below.

4.1.1 Concept A

In many cases, buildings in the educational institutes are designed as rectangular or square shapes. Therefore, the concept A (Figure 4.1) is designed as a rectangular and modular layout that is adjustable. In this design, two or more rooms can be combined together which results in having a big shared area, an improved workflow, and reduced transportation and movement wastes. Additionally, it is easy to change rooms’ size and have entrances and exits in different places for each room.
Figure 4.1: Laboratory Layout A.
4.1.2 Concept B

This concept (shown in Figure 4.2) provides different room sizes as well as illustrates an optimal space utilization. It also reduces the transportation and movement wastes since the layout has a circular shape and people and materials can move in a circle. The problems with this layout are: it does not fit buildings’ shapes in educational institutes, it is not adjustable, and it results in unfavorable rooms shapes. Additionally, the transportation and movement improvement are limited since students and staff have to step out of each room in order to go to another one and cannot move through rooms.
Figure 4.2: Laboratory Layout B.
4.1.3 Concept C

Concept C (Figure 4.3) helps to get two or more rooms open to each other. This layout also helps to adjust room sizes if needed. The drawbacks are that this layout does not represent the optimal use of space since there is a whole aisle space that is unused because it is being used for entry and exit. There is a limited scope for future adjustments since it is difficult to have entrances on multiple sides without affecting the workflow.
Figure 4.3: Laboratory Layout C.
4.2 Comparison

Table 4.1 below qualitatively compares the three concept designs. It seems that the layout (A) has the best features since it takes into consideration the shapes of the buildings in the educational institutes as well as it is modular.

Table 4.1: Qualitative Comparison of Three Concept Laboratory Layouts.

<table>
<thead>
<tr>
<th>Layout #</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| A        | • Adjustable and usually fit most of the buildings in the educational institutes.  
<pre><code>      | • It could be designed as a rectangular or square shape.                     | • Not as good as layout (B) in terms of space utilization. |
</code></pre>
<p>|          | • Two rooms or more can be combined together which results in having a big shared area, an improved workflow, and reduced transportation and movement wastes. |                                       |
|          | • Each room can have inside and outside doors.                               |                                       |
|          | • It is possible to have one or two exits and entrances on any side of the laboratory. |                                       |
|          | • It is possible to have different sizes of rooms.                           |                                       |</p>
<table>
<thead>
<tr>
<th></th>
<th>• It is possible to set light shared tools in the middle and return it to storage at the end of the day.</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>• A good space utilization.</td>
</tr>
<tr>
<td></td>
<td>• Different rooms sizes.</td>
</tr>
<tr>
<td></td>
<td>• Not Adjustable.</td>
</tr>
<tr>
<td></td>
<td>• Does not fit buildings’ shapes in the educational institutes.</td>
</tr>
<tr>
<td></td>
<td>• Limited improvement for the transportation of materials and the movement of people.</td>
</tr>
<tr>
<td>C</td>
<td>• It is possible to have two or more rooms opened to each other.</td>
</tr>
<tr>
<td></td>
<td>• It is possible to have different sizes of rooms.</td>
</tr>
<tr>
<td></td>
<td>• Limited Adjustment.</td>
</tr>
<tr>
<td></td>
<td>• Not the perfect utilization of space, where the aisle space is opened for entrance and exit.</td>
</tr>
<tr>
<td></td>
<td>• Cannot have more than one entrance.</td>
</tr>
</tbody>
</table>

Table 4.2 below performs a quantitative ranking of the three alternative layouts, where a weighted sum approach is used for analysis. Table 4.2 shows that each concept design is ranked based on four criteria: flexibility, space utilization, modularity, and workflow enhancement. A ranking scale from 0 to 10 is used. The respective weights are listed in front of each criterion in the table.
Table 4.2: Quantitative Ranking of the Three Alternative Layouts.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>A (0 - 10)</th>
<th>B (0 - 10)</th>
<th>C (0 - 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible (0.2)</td>
<td>10</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Optimal Space Utilization (0.2)</td>
<td>7</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Modularity (0.4)</td>
<td>10</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Enhances the workflow (0.2)</td>
<td>10</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9.6</strong></td>
<td><strong>4.8</strong></td>
<td><strong>6.6</strong></td>
</tr>
</tbody>
</table>

Based on the qualitative and quantitative analysis and ranking, the concept design A was selected as a final choice for the detailed CAD design.
4.3 Detailed Design (CAD Layout)

The detailed 2D CAD layout of the Concept Design A is developed as shown in Figure 4.4.

In this design, the various components of the product life cycle are properly integrated and organized. It is clear from figures 4.5 and 4.6 below that the design is flexible and adjustable, and have multiple features. The CNC and Lab Services sections are placed on the backside in order to improve transportation of materials. Both of the sections contain a back gate.
that facilitates the entry of big items into the laboratory without interrupting students’ work. Additionally, it is easy to merge two or more rooms together, which improves students’ movement inside the laboratory. It is possible to combine the CAD Lab with the Classroom as well as the Quality Control with the Prototyping Lab. Moreover, having the Collaboration Space in the center is a great idea, but optional. This allows students to gather and work on certain activities while there is another group of students in other sections. There are couches in the laboratory that provide comfort as students are able to take a break or wait for a room to be available. It is important to have two offices in the laboratory where in some cases it is necessary to have a faculty member’s space beside the lab technician’ space. Therefore, both of them have an office. Furthermore, the ceiling of this laboratory is designed to be 20 feet in height and could be less than that for the CAD Lab and the Class Room. Students have an easy access to restrooms since it is included in this design. Finally, the parking lots could be placed in the front and the left sides of the facility.
Figure: 4.5: Three-Dimension View of the Detailed Design, front corner.
Figure 4.6: A Three-Dimension View of the Detailed Design, Rear Corner.
Chapter 5: Conclusion and Future Research

5.1 Conclusion

The use of lean principles helps to improve the environment of service facilities and the layout of the manufacturing systems laboratories in the educational institutes, where the components of the product life cycle are properly integrated to work together in a concurrent manner. This is demonstrated by a case study of a current manufacturing systems laboratory in an educational institute. The study helps to understand the limitations and deficiencies related to the existing laboratory facilities design. Based on the case study and the proper application of lean principles, several concept designs are presented in this research for comparison. An optimal design template, which meets lean requirements, aims to eliminate the limitations and deficiencies, and improves the product lifecycle, has been developed and can be adopted by the educational institutes in future.

Since the waste reduction is an essential factor in any lean project, this research illustrates the wastes in current manufacturing systems laboratories. The case study indicates to the disadvantages of the current designs that result in different types of waste and thus affect the product lifecycle process design as well as students’ work in the educational laboratories. This approach (determining wastes) has effectively helped to design a layout that reduces transportation and movement wastes and improves the workflow.

Additionally, the improper space utilization results in different wastes, so it is necessary to perform a detailed analysis of the current area of the laboratory that reveals the limitations in the current design and helps to avoid those limitations in the new design that achieves the optimal space utilization.
5.2 Future Research

Below are the recommendations for future research:

- A stakeholder survey in several fields including the educational laboratories will provide better and deeper understanding of the lean projects, especially when it comes to facilities design.

- The optimal laboratory design layout is just the first step, which should be followed by developing a strategy to implement the Lean Five S’s in educational laboratories on a continual basis.

- Since this research does not cover the cost analysis aspects of the redesign of the educational laboratory spaces, it will be great to address this important topic in similar future research works.
References


Hohmann, C. (2016), what is a spaghetti diagram, retrieved from https://hohmannchris.wordpress.com/2017/08/30/what-is-a-spaghetti-diagram/


