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Layout Optimization of Battery Swap Machine Production Using Simplified Systematic Layout Planning

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“Everything should be made as simple as possible, but not simpler.”

Albert Einstein

Table of Contents

List of Figure

List of Table

Abstract

Every industry is faced with layout problems that affect system performance. It is critical for industries to enhance plant layout design while also considering how to cut costs and expenses in order to thrive in a competitive market. Although there are many methods to optimize the plant layout, SLP is one of the widely used because it allows analyzing the relation between each process or department that has a reducing effect on the productivity of the company.

The objective of this research is to examine the existing plant layout of battery swap machine production unit and to design a simplified and efficient layout using SLP (Systematic Layout Planning) to increase its productivity. The analysis of the existing layout was investigated by examining material flow, activity relationships and space requirements of activities. Later, alternative facility layouts were designed and compared with the existing layout to select the most optimal layout. The new plant structure that was eventually chosen resulted in a considerable reduction in the distance of material and workflow movement, which increased the unit's production. Material movement across the plant area is decreased by 26 percent, and an additional 16 square meters of area is generated according to an analysis of existing layout and final layout produced by Systematic Layout Planning (SLP).

The production line is considered in this thesis belongs to the battery swap machine developed by Eurofork S.p.A, an automated material handling company based in Turin/Italy.

1. Introduction

It is very difficult for companies to provide a sustainable competitive advantage in the industry they are in, considering the increasing number of competitors in the global market. In order to achieve this advantage, manufacturers must not only offer the highest quality product but also offer this product to the market at the lowest price. There are many factors that have an effect to reduce the cost of the product. One of the most important of these is to determine the cost of production and potential and/or current losses. In this context, one of the main factors influencing costs is inefficient production layout, or in general term is inefficient plant layout.

Plant layout indicates the arrangement of equipment, machine, and all other physical facilities within the factory in order to provide material flow as quickest, the production cost is lowest and the amount of handling in processing is minimum; this includes all the processes from receiving raw materials their suppliers to the shipment of the finished product to the client.

Optimizing plant layout is a critical step in making the industry more efficient and leaner. This ensures the elimination of non-value-added steps of Lean Manufacturing such as over-motion over-transportation etc. caused by inadequate layout design and management. Furthermore, in this way, the manufacturing throughput time is considerably reduced, and this provides increased productivity and reduced cost. Previous studies have demonstrated the practical importance of adopting Systematic Layout Planning in enhancing productivity and space utilization in a manufacturing unit.

This study was carried out at a battery swap machine production unit in Eurofork S.p.A. In the cost analysis, which is the first step of the study, it is observed that the production cost of the battery swap machine is fluctuated and tends to increase. Problems encountered in unit cost are related to unnecessarily long production time and costs because of an inefficient production layout. The distances travelled by components and workers throughout the production process are viewed as a cause of production delays. Excessive motion and transportation result in unnecessary expenditures and wasted energy. Considering this cost increase and increased demand due to the increased usage of electric vehicles, it is clearly understood the need of analyzing the existing layout and taking corrective actions.

Considering these problems, the Systematic Layout Planning technique is applied to make the existing layout more efficient and reduce waste. As a first step, the relationship of different production steps is established. This is the most important and effective step of the SLP because this technique based on the idea that all the inter-related activities must be close to each other to decrease the transportation time and to manage the process easily and to use the equipment in an effective manner. Following this, the necessary area and equipment for each activity field are determined. A final layout is decided after necessary revisions and considerations for any practical constraints have been made by comparing with other possible alternatives. As a final step, the existing layout and the new layout were compared, and the improvement was observed as 26 percent.

2. Electric Vehicles and Battery Swap Technology

This section provides a general overview of the battery Swap Machine in order to make the production steps taken into consideration while creating the layout more easily understandable thanks to explaining the working principle of the battery Swap Machine inside the station.

2.1. New Era of Transportation: Electric Vehicles

The day-by-day developing technology and the growing global population have been causing the problem of energy sources all over the world. Nowadays, the energy used in the world is mostly provided by petroleum and its derivatives fuels. Oil reserves have been rapidly depleting, and their prices have been increasing every passing day. Considering the possibility of petroleum and petroleum-derived fuel resources running out one day, their high costs, current and possible oil wars to control these resources, and the environmental damage caused by these resources; the trend towards renewable energy sources has accelerated in order to create a cleaner and more natural environment. Electric vehicles (EVs), which use only electric motors, instead of vehicles with internal combustion engines, are a novel technology to minimize fossil fuel consumption (Kerem & Gurbak, 2020). In this regard, EVs are viewed as a key role in lowering the use of fossil fuels ((Sutopo et al., 2018) and countries' reliance on foreign energy resources, as well as solving climate change caused by hazardous gases emitted into the environment (Maggetto & Van Mierlo, 2000). Electric vehicle research dates back to the mid-1800s. However, due to the range issue, it has remained on the shelf for years. (Sen et al., 2011).

Electric vehicles with fuel-saving, petroleum-free, silent, and high-efficiency engines have been created as a result of the technological era. In addition to the engine, the electric vehicle is powered by a battery made up of lithium-ion batteries (Larminie & Lowry, 2003). However, these batteries, like those in other electrical gadgets, must be charged.

Electric cars are charged using three fundamental principles: battery change, static charging by cable or other conductive charging (through cable or rails on the ground), and dynamic charging via wireless inductive charging (magnetic energy transfer or cable in the air or on rails while driving). Conductive charging is available in a variety of charging speed and cable specifications. Inductive charging is also connected with variations in energy transmission and charging speed. Inductive wireless charging can take place either when the automobile is stationary or through dynamic charging while the car is moving. However, at this point, inductive charging has not progressed beyond the experimental level. The most recognized and extensively used charging methods are rely on a plug-in cable connection from a charging station to the car. The third technique of obtaining energy is to exchange discharged batteries from a vehicle for charged batteries from a supply station.

2.2. Overview of Battery Swap Machine

The battery swap machine's operation cycle is illustrated in Figure 1, and as seen there, when the car enters the system, the car should be precisely positioned in the X direction, and the vehicle's power is switched off for security, The left side of the machine starts to operate to remove the empty battery from the car and transfer it to the charging warehouse. When the left side of the machine has completed its operation, the right side of the machine will place the full battery on the car, and the cycle will end when the automobile leaves the station.

It should be noted that the way of operation of each battery swap machine, as well as the cycle time values, varied. For example, before Tesla's battery replacement machine can begin to function, the car must first be elevated. However, the battery replacement equipment built by Eurofork, shown in Figure 1, does not require this.

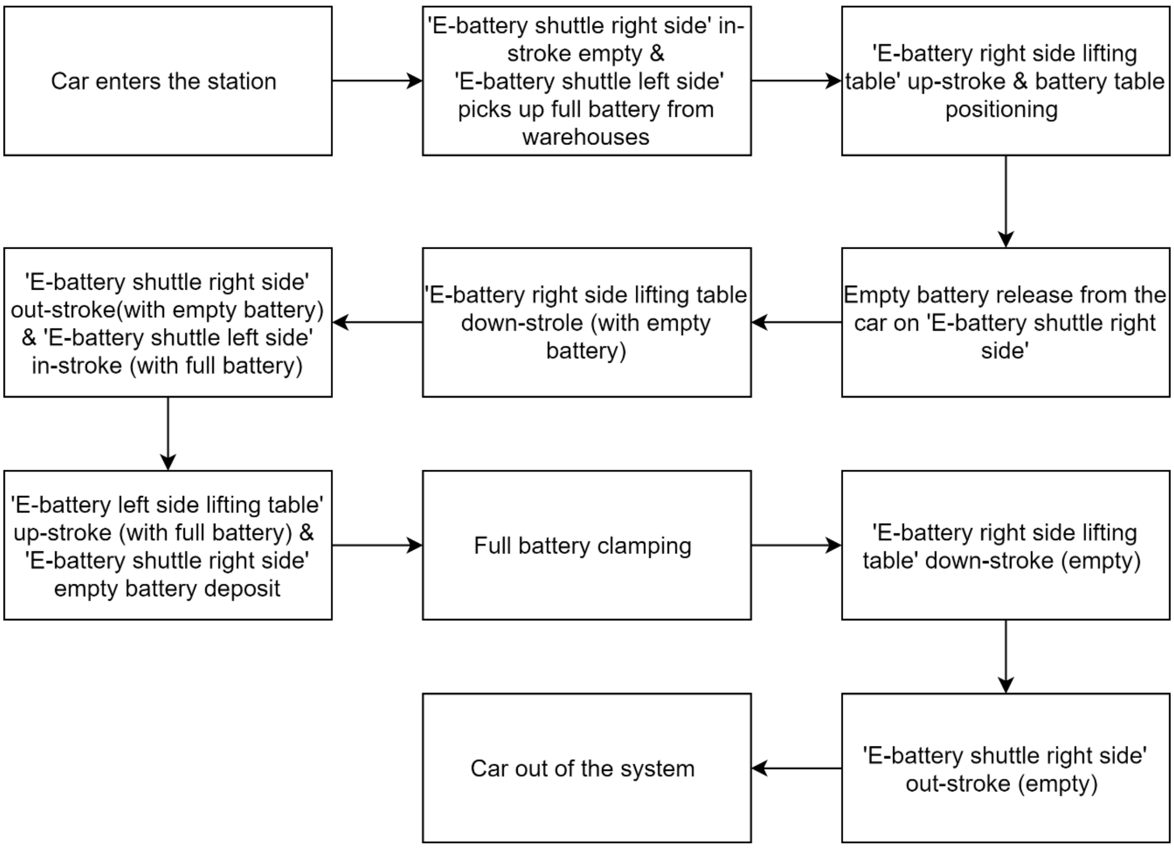

Figure 1. Battery Swap Machine Working Procedure

At this point, it is important to underline that the battery swap machine's operating system is quite similar to that of an automated material handling system. The system necessitates automated horizontal and vertical movement, lifting, picking, dropping, and other actions though the use of a shuttle and a lift table.

2.3. Battery Swapping: Automated Material Handling Solution

Material Handling is the process of transferring items and materials within a building, facility, factory, or warehouse across small distances. Material handling encompasses a wide spectrum of items, from small boxes to massive and heavy components for manufacture. Rapid industrialization and substantial advancements in technological fields such as Radio Frequency Identification (RFID), Artificial Intelligence (AI), and the Internet of Things (IoT) are now propelling the global material handling equipment market forward (Kasim et al., 2013). Agriculture, automotive, aerospace, construction, and e-commerce are among the industries that have begun to appreciate the possibilities of next-generation automated material handling technology. More modern tools are replacing older manual material handling techniques in many regions of the world.

Automated material handling systems (AMHS) provide effective material delivery from one location to another in the manufacturing area—whether it's inside the same department or bay, on opposite ends of the production floor, or even in two distinct buildings. An AMHS moves material via conveyors, vertical elevators, and autonomous vehicles using the route and process step information given by the MES. To identify the position of an item or carrier for delivery by the AMHS, numerous technologies such as RFID, optical character recognition (OCR), barcoding, near-field communication, or ultra-wideband indoor tracking are used. AMHSs use carrier and material tracking systems to detect material dropped by the operator at a "pick-up" point, process the material identification to specify the next destination and then carry the material. Without considering the type of transportation, these systems provide more benefit when the material information is available and accessible in the systems by the production employee. There would be no human involvement with carriers, transport systems, or material in a fully realized AMHS. The system would manage the identification, routing, and delivery of material to the proper tool, even putting and removing material from the tool's load ports.

Eurofork S.p.A., which is the company that is made a collaboration for thesis work, is an Italian company that produces automatic handling systems for 20 years. Eurofork has 2 main product groups: telescopic forklifts and shuttle systems. While telescopic forks are commonly employed in automatic warehouses and industrial automation systems to handle loads, the Esmartshuttle system is a patented solution appropriate for high density storage. A lift system, in addition to the many types of traditional forks, permits load handling in the event of forks placed on shuttles, AGVs, LGVs, or other similar applications that lack a lifting function. Eurofork provides a range of lifting systems that may be customized dependent on the weight of the loading unit; this solution may be installed in any forks device (“Lift System” 2021). The visual of battery swap machine can be found in Figure 2.

The battery swapping process, which is explained in detail in Section 2.2., is carried out in a short time thanks to the telescopic forklift system of Eurofork. Carrying a 200 kg battery is a major effort for us people, but it is a lot easier for this machine. The battery swap machine uses an optical search system to detect the battery compartment, and later removes the discharged battery, and send it to the battery storehouse for recharging before replacing it with a fully charged one.

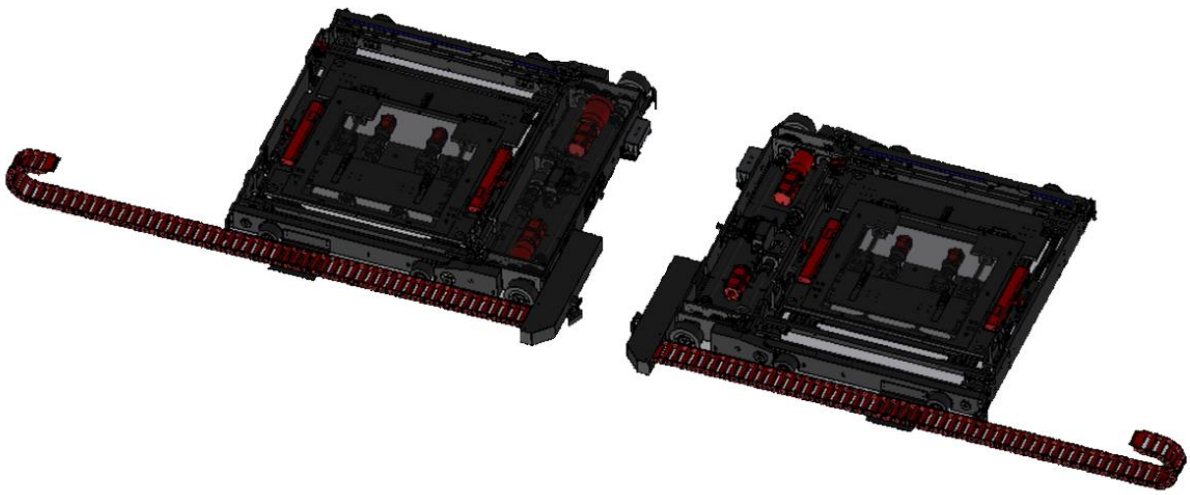

Figure 2. Battery Swap Machine Visualization

Considering the working principle of the battery swap machine described in Section 2.2. and the automatic material handling systems described in this section, it is clear that company specializing in the automatic material handling industry, such as Eurofork, can produce a battery swap machine by making smart and innovative changes to its existing products.

3. Literature Review

In this section, after an introduction on layout planning, a detailed description of each step of Systematic Layout Planning, which is the main subject of this research, will be made based on previous research and articles.

3.1. Introduction

In this section, the general overview of the layout planning, its advantages, types and, most-known layout algorithms are explained.

3.1.1. Why Layout Planning?

The manufacturing and service industry needs a selected area or location to carry out its operations and organize various physical facilities such as equipment and machinery. In addition, space is used to keep a stock of various tools, raw materials, accessories, and support services (Muther, 1973).

A certain area is determined to meet the above different needs of a production unit, and then the apportionment of different movements and activities is done by dividing the space accordingly. Organizing the space in this way is referred to as the layout, which defines the physical arrangement of work and storage areas, departments or equipment within the boundaries of some physical structures such as factory, office, warehouse or service facility (Venkataraman & Pinto, 2019). The layout consists of the regulation of workstations in physical form, material-handling space, utility places inventory storage, and others necessary for the smooth running of production and operations.

Facility layout is the arrangement of operations, machines and areas and the correlation between them to provide the fastest material flow at the lowest cost (Sutari & Rao, 2014). Layout enables efficient use of manpower, equipment, materials, and energy. This helps to achieve the desired results of the production. Well-organized machinery or department arrangements and convenient transportation routes create an efficient facility (Bock, 2007). Improving the facility layout can significantly reduce the distance and duration of material movement from one workstation to another (Bhawsar & Yadav, 2016). Therefore, the correct workflow in the production process will reduce production costs (Hossain, Rasel, & Talapatra, 2014). The correct arrangement of facilities reduces the total operating cost by up to 50%, thanks to this, it contributes to the overall efficiency of operations (Tompkins et al., 1996).

Making decisions regarding the physical arrangement of all available resources in the production system that occupies space within the range of a facility is called layout planning (The Institute of Cost Accountants of India, 2021). Different resources can be a desk or a workstation, an entire office, or a person or a department. This type of layout planning decision is taken when designing a new facility or during any change in resources, such as the addition of a new worker, the movement of any machine. Layout planning can also be carried out during the expansion of the facility or during the reduction of the area. Layout planning must be flexible so that it can be changed according to new production processes and techniques. The layout should be designed to meet the needs of all relevant stakeholders of production systems such as managers, workers, supervisors. Therefore, the facility layout has the following objectives (Venkataraman & Pinto, 2019)**:**

- Providing a layout that allows to achieve competitive costs
- To provide a general level of satisfaction to all stakeholders
- Minimizing the cost of internal transportation between different operations and make easier to control in terms of both people and material
- Avoiding unnecessary capital investment
- Facilitating effective use of labour
- Achieving economies of scale in the management of raw materials
- Reducing working time in the process
- To use the available space in the most effective and optimum way
- Minimizing the obstacles in different production processes.
- Introducing to the production control system
- Providing better quality products at a lower cost to the customers
- Raising the morale of the employees and ensuring their loyalty
- To reduce the likelihood of accidents
- Providing adequate storage and packaging facilities
- Determining future expansion possibilities of the facility

3.1.2. Types of Layouts

According to Standridge (1993), there are four types of layouts in manufacturing systems. These are process, product, group technology and fixed layout. Based on the different characteristics of a production process - mainly production capacity and product variety -

workstations should be properly organized. It is possible to refer to a schematic classification, represented in Figure 3, emphasizing the existence of four types of layouts (Tompkins, 2010).

- ***Product (Line) Layout:*** If all equipment and machines need for the production are arranged in the flow of processing of the finished good, the layout is called the product type layout. In this type of layout, each operation area is designed to produce only one product from one type of product. One machine's output is the input of another machine. To make the efficient this kind of layout, the product must be standardized and produced in large quantities. The raw material is supplied from one end of the line and goes from one process to the next quickly with minimal effort in processing, storage, and material handling (Amine Drira,2007).

  The product type of layout provides some advantages, such as reducing the material handling time and work-in-progress material, requiring less floor area for material-in-transit and temporary storage, providing simplicity for production control, minimizing total production time. Despite all these advantages, this kind of layout has limitations due to the less flexible nature. For example, if one or more lines working slow, there can be considerable machine idleness and if just a single machine breaks down whole production line can be stopped. On the other side, if production volume decreases, the manufacturing cost increases. To handle all these limitations specialized and strict supervision is important (Venkataraman & Pinto, 2019).

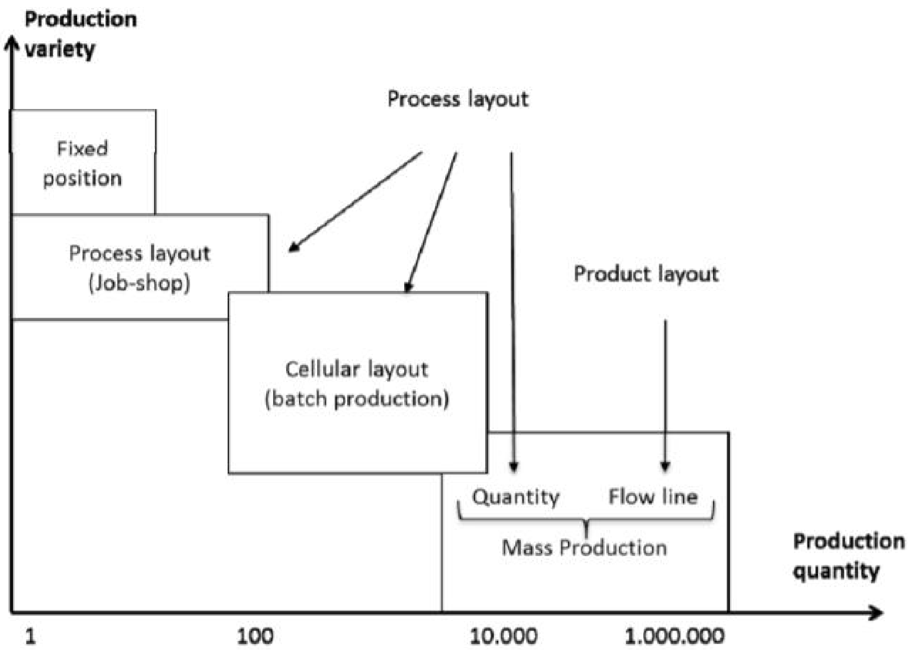

Figure 3. Variety-quantity production relationship (Groover, 2007*)*

- ***Process (Functional) Layout:*** Process layouts are primarily found in job shops or companies producing customized, low-volume products that may require different machining requirements and process sequences. Process layouts are plant configurations in which processes with a similar structure or function are grouped together. For this reason, they are sometimes referred to as functional layouts. Their purpose is to produce goods or provide services that contain a variety of processing requirements. A manufacturing example could be a machine shop. It usually has different and separated departments where general-purpose machines are grouped consistent with their functions (for example, milling, grinding, drilling and hydraulic presses). Therefore, facilities structured based on the individual functions or processes have a process layout. This type of layout provides the needed flexibility to handle a variety of routes and process requirements (Amine Drira,2007).
- ***Fixed-Position Layout:*** A fixed-position layout is suitable for a product that is too large or too heavy to be transported. In this case, the material remains fixed in one place and the resources required to do this work must be portable so that they can be brought to work for "on-site" performance. It is appropriate for shipbuilding, heavy machinery industries, etc. (Amine Drira,2007).

  This kind of layout requires a very small investment in the layout. The layout is flexible because changes in the design of the job and sequence of operations can be easily integrated. These also make easier adjustments to compensate for the materials or workers shortage. Requirement of very high capital investment due to the long production period, need of very large space for material and equipment storage close to the product, and the possibility of confusion and conflicts among different workgroups as several operations are often carried out simultaneously can be counted as disadvantages (Venkataraman & Pinto, 2019).

In most industries, applying one type of layout, such as only a product layout or a process layout, or a fixed location layout, does not provide an efficient solution. Namely, the combined (hybrid) layout can be followed where the manufacturing of several products in repeated numbers with no likelihood of continuous production (Edward, 1971). The hybrid layout combines the flexibility of process layout and the efficiency of product layout. For example, for industries involving the fabrication of parts and assembly, fabrication tends to employ the process layout, while the assembly areas often employ the product layout. The most popular hybrid layout is Cellular Layout.

- ***Group Technology or Cellular Layout*****:** It is considered a method by which it is possible to identify and group similar or related parts involved within the manufacturing process; in order to use the intrinsic economy of flow production methods. Groups formed in this manner are called cells, as mentioned for example in (Hamann & Vernadat, 1992). Thereby, a cellular layout is an equipment layout configured to give support to cellular manufacturing. Processes are grouped into cells employing a technique referred group technology (GT). Group technology includes describing the parts that have analogue design and processing characteristics. Workers in cellular layouts are cross trained in the order they will be able to work with all the equipment inside the cell and take responsibility for its output. In some cases, cells are fed into an assembly line that produces the final product. A flexible manufacturing system (FMS) is the automated version of cellular manufacturing. In the case of using FMS, a computer controls the movements of parts to varied processes. In this way, manufacturers gain some advantage of product layouts while maintaining the flexibleness of small batch production (F. Huq et al.). The advantages of Cellular Layout are the fewer work-in-process inventories, reduced material handling costs, less flow time of materials, and quicker setups through improved visual control of the process (Hassan, 1995). The unfavourable ways of this layout are being not very flexible and the possible need for spare equipment in order not to carry parts between cells.

3.1.3 Layout Procedures and Algorithms

There are different procedures and algorithms to design facility layouts. These procedures and algorithms can be classified into two main categories, which are traditional and computerized. Traditional facility layout design procedures consist of (Kulkarni et al., 2015):

- Naddler's Ideal System Approach (1961)
- Immer's Basic Steps (1950)
- Apple's Plant Layout Procedure (1977)
- Reed's Plant Layout Procedure (1961)
- Muther's Systematic Layout Planning (1961)

The computerized method is divided into two parts which are constructive and improvement type. Whereas Automated Layout Design Program (ALDEP) and Computerized Relationship Layout Planning (CORELAP) are methods used for the constructive type, the Computerized

Relative Allocation of Facilities Technique (CRAFT) is a method used for improving the layout planning. The need to arise computerized method is because traditional methods are used for small manufacturing and take a large time of improvement. This disadvantage is overcome by the computerized method.

Systematic Layout Planning (SLP) is still widely used for layout design, despite it is a traditional approach and derived way back in 1961. Most automated layout design techniques, especially CRAFT (Computer Relative Allocation of Facilities Techniques), use the same procedure as SLP to solve facility layout problems.

Due to the working on the existing layout, CRAFT is explained in this section as an alternative to this study.

CRAFT is developed by Armour and Buffa and widely used than ALDEP and CORELAP. It is a heuristic technique designed to solve a problem faster when classical methods are too slow or to find an approximate solution when classical methods cannot find a definite solution.

To start to work on the CRAFT the initial layout, flow data, cost per unit distance, total number of departments and location of those departments, area of departments must be known (Kher et al.). CRAFT algorithm starts with the after getting above mentioned inputs and continues with obtaining the department centroid, calculating the inter-department rectilinear distance, calculating the initial cost of the layout by multiplying flow matrix-cost matrix-distance matrix must be done, respectively. Then CRAFT considers all the possible two- or three-ways departments based on common border or equal area criterion and identifies the best exchange. After these, the layout is updated, and the new department centroid is calculated. This step is repeated until no further reduction in the cost can be obtained (Kher et al.).

A detailed explanation of SLP is done in the following section.

3.2. Systematic Layout Planning (SLP)

In this section, detailed information about the phases of Systematic Layout Planning, its application method and rules are given based on previous studies. Simplified Systematic Layout Planning, is the simplified and useful way of SLP for the small areas, is detailed.

3.2.1. Introduction to Systematic Layout Planning

Systematic Layout Planning (SLP), developed by Richard Murther in 1973, is one of the most frequently used methods in the design and/or redesign of a facility layout (Carlo et al., 2013).

This technique merges quantitative measurement of material movement with non-flow aspects such as communication, supervision, staff comfort and movement. The main advantage of SLP is that it lays out the logic of the layout and easily allows input from all staffing levels (Khariwal et al., 2020). SLP is formed by a framework of phases through which each layout project goes through. A pattern of procedures for step-by-step planning and a set of conventions to describe, visualize and rank the various activities and their relationships and alternatives involved in any layout project (Muther, 1973).

The arrangement of the supporting activities, such as receiving and shipping, shops, tool room, maintenance department, etc., is also an important aspect of the plant layout besides logistic activities. For this reason, it is necessary to associate the flow of logistic activity with the supporting activities in relation to the degree of closeness required by process and information. In such a situation where activities are not part of the flow, we use the SLP technique and analyze the interrelation with the aid of an activity relationship solve to solve the layout problem. One of the main goals of SLP is to increase productivity by reducing idle time and working on process inventory (Khariwal et al., 2020).

According to Tortorella and Fogliatto (2008), SLP has three specific phases, these are:

- Data collection and analysis;
- Searching among the possible layout solutions;
- Identifying alternative layouts and choosing the best

SLP is a well-attested tool and uses the activity relationship chart as a keystone (Tompkins, 2003). An activity relationship chart emerges from the analysis of different activities and how they relate to each other. It is carried out based on input data such as product, quantity, route, support activities, time, and understanding the roles and relationships between activities. The input data helps create a material flow analysis chart, normally referred to as "From-to-Chart". A relationship diagram is developed from the analysis of from-to-chart and activity relationship chart (Tompkins, 2010). After determining the required space for each activity and allocating available space to these activities, field templates are made to obtain the space relationship diagram for each department. After the data collection and analysis phase is finished, the next step involves developing and evaluating several layout alternatives based on modification considerations and practical limitations. Developed alternatives are then evaluated according to the criteria of the facility designers in order to select the appropriate one. In Figure 4, the procedural layout design approach is shown to summarize the information given above.

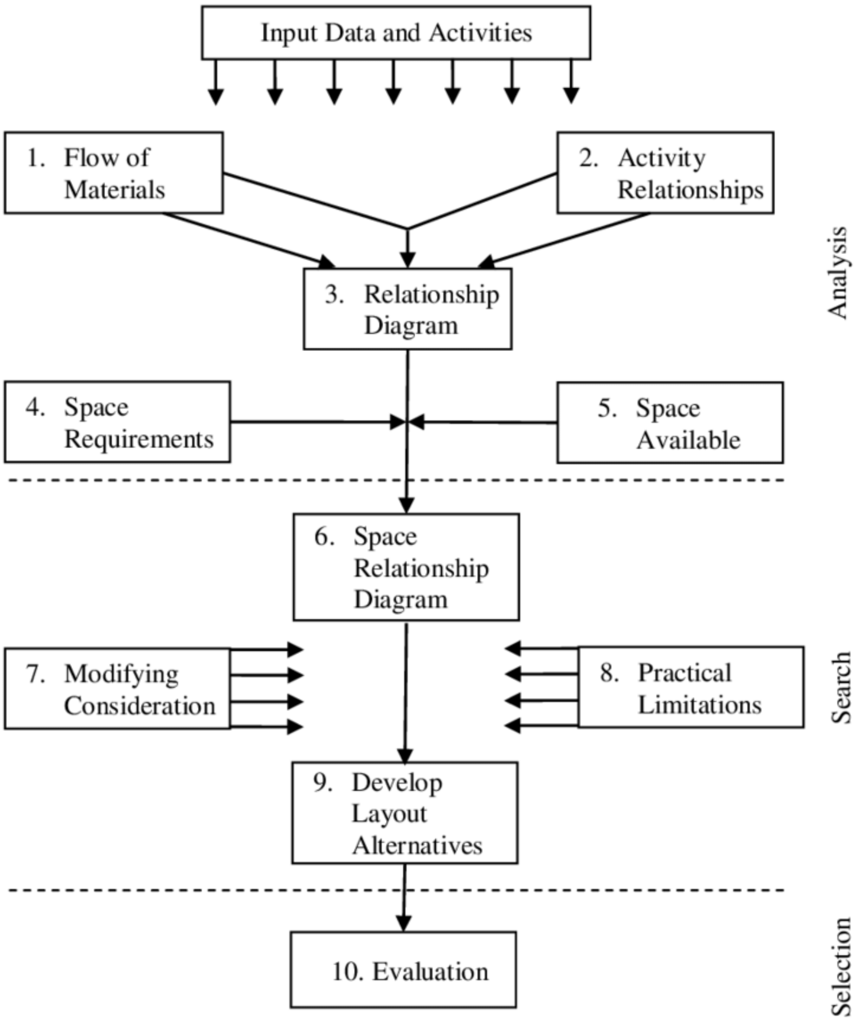

Figure 4. Systematic Layout Planning Procedure. Tompkins (2010)

3.2.2. Phases of Layout Planning

From beginning to end, layout planning consists of 4 phases. Despite these four phases are in sequence in the literature, overlapping each other provides to get the best result, as indicated in Figure 2. These include the following (Muther, 1973):

Phase I - Location

Determine the placement of the area to be set out. It always not have to be a new site problem (Suhardini et al., 2017). Generally, a new layout will be within the same place it is currently. This phase is used to determine whether a new place will be a newly acquired building, storage area made empty and ready to use for this purpose, or another potentially available place.

Phase-II - General Overall Layout

Determine the general arrangement of the area to be placed (Suhardini et al., 2017). Here the basic flow models and allocated areas are combined so that the overall size, relationships, and configuration of each main domain are roughly established. Phase-II is sometimes referred to as block layout or just the area allocation of the rough layout plan.

Phase-III - Detailed Layout Plans (to be done in this study)

Determine the place of each specific piece of machinery and equipment (Suhardini et al., 2017). In this phase of the layout planning, the actual location of each specific physical feature of the area to be arranged is determined and utilities and services are included. The detailed layout is a customarily sheet or board containing copies of individual machines or equipment that are placed or drawn on it.

Phase-IV - Installation

Plan the installation, get the approval of the plan, make the necessary physical movements (Suhardini et al., 2017). After the detailed layout plans are completed (Phase III), important details of the installation drawings and the planning of the movements should be worked on. Funds must be allocated for installation and actual actions must be taken to set up machinery, equipment, and services as planned.

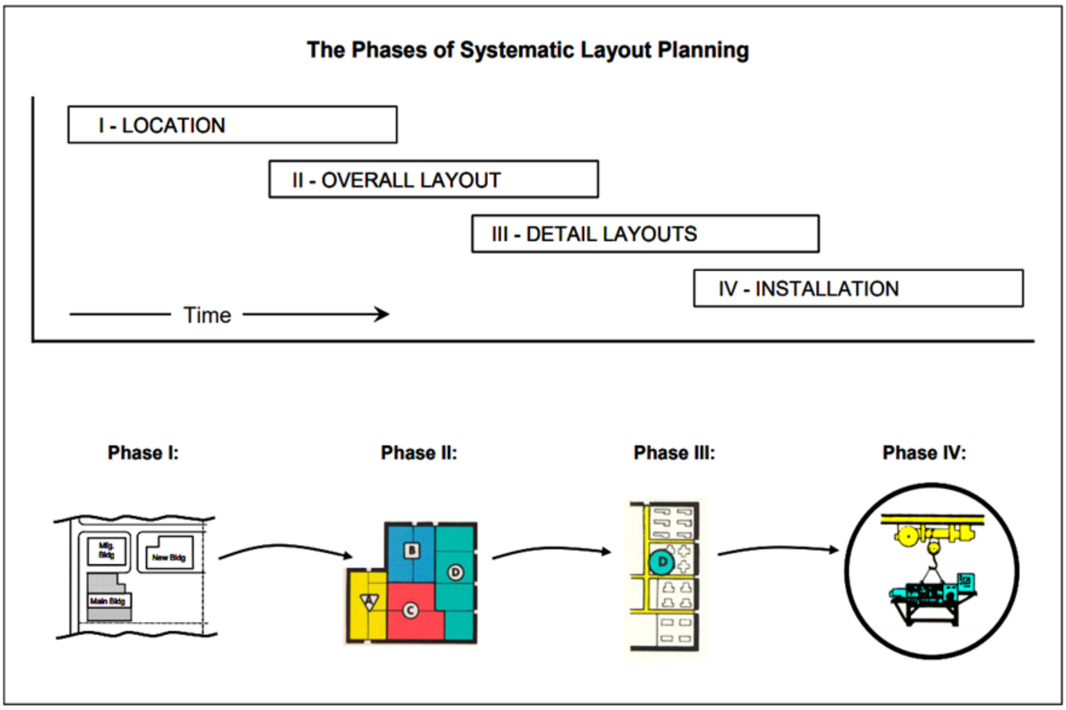

Figure 5. Four Phases of Systematic Layout Planning Muther (1973)

3.2.3. Input Data and Activities

There are two basic elements on which every layout problem is based:

1. Product or material to be put into service. This element indicates the goods produced by the company, starting materials (raw materials or purchased parts), shaped or processed parts, finished products, and/or service items supplied or processed. Products can be called assortments, models, styles, part numbers, formulations, product groups, or material classes (Peron et al.,2020)

2. Quantity or volume. It means the number of goods or services produced, supplied, or used. The quantity can be called the number of pieces, tons, cubic volume, or the value of the quantity produced or sold.

These two main items have the power to emphasize all other features or conditions in the layout. Therefore, the facts, estimations, or information on these two elements are significant for layout planning.

After getting the information of product and quantity, the routing, or in other terms process, should be learned. Routing indicates the process flow of how the product or material is made. By routing the process, its equipment, its operations, and their sequence are insinuated. Routing can be identified by process and equipment lists, process, flow sheets, and the like.

One of the most important items for every layout problem is the support activities due to the fact that they generally use more space than the producing department itself. For that reason, sufficient attention must be paid to them. The supporting service element includes things like maintenance, machine repair, tool room, toilets, cafeteria, first aid, offices, and shipping and receiving. The service department supports the production system and thus consolidates the production efficiency (Peron et al.,2020).

Another fundamental element of the layout problem is timing. By the time we mean when, how long, how often, and how quickly (Muther,1973). Timing includes when products will be produced or when the planned layout will run (one or two shifts, during special periods like Christmas time, etc.). This time information is used to determine how many of a particular machine part are required, which determines the required space, manpower staff, and operation balancing for manufacturing operations. The urgency is also one of the parts of timing it influences all five elements.

3.2.4. Systematic Layout Programming Pattern -Phase II

This section is aimed to provide a brief overview of the SLP procedure as shown in Figure 6. A detailed explanation of applying each step is given in Section 2.2.5.

When layout planning applied from the very beginning to the end, phases of any facilities redesign comprise generating a general overall layout and then detailing this layout plan for each portion of the general overall layout. The pattern to be followed in both Phase II and Phase III is basically the same. Every layout based on the three pillars (Muther, 1973):

- Relationships - the desired or required degree of relative closeness between things.
- Space - the type, amount, and shape or configuration of things being organized.
- Adjustments - realistic optimal arrangement of objects.

The pattern of the layout planning procedure is based upon these three fundamentals that are always the crux of any layout planning without regarding project size, processes and products.

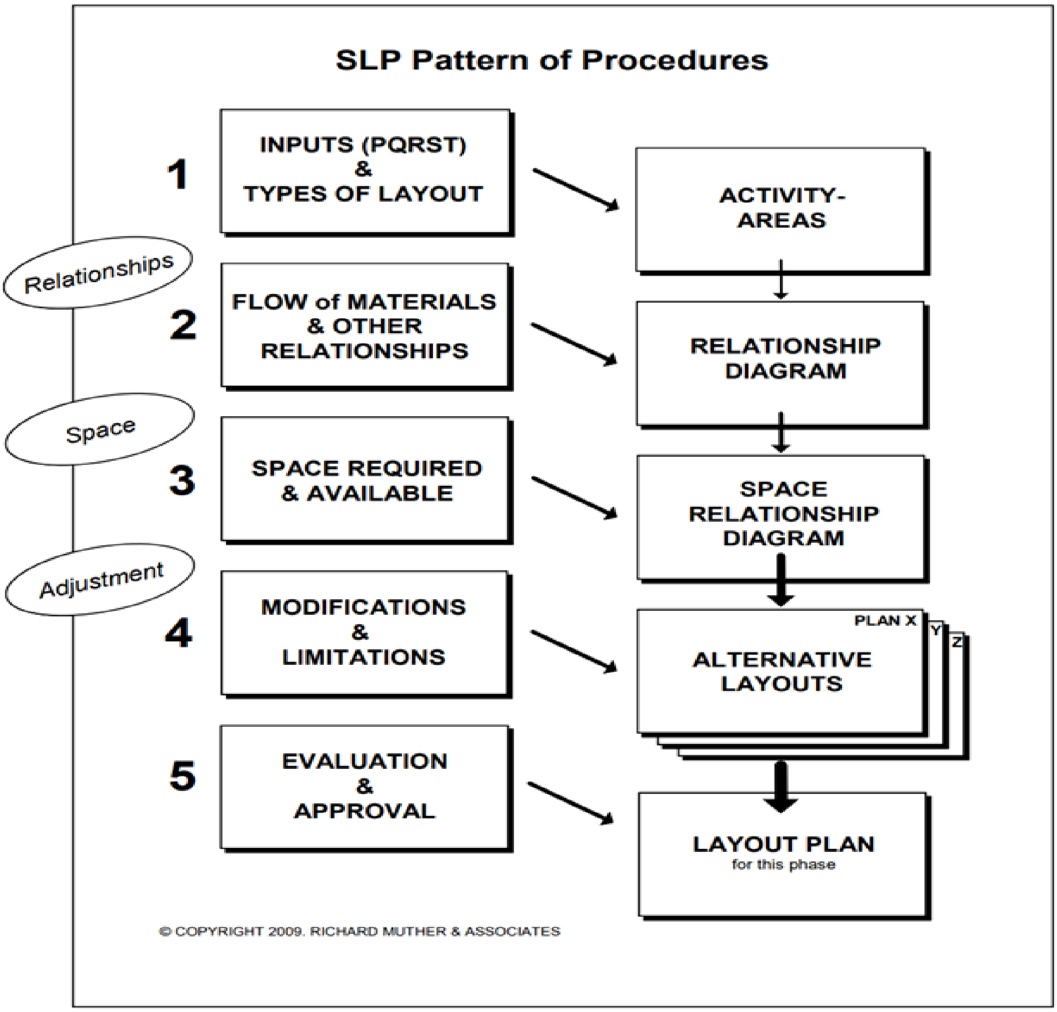

Figure 6. SLP Pattern of Procedures (Muther, 1973)

Planning follows the five parts of the pattern box-by-box. The procedure starts with the analysis of inputs and possible types of layout; the aim of this step is to clarify the division of the total area revealed. A list of Activity-Areas such as departments, cells, workgroups, etc is the output of this section.

The second part establishes and visualizes the relationships to be met by the layout. In process-intensive industries, Material Flow is often the most important aspect of layout planning. By planning the layout around the sequence and intensity of material movements, we achieve a gradual flow in the areas with minimal material handling effort and cost. On the other hand, many supporting service areas must be integrated and planned additionally to production or operating areas. Based on this, other relationships which indicate the relationship between service or support activities, or functions are developed. Generally, other relationship is equal or greater than material flow relationships alone. The second part is finalized by combining these two studies into a flow and/or activity Relationship Diagram. As an output of this step, the various activities, departments, or areas are geographically related to each other, regardless of the actual space needs (Yang et al., 2000).

In the next section,3, the required field for each activity-area is determined. This has been developed from the analysis of the required process machinery and equipment and the associated service facilities. However, the space requirements must be balanced with the available space. The space allowed for each activity is then stuck into the activity relationship diagram to create a Space Relationship Chart. The space relation diagram is essentially a layout Yang et al., 2000). However, it is not an effective layout till it is configured to accommodate modifying considerations in section 4.

Typically, modifications can be made for basic considerations such as operating practices, storage, handling method, scheduling, etc. When each potentially good idea is proposed, each of the practical limitations such as cost, safety, and employee preference should be reconsidered.

One idea after another is studied, while the integration and adjustment of various modifying considerations and practical constraints are examined. While valuable practical ideas are retained, unsuccessful ideas are discarded. After abandoning these unworthy plans; two, three, four, or five alternative layout proposals are left. The problem is deciding which of these plans to choose while each of them will work; each has a value. These Alternative Layouts can be called Plan X, Plan Y, and Plan Z (Muther, 1973).

In section 5, some form of cost analysis should be carried out for comparison and justification. In addition, some considerations of intangible factors should be made. Finally, one of the alternatives is chosen. After approval, the chosen alternative becomes the Layout Plan. Phase II is completed with the selection of the general overall layout plan.

3.2.5. Phase III Connection - Detailed Layout Plans

After developing the general overall layout in Phase II, a detailed layout plan of each piece of machinery, equipment, storage area for each of the activities, department, or areas, which are roughly thought down and prepared in the general overall layout, is obtained in next phase, III.

As seen in Figure 5, Phase II overlaps with Phase III. This means that certain details need to be considered before completing the general overall layout. For the reason of overlapping, Phase III, which requires detailed work in specific areas should be taken into account before Phase II is selected. Not only does this mean that adjustments are made within these detailed areas, but it also means that some readjustment of the chosen general overall layout may be necessary. That is, even if a basic general order has been agreed upon, the details can be adjusted and changed within limits as they are studied.

In the planning of detailed layout plans, the same model used in Phase II is repeated. However, in this phase, the flow of materials now turns into the movement of materials within the department at issue, and the activity relations, activities within this department. In the same way, while space requirements turn into the required space for each specific piece of machinery and equipment, the space relationship diagram becomes the rough arrangement of templates or other copies of machinery and equipment, men and materials or products. The procedure again results in several alternatives, and alternative plans (for each department) are evaluated to select the best layout plan. The same pattern is repeated for each departmental area to be laid out in detail (Muther, 1973).

3.2.6. Simplified Systematic Layout Planning

Some layout planning does not require four phases and repeated five-section pattern of the planning procedure by reason of their scope are small enough and their required or design or redesign issues so limited. For these types of projects, Muther (1973) proposed a short form, Simplified Systematic Layout Planning consist of 6 main steps. This simplified version of SLP can be preferred to small areas, job-shop production area, and some non-production activities, while there is no certain restriction, this procedure is suggested for (Muther, 1973):

- “office areas up to about 3,000 square feet,
- shop or laboratory areas up to about 5,000 square feet,
- storage areas up to about 8,000 or 10,000 square feet”.

It basically consists of six procedures or steps that cover the three fundamentals of any layout planning project. The six steps that make up a logical sequence form a viable layout starting from the analysis of the raw data, as in the 4-step general procedure. Unlike traditional SLP, the simplified version concentrates the stages, levels, and tasks of the entire methodology on the following steps (Loucka, 2006):

1. Creating a Relationship Chart
2. Determining Space Requirement
3. Creating Activity Relationships Diagram
4. Creating Space Relationship Diagram
5. Developing Layout Alternatives
6. Detailing the selected layout plan

Simplified SLP is often used in Phase III planning. Having said that simplified SLP uses only one symbol - circle - to create a relationship diagram, does not use colour or shading codes, and provides no quantitative method for determining material flow. It is not suitable for large projects or projects with large material flows.

Step 1: Creating a Relationship Chart

Activity relationship refers to the relationship between activities - these can be machines, departments, storage, etc. - on the working area of any industry. While the relationship between activities may be important, insignificant even sometimes undesirable (Singh, 2009).

In order to determine which activities or departments or working groups should be placed alongside others, the relative closeness required should be measured and recorded in a simple way showing the desired relative closeness between each pair of activities. Additionally, we need to find a way to record why this closeness rating is assigned. These are represented with the help of a chart, the 'Relationship Chart', which is a cross-sectioned form to record the results of these decisions in an organized manner (Muther, 1973). This chart is a crucial tool to design a layout for any type of industry, for that reason it must be considered very carefully when designing the layout (Sharma & Mor, 2015). “The chart itself is almost self-explanatory.” (Muther, 1973). For example, the relationship between activity 2 and activity 3 is recorded where the activity on the downward sloping line 2 intersects the activity represented by the upward sloping line 3. As such, for each activity pair, there is an intersecting box.

The relationship is represented by some ratings called the degree of closeness (Tompkins, 2010). Creating a relationship chart requires defining the relationship between activities and resources (Benjaafar & Sheikhzadeh, 2008). This information can be acquired via survey/interviews. In the survey, employees related to the activities are asked to determine where / who they will get their work from and the destination of their work after it is completed. At this point, relationship chart allows compiling the survey results. The relationship chart shows which activities are related to others and also evaluates the importance of closeness between them, the degree of closeness is shown in Table 1.

According to the Muther, (1973), following basic rules should be applied:

- Less than 5% of A and X).
- No more than 10% of an E.
- No more than 15% to be I.
- No more than 20% O.
- Approximately 50% of U

Rating	Closeness	Meaning
A	Absolutely necessary	put activities closer to each on the shop floor
E	Especially important	put these closer, if possible, after putting the A - relation
I	Important	will be consider after E relationship
O	Ordinary closeness	
U	Unimportant	no need to consider
X	Undesirable	important in case of harmful situation to each other

Table 1.Closeness Rating (modified from Grassie, 2009)

As seen in Figure 7, the closeness-rating letter is posted in the upper half of the diamond-shaped block showing the relationship between a pair of activities. In addition, there is always a reason behind the closeness rating between activities. It may be any reason, like the flow of materials, contact necessary, etc., and the reason is coded by numbers, entering the number in the lower half of the block. The reason encoded in each number is explained in a separate section of the form. This way, the individual relationship between each activity pair is rated, validated, and recorded.

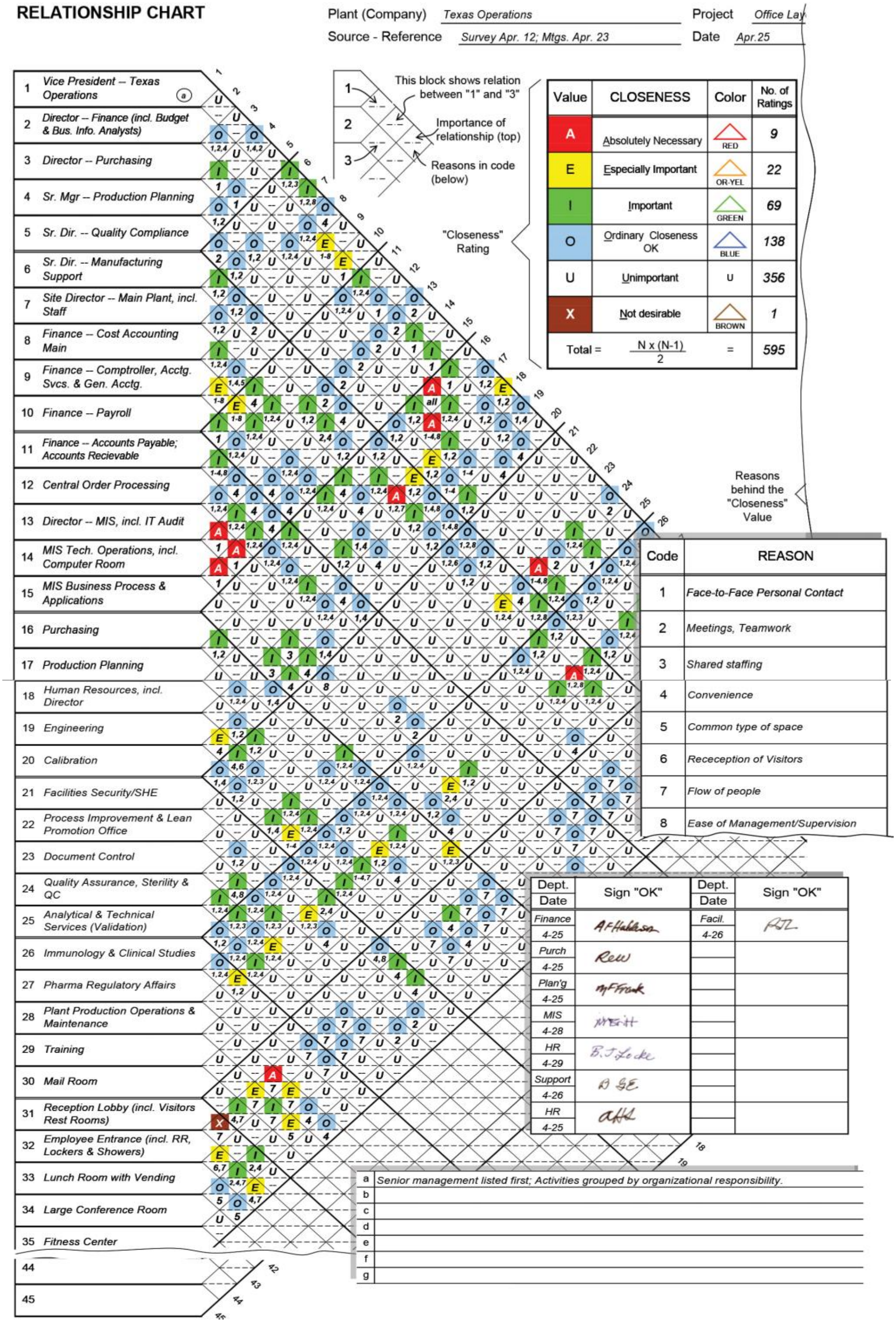

Figure 7. Relationship Chart Example (Muther, 1973)

Step 2. Determining Space Requirement

In determining the space requirements for the next step, the same activities as in Step 1 are used. Then establish and record the space required to support each activity. These required space measurements can be obtained in a number of ways. One is to identify the areas currently used for each individual activity to take place, and then apply one factor for the effectiveness of the available space use and another factor for any anticipated change in the level of operations to be supported (Muther, 1973). Another way is to scale an area for each equipment, taking into account the work area, access corridors, maintenance room and the like. In this way, what is required for each work area is determined and the area required for the whole operation is obtained by summing the values required for each work area. Standard space requirements can be used for restroom, private offices and parking spaces.

Step 3. Creating Activity Relationships Diagram

Up to that time, tabulated and accumulated data is collated. At this step, by preparing an activity relationship diagram this data will be returned into a more useful form. In order to represent the activities circles, which are numbered to make identification easier, are used. Each activity pair is connected to each other by parallel lines based on the rankings, which is determined in the relationship chart prepared in Step 1. The highest rate of relationships (A) are represented by four connecting lines; E's and I are triple and double lines, respectively. Later, O's and X's are added and the diagram is redrawn to get the best relationship fit. X's are shown as zig-zag or wiggly lines. In the meantime, care is taken that the lines of the relationship do not cross each other. The diagram can be rearranged a second or third time for the best fit of all relationships.

The aim is to place the activities according to the closeness rating. According to this, the highest ratings will be nearest to each other and lower ratings relatively farther away. Required space is plotted on the diagram next to each activity circle after the best arrangement is obtained. This diagram represents the theoretical ideal arrangement of activities as it is prepared without considering the actual space involved for each activity. This diagram is the most important step of the whole procedure. If not done properly, a final layout with the best overall arrangement cannot be achieved.

Step 4. Creating Space Relationship Diagram

After solving the first two fundamental problems, relations and space, the diagram can be adjusted to a layout. According to the Step 3, The space required for each activity is blocked, the relative position of each activity is maintained. Layout plan can be influenced from consideration regardless of whether the problem is reorganization of existing facilities or a completely new area. These considerations can be building features, equipment configurations, availability of utilities, staff convenience, procedures and controls, access roads, and the like. Few viable layouts often result from this planning, and normally two, three or four alternatives are best prepared.

Step 5. Developing Layout Alternatives

An evaluation procedure is used to assess objectively the relative value of the alternative layouts. After identifying each alternative plan, then all the objectives to be achieved and factors influencing the choice are listed. Relative weights to each factor are assigned starting with 10 for the most important. Later, the effectiveness of each arrangement for each factor, again using A, E, I, O, and U, in descending order of results provided by each plan is rated. After all the ratings are made and recorded in this way, the letter ratings are converted to the corresponding numerical values: A = 4, E = 3, I = 2, O = 1, and U = O. Then the numerical values are multiplied by each of its own weighted factors. The sum of the weighted nominal values is calculated for each alternative arrangement. The highest total value should show the most appropriate layout.

Step 6. Detailing the selected layout plan

The final step of simplified SLP is redrawing the layout to scale the layout, identifying areas, showing main features and equipment, drawing details of each equipment and/or machine item, and showing individual utilities as needed. To re-evaluate the appropriateness of these details, appropriate identification data and dimensions should be provided, and the required number of copies should be duplicated. After final approval, the plans can be given to those who will actually install the equipment.

4. Implementation and Results

In this section, Simplified Systematic Layout Planning algorithm was applied to the battery swap machine production. In order to have an idea about the necessity for this process, a cost analysis was carried out.

4.1. Cost Analysis

Cost analysis is applicable for any technology and manufacturing process to gain knowledge about manufacturing cost, to understand supplier cost structure, and to create fact-based comparison between different technical solution. Companies can use this analysis to understand what their focus should be, what should be their strategic plan to increase profit margin. On the other side, cost analysis plays an important role to find the right supplier and make good negotiation with them.

Within the concept of this project, cost analysis of battery swap machine was made based on the material, transportation, and labour cost with 9 different projects for year 2020. Despite the big part of the projects was same, there are some differences due to the customer requests, drawing revision and industrial relationship etc. This allowed to work on it and see how cost changes over time.

Battery swap machine is a highly complex, customized product and there is an important technology behind it. The product includes 3 different material types, these are mechanical raw materials, commercial raw material, and screws. While screws and commercial raw materials are common and can be found easily from the different suppliers, mechanical raw materials are designed for Battery Swap Machine and their quality, cost and supplier relationships are important for the production. However, considering the quantities used in the machine, the importance of commercial raw materials should not be ignored.

Battery swap machine includes different kinds of raw materials in different quantities within the different raw material groups. It can roughly be considered that inside the machine there are 314 mechanical raw materials from 126 different mechanical raw material types, 5017 commercial raw materials from 43 different commercial raw material types, and 1313 screws from 83 different types of screws. This indicates that there is highly complex supplier relationship is involved on the production of the product.

While the raw materials themselves are an important parameter for this analysis, extra machining, finishing, and painting processes are a huge effect on the cost of the machine. These processes are considered raw material costs because these operations are carried out under the responsibility of the suppliers.

In terms of transportation cost, the cost between the company and its suppliers is not evaluated, because, in their agreement, the shipping is supplier's responsibility. The only transportation cost considered is the amount between the customer and Eurofork S.p.A. Labour cost analysis is done based on the data entered the system manually by the employees. The detailed total cost values of each project can be found in Table 2.

	Batch Size	**Material Cost**	**Extra Cost**	**Transportation Cost**	**Labour Cost**
Project 1	12	€ 185,738.65	€ 2,123.03	€ 16,099.56	€ 15,632.09
Project 2	12	€ 185,545.52	€ 22.44	€ 4,226.84	€ 16,014.58
Project 3	12	€ 185,978.31	€ 216.83	€ 4,307.74	€ 20,418.29
Project 4	20	€ 300,761.01	€ 1,870.68	€ 6,583.04	€ 28,433.43
Project 5	24	€ 356,407.62	€ 175.44	€ 4,926.60	€ 31,808.33
Project 6	24	€ 355,781.03	€ 64.92	€ 5,648.16	€ 30,119.61
Project 7	24	€ 358,683.31	€ 48.96	€ 6,720.99	€ 28,711.37
Project 8	24	€ 353,643.32	€ 47.12	€ 5,041.41	€ 30,194.61
Project 9	24	€ 353,248.51	€ 72.09	€ 7,263.08	€ 36,656.73

Table 2. Cost of Projects

As seen in Table 2, there is a rather interesting material cost reduction from Project 1 to Project 9. Further potential savings could be achieved from supplier negotiations and all of them were analyzed and required actions were taken. However, this issue is not part of this thesis work and will not be mentioned. The extra cost consists of several different material requests of drawing teams to try some improvement options and possible raw material garbage due to the lack of experience of employees on this machine. It is quite normal that this cost will decrease as time passes. In terms of transportation, there was some fluctuation, due to COVID-19, the company sometimes has used different transportation channels for non-regular order delivery.

The most interesting part of this cost analysis is labour cost. It is calculated by multiplying production time and cost of labour which is considered 35€/hour. In Figure 8, close attention is given to the labour cost change. As it is seen, although the unit product cost tends to decrease, the same is not the case for the labor cost. As the workers produce more products, they should become more familiar with the production and as a result, the standardization effect should have occurred. Consequently, the production time and cost should have decreased. However, Figure 8 is showed that in the last 3 projects, the labour cost tends to increase.

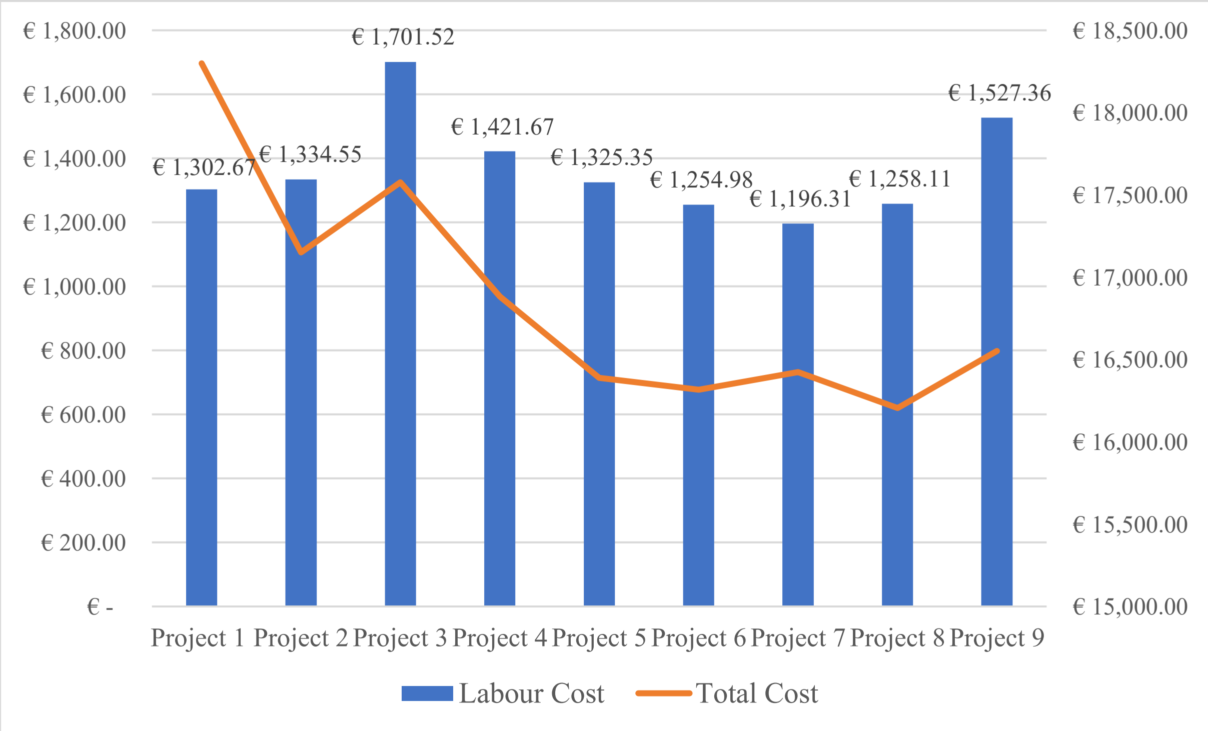

Figure 8. Labour and Total Cost Change of Machine

After this unexpected change is recognized, it is decided to make the more detailed production time analysis. However, despite having total production hours for each project, due to the manual nature of data track and lack of employee attention, there is no time information for each specific phases of each project. While Table 3 is showed the total labour time information for each machine set at each project, in terms of hour, Table 4 indicates the example time values for each specific phase. These sample time values were collected from the employees' survey because the active production required for time and work-study is not available during this analysis period.

	P1	P2	P3	P4	P5	P6	P7	P8	P9
Pre-assembly	17.60	9.57	19.50	14.98	13.09	11.53	11.08	9.88	14.23
Assembly	16.86	25.20	27.24	24.25	23.02	22.83	21.57	24.78	27.54
Packaging	2.77	3.36	1.87	1.39	1.76	1.50	1.53	1.28	1.87
Total	**37.22**	**38.13**	**48.61**	**40.62**	**37.87**	**35.86**	**34.18**	**35.95**	**43.64**

Table 3.General Phases' Time (hour)

The biggest attention should be given that there are not material handling and inside transportation cost information in both tables. While employees were entering these values, they have considered these parts inside the general phases. It means that the increase of pre-assembly and assembly costs can be due to these unconsidered material handling. While considering this situation and the increased demand of the battery swap machine, applying Systematic Layout Programming have decided.

Station	Phase	Description	Time (min)
1	Testing	Checking doubling for wheel, gear and etc.	40.8
1	Pre-assembly	Pre-assembly of transmission motor	71.4
1	Assembly	Assembly of transmission motor and lift	224.4
1	Checking	Modification/adaptation/unforeseen events	0
2	Chain Cutting	Chain cutting and pre-assembly of bearing press	44.88
2	Pre-assembly	Pre-assembly of long and short shaft lifting, chain tie and tensioner transmission	144.66
2	Assembly	Assembly of central body transmission, eccentric chain tensioning and shrink disc closure	326.4
2	Checking	Modification/adaptation/unforeseen events	5.1
3	Pre-assembly	Pre-assembly of lifting parts	367.2
3	Assembly	Assembly of lift	122.4
3	Checking	Modification/adaptation/unforeseen events	0

3	Pre-assembly	Pre-assembly of table alignment	61.2
3	Assembly	Assembly of table alignment	61.2
3	Checking	Modification/adaptation/unforeseen events	0
3	Pre-assembly	Pre-assembly of release bench	61.2
3	Assembly	Assembly of release bench	61.2
3	Checking	Modification/adaptation/unforeseen events	5.1
3	Testing	Movement and bulk test	30.6
3	Cleaning	General Cleaning and Various Maintenance	86.7
4	Assembly	Final Assembly	51
4	Finishing	Finishing	193.8
4	Painting	Painting for details	0
5	Packaging	Pre-assembly for packaging	51
5	Packaging	Packaging	40.8

Table 4. Time Estimation of Specific Phases

4.2. Battery Swap Machine Production Steps

Battery swap machine has a long and complicated production process. However, only the pre-assembly and assembly phases of finished raw materials are considered based on the thesis coverage. After all technical raw materials and screws are reached to the storage area from the suppliers of raw material, machining, and painting; responsible storage area employee/s prepare the raw materials into big pallets to send assembly area. On the other side, after the pre-assembly of the mainframe, lift, and alignment plate are finished in Eurofork, these are sent to a supplier for the painting and when the finished raw materials return to the Eurofork, all the needed raw materials become ready. Together with the pallets that consist of technical raw materials and screws; the painted mainframe, lift, and alignment plate are moved from the storage area to the assembly area at the desired amounts to feed the assembly. With moving the pallets to the assembly area, the real process starts because the main work done at Eurofork is assembling the finished materials into the mainframe and in this way creating a battery swap machine.

Without not considering the workplace, the assembly stages of the battery swap machine are explained in Figure 9. The process starts with, checking the doubling of the wheel, gears, and shaft that need to pair is done. Each of these three kinds of raw materials should be used with their correct pair. If they are not a correct couple in each other, the power transmission could be a problem. To prevent this situation, the shaft-wheel-gear, shaft and wheel, shaft and gear pairs are checked, respectively. This operation is closed by marks on all system screws, so it must be sure all is good and checked by a skilled operator.

This process is followed by the assembly of the transmission lift and motor. This is the first assembly step of the battery swap machine because the cardan shaft is a long and big raw material, and it is not easily be assembled during further line steps. These two different assembly processes should be done together because a pre-assembled transmission motor, consist of pre-assembly of reducer translation, is a part of the assembly process of transmission lift together with the pre-assembled reducer lifter group and support for the long shaft lifting. Each assembly step is finalized with the checking of unexpected mistakes, if exist, and adaptation of correct actions for them.

As a second step central body transmission, which provides the transferring of the lifter motion from the reducer lifter group to the lifter eccentric cams by a chain, is done. In this way, the lifter movement can be done, and the swapping battery system can reach the right position under the car before starting the unlocking operations. For this step, there are some perquisites. These are chain cutting and, pre-assembly of bearing press for all different 3 kinds of wheels used inside the machine. The first component of this step is the pre-assembly of the chain tensioner. Central body transmission assembly is finished by montaging already pre-assembled components such as eccentric cams, chain tensioner, and the pre-mentioned 3 different kinds of wheels, and transmission lift. As already mentioned, after this assembly process, transmission lift assembly becomes a part of central body transmission. Necessary correction is also done at this stage.

Assembly of central body transmission is followed by the assembly of the lift inside the mainframe. This process requires a pre-assembled lift mainframe; which consists of a pre-assembled guide group, ball screws group, and ball screw reducer group; together with the assembled central body transmission. As seen, while the central body transmission is a part of the lift, transmission lift is a part of central body transmission. This clearly indicates the continuous nature of the assembly processes. After all mistakes are fixed, the process continues with the assembly of table alignment. To be able to do this, the completed lift should be assembled to the mainframe together with the pre-assembled alignment plates group and guide group. Following the necessary modification, assembly of the release bench is done by mounting a pre-assembled unlocking system and table alignment. After the unforeseen events are checked movement and bulk test should be done to control the weather is lifting, alignment and unlocking movements are done by the machine properly or not. The most important check at this stage is being sure that the eccentric cams must be at the same angle position. If this condition is not satisfied, the system will not work properly and chains will be under unexpected force, which will cause its easy break.

After the testing, the final assembly is done which is related to adding protection plate into the machine. This is followed by the painting phase, which is used when there are existing discolorations on the machine as a result of working on it, and then the cleaning and finishing phases. The final step is the packaging however, this can be considered as a pre-packaging because putting the machine inside the wood box is done in the storage area. All these steps are done for both the right and left sides of the machine.

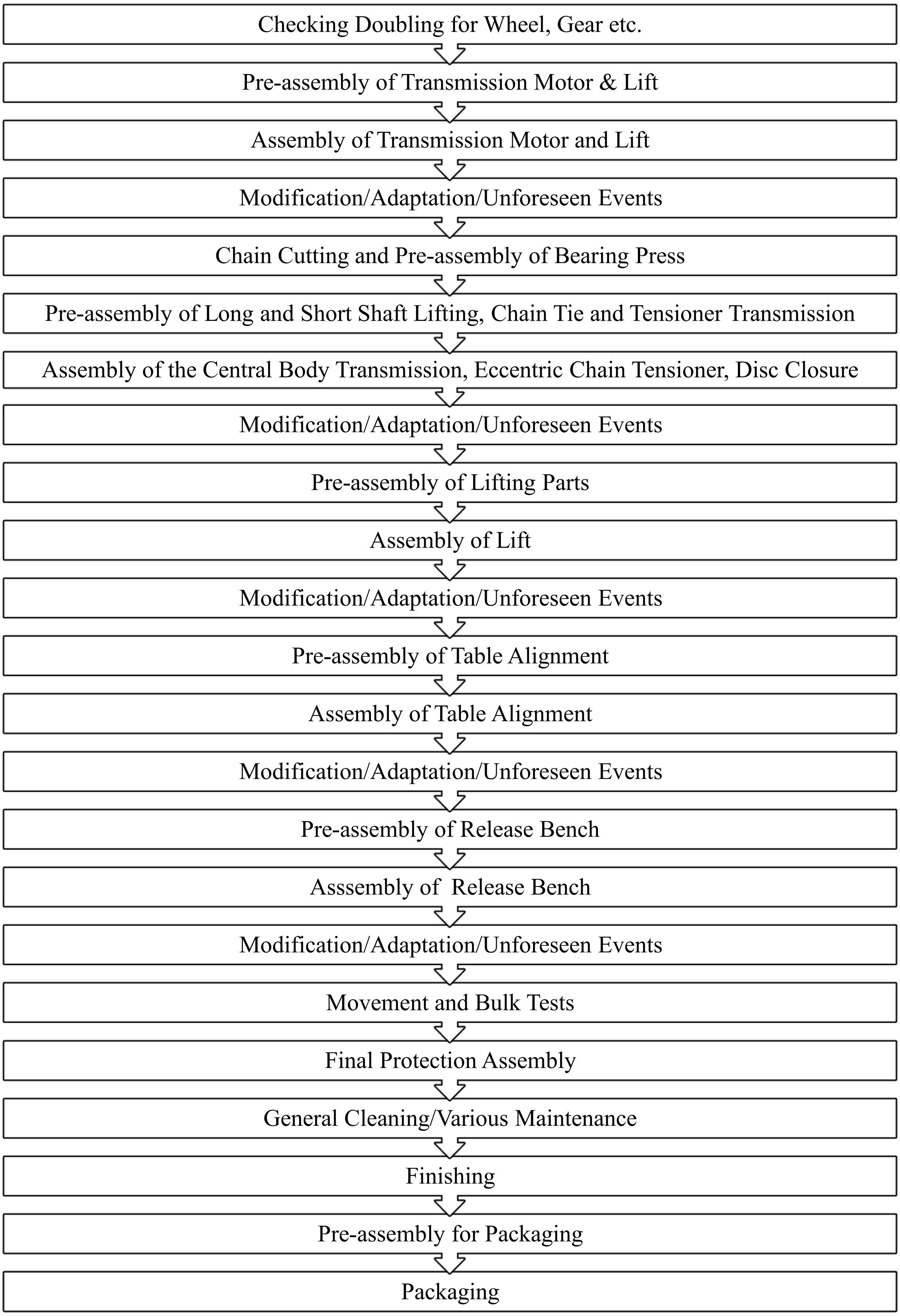

Figure 9. Production Steps

4.3. Analysis of Existing Layout

Before starting to work on the implementation of Systematic Layout Programming, it is critical to examine the current situation and make decisions based on the shortcomings and missing points. Since there were preparations to modify the layout at the time of this research and was not having active production there was no chance to examine the existing layout with a time study to measure material handling, employee movements, and actual material flow rather than the theoretical. For that reason, the analysis of the existing layout was done by collaborating with the responsible employees of battery swap machine production and the project manager.

The first thing that we need to know in this layout is that the left and right parts of the machine were positioned transversely to the assembly station. We can imagine this situation like that while the right side flows on one line, the left side flows on another line. Since two parts of the machine were placed sideways, a large area was needed. The other important thing is that there was a common pre-assembly area to prepare all the components before putting them inside the machine. After raw materials prepared, they were moving to the relevant assembly area. This situation clearly indicates the excessive amount of material handling for the pre-assembled components. This excess material handling is also valid for other parts that will be placed inside the machine during assembly without the need for pre-assembly. These parts were prepared in the material storage area, at the very beginning of the production line, and transported for each assembly area. There were shelves in the line to store the screws that are usually needed throughout the assembly phase. When the employee needed these screws, he had to choose the proper screws from the storage and place them on the movable table to bring with him to the assembly area. This explicitly indicates that more time is required to choose, movements for transportation.

Labour cost change which is indicated in Figure 8 clearly shows that there is no certain and applied working procedure for the battery swap machine production line. In the opposite case, there should be a predictable labour cost decrease based on the standardization. As it seen in the Table 3, the average production time of one machine set (together with right and left side) is around 39.5 hours in this existing layout. If we assume that the labours were doing the assembly and pre-assembly activities at the same time in every project, it should be the case, in the worst situation without considering standardization, because there is no change in the machine drawings; the problem can be only about the material movement and/or employee motions. This is the result of the poor and inefficient layout. When this cost analysis conclusion was combined with the qualitative analysis, it provided huge incentives to work on this layout problem and design an efficient production line based on it.

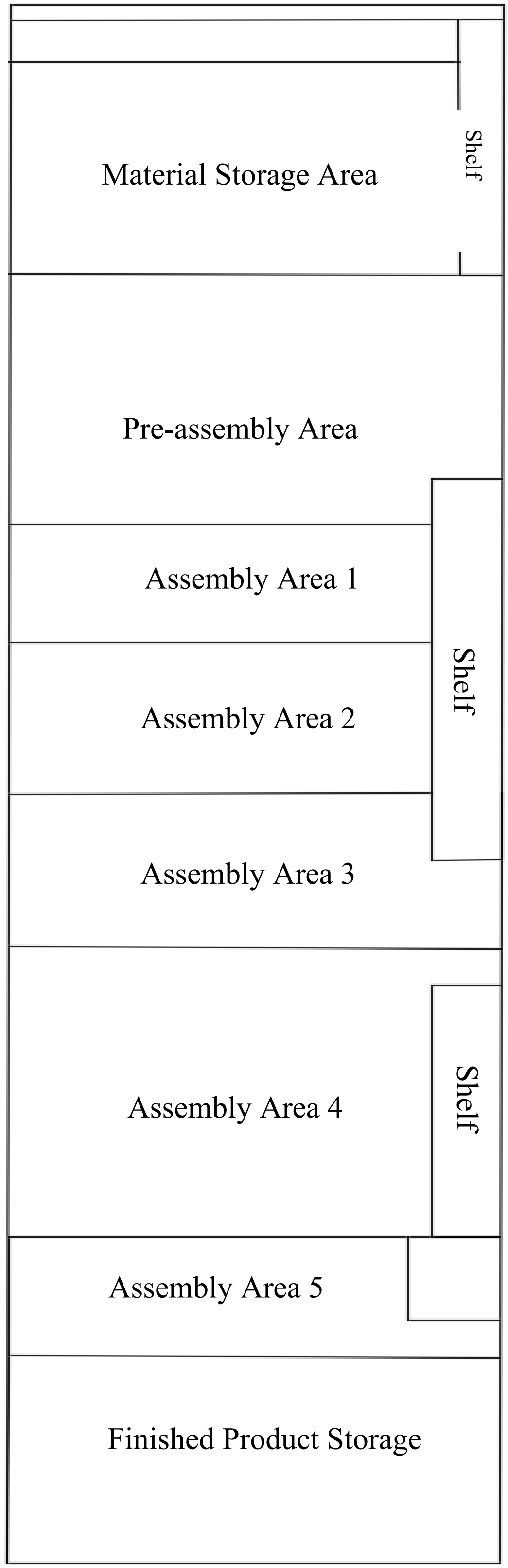

Figure 10. Existing Layout Diagram

4.4. Implementation of Simplified Systematic Layout Programming

4.4.1. Creating Relationship Chart

Relationship Chart is the best way of showing the relationship between the activities and/or departments. Before creating it, determining the layout type is an important step to understand the relations and placing activities in an appropriate way. Battery swap machine production is a typical assembly line and should be followed the defined production order. This clearly indicates that job-shop layout should be followed. A job-shop is a sort of manufacturing operation that produces small quantities of customized items and similar equipment, or operations are clustered together.

Relationship Chart of Simplified SLP can be considered as the combination of Flow of Material Analysis and Activity Analysis of general procedure of SLP. While flow of material is related to the quantitative analysis, activity analysis is related to the qualitative factors that affect the determination of the activity/department location should be placed. In the production process of battery swap machines, applying a flow of materials is not make sense due to the small number of production batches and always the same number of materials transferred from one activity to another. For this reason, the Relationship Chart will be based on qualitative analysis.

The production process of the battery swap machine, as shown in Figure 9, is used to create the Relationship Chart. Due to the simplified nature of this procedure, the activities which have to be done exactly at the same station should be merged. In the case of battery swap machine production, the activities that should be thinking like as one activity are shown in Figure 11. The reason behind these merging is related to the continuous nature of assembly processes are:

- Modification/adaptation/unforeseen events must be performed after all assembly steps and there is no further equipment needs and it should be done by the same employee who is responsible of the assembly step.

- Gear, wheel, and shaft which are checked for doubling, are the raw materials of the pre-assembly step of the transmission motor and lift.

- Assembly of lift, table alignment, and release bench are extremely related tasks, and the output of the previous work is the input of the next. The part of the battery swap machine that is obtained after all these assembly stages is served for the same purpose: providing appropriate chain tensioning. For that reason, all these steps should be done by the same skilled employee at the same station because working on one of these is also related to the other processes.

Movement and bulk test should also be by the same employee and due to the no special need of equipment and place it can be done at the same place.

- After the protection assembly, cleaning and finishing should be done. After all these short-time processes are finished, the packaging of the machine has to be started. These processes can be done in the same area as the final assembly because they are short-term and do not require any special skills and space.

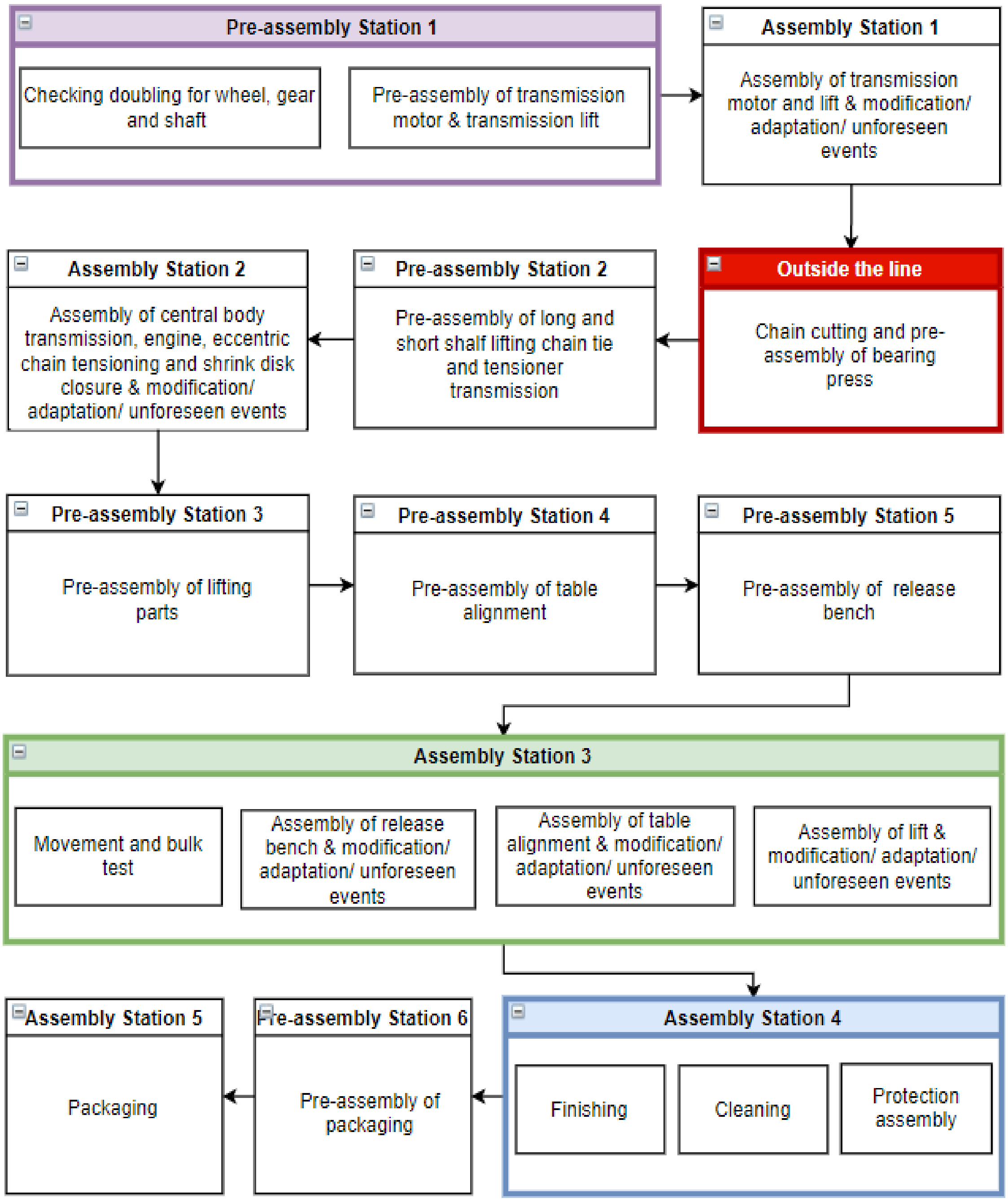

Figure 11. Merging related activities

It should be underlined that the SLP enables for the arrangement of predetermined working groups and/or departments, rather than which tasks should be performed together and at the same station.

In Figure 11, there is an information of possible station name was entered. The necessary changes were made in the subsequent phases of SLP. All these decisions were given by the technical drawing teams of the machine, project manager and the responsible of the production area as a co-decision. When creating a Relationship Chart, the left and right sides of the battery swap machine are combined into a single operation.

Number	Reason
1	Material Flow
2	Need of Contact
3	Using same equipment
4	Sharing same personnel
5	Supervision and checking

Table 5. Reason of Closeness

Code	Closeness Rating	Meaning
A	Absolutely necessary	Must be next to each other
E	Especially important	Need to very close
I	Important	Need to on the same side
O	Ordinary Important	Anywhere in the working area is OK
U	Unimportant	No significant relationship
X	Undesirable	Keep separate and far away

Table 6. Rating of Closeness

After determining closeness rating, detailed explanation is done in Table 6, and possible closeness reasons, which is showed in Table 5, Relationship Chart was created. During this, "chain cutting and pre-assembly of bearing press" phase was not considered because this process requires a specific machining equipment at the different area of the plant, due to coverages of this thesis, it was worked on the pre-determined area, that is suitable to use different product families.

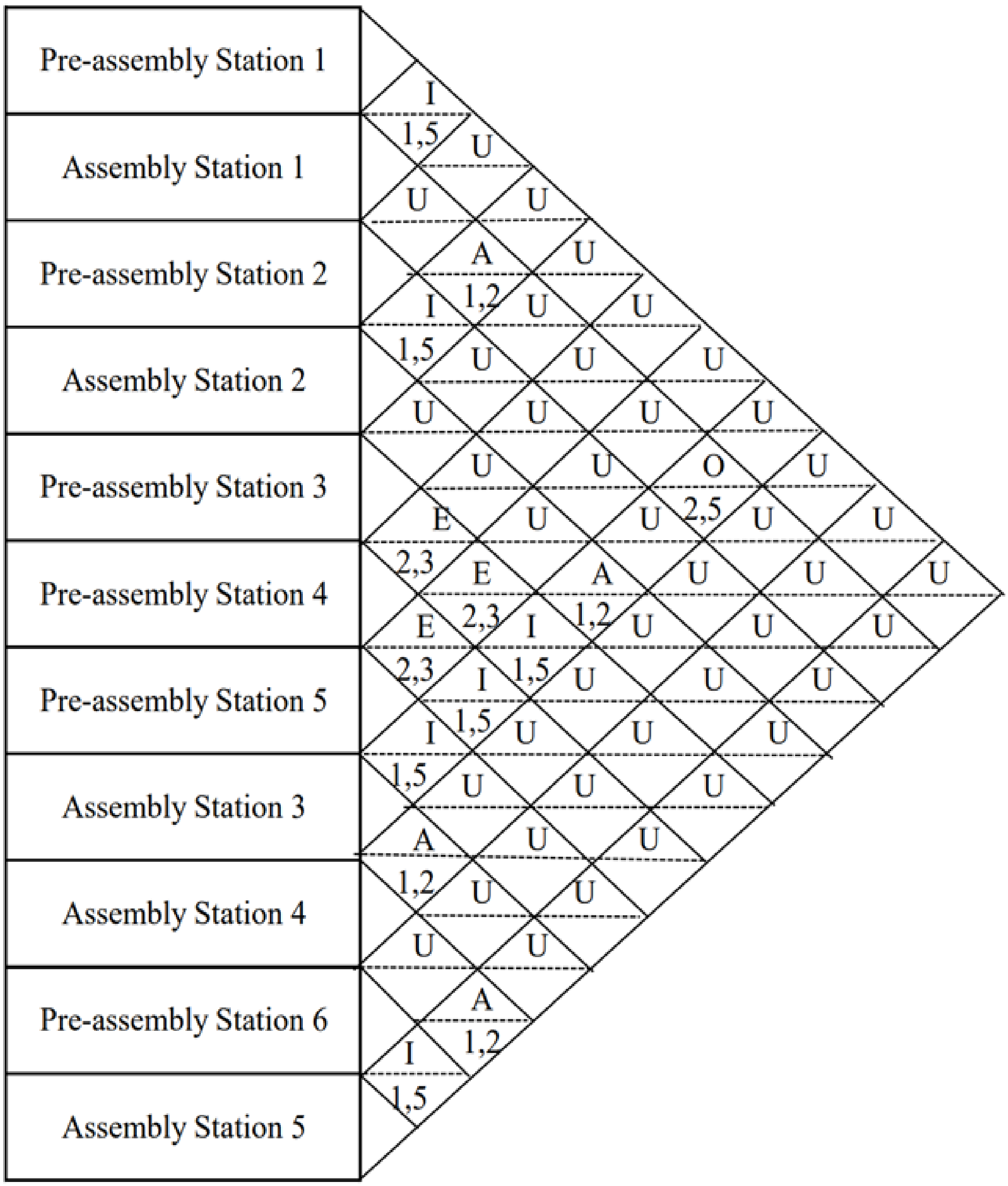

Figure 12. Relationship Chart of Battery Swap Machine's Production Steps

Without taking into account any constraints or space requirements, it is clear that there is a special closeness need between Pre-assembly Stations 3, 4, and 5. This circumstance is not surprising, as it was already mentioned in Section 4.2. Furthermore, assembly stations require "absolutely important" closeness due to the difficulty of material movement of large and heavy products.

4.4.2. Determining Space Requirements

The space requirements of each activity and their supporting activities have been calculated and can be found in Table 8. Although the new layout has not been placed to a very different area in terms of size, it is aimed that area will be effectively used to meet the increasing demand with a efficient labor cost reduction.

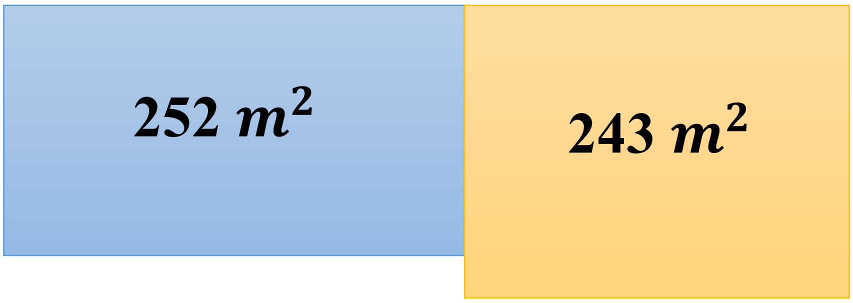

Figure 13. Layout Area Change

The Battery swap machine is assembled on a manually handled wheeled table that is precisely tailored to the machine's dimensions to maximize space utilization and is carried between assembly stations using the same tool. This manual transportation equipment has a length of 1.8 meters and a width of 1.5 meters. While considering the working place of employees at the assembly station, 60 cm to the left, 60 cm between the right and left side of the machine, and 60 cm to the right to the station are required for the passing of employees. However, the actual working place of the assembly station should be in front of the right and left side of the length of the machine since this allows employees to reach all inside the machine and make it simpler to work on it. For this working area, it was deemed appropriate to allocate 1 m of space on both sides. Taking all of this information into account, it was estimated that each assembly station should be 18.9 square meters in total, with 5.4 meters in length and 3.5 meters in width. The same dimensions were required for both assembly station 1, 2, 3,4 and 5.

In addition to the space where the actual assembly process takes place, an additional space of 0.6 square meters is required for an assembly activity. This area is for screw storage, and it is the same as the needed area for pre-assembly activities. Furthermore, Station 4 requires two separate spaces of the same size for label printing and adhesives, as well as a screw storage space. However, screw storage is not required for the final assembly station because packaging does not need such materials.

Generally, each pre-assembly station requires the use of two separate tables. One is for working on and performing pre-assembly activities, while the other is for storing pre-assembled and ready-to-use components for the assembly area. While the pre-assembly working area requires 0.8 square meters area with 80 cm width and 100 cm length, buffer storage area requires 0.6 square meters area with 60 cm width and 100 cm length. Furthermore, in some cases, each pre-assembly station requires another table, at the same dimensions with buffer storage table, to use as a storage of small screw parts that are used all the time during the pre-assembly activities. There is an exception to this situation. Unlike the others, pre-assembly 3, 4, and 5 are stations that operate with large components; thus, they require three big work desks, each approximately one square meter. The components pre-assembled at these three stations are made, as indicated in section 4.2, by the assembly of pieces that also need additional pre-assembly. However, because the numbers of these parts are limited, a single initial assembly, buffer storage, and screw storage area is considered enough for these three stations.

Station/Activity	**Quantity**	**Dimension(cm)**	**Area (m^2)**
Assembly Station 1	1	120x80	1
Assembly Station 1	1	80x60	0.5
Pre-assembly Station 1	1	120x80	1
Assembly Station 2	1	120x80	1
Pre-assembly Station 2	1	120x80	1
Assembly Station 3	1	120x80	1
Pre-assembly Merged Station	1	120x80	1
Pre-assembly Station 3	1	120x80	1
Pre-assembly Station 4	1	120x80	1
Pre-assembly Station 5	1	120x80	1
Assembly Station 4	3	120x80	1
Pre-assembly Station 6	3	120x80	1
Assembly Station 5	1	80x60	0.5

Table 7. Pallet Requirement of Station

As it has already mentioned at the Section 4.1., the commercial and mechanical raw materials are moved from the storage area to assembly area with the enough quantity to feed the production and to manage efficiently this transportation process. Based on this, storage area employees prepare pallets that are enough to produce 3 machine sets. In the existing layout, each of these pallets consists of raw materials that could be needed at any stations without considering the usage of raw materials at the specific working area. For that reason, it was required another material preparation processes at the assembly area.

In the new layout, all raw materials are arranged according to their needed at the stations and pallets are prepared for each specific stations. The number of pallets required for each station was determined by considering the amount and dimensions of materials required for each activity. Based on this, each station needs different number of raw materials pallets. There are 2 different sizes of pallet for the raw materials storage, while the larger one is more common with the 80 cm width and 120 cm length, 1 square meters as a total, the small one is only using at the station 1 and 4 with approximately 0.5 square meters. Table 7 demonstrates the required pallet numbers for each station.

Place	**Dimension(cm)**	**Area (m^2)**
Assembly station 1 working area	540x350	18.9
Assembly station 2 working area	540x350	18.9
Assembly station 3 working area	540x350	18.9
Assembly station 4 working area	540x350	18.9
Assembly station 5 working area	540x350	18.9
Assembly station 1 screw area	60x100	0.6
Assembly station 2 screw area	60x100	0.6
Assembly station 3 screw area	60x100	0.6
Assembly station 4 screw area	60x100	0.6
Assembly Station 4 label printing area	60x100	0.6
Assembly Station 4 adhesive area	60x100	0.6
Pre-assembly station 1 working area	80x100	0.8

Pre-assembly station 1 buffer storage area	60x100	0.6
Pre-assembly station 1 screw area	60x100	0.6
Pre-assembly station 2 working area	80x100	0.8
Pre-assembly station 2 buffer storage area	60x100	0.6
Pre-assembly station 2 screw area	60x100	0.6
Pre-assembly merged station working area	80x100	0.8
Pre-assembly merged station buffer storage area	60x100	0.6
Pre-assembly merged station screw area	60x100	0.6
Pre-assembly station 3 working area	100x100	1
Pre-assembly station 4 working area	100x100	1
Pre-assembly station 5 working area	100x100	1
Pre-assembly station 6 working area	80x100	0.8
Pre-assembly station 6 buffer storage area	60x100	0.6
Bubble wrap packaging machine area	133x185	2.5
Packaging storage platform	160x190	3
Ready-to-packaging storage	130x150	2

Table 8.Space Requirement of Battery Swap Machine Production Steps

The information received in this step will be utilized to transform the visual representation acquired in the following stage, the activity relationship diagram, to the possible layout alternatives with the exact values. To be more precise and determine the most efficient layout, the areas currently used for each individual activity to take place and their support activities are examined while gathering all this information.

4.4.3 Creating Activity Relationship Diagram

An activity relationship diagram is a visual representation of the departments/activities based on a spatial organization of the departments. This type of diagram is also known as an adjacency graph. This diagram is the most significant phase in the entire procedure since it is the only way to get a final layout with the best overall arrangement.

Up to that point, connection between the activities and their space requirement data has been collected. This data was returned to a more comprehensible format at this step by constructing an activity relationship diagram. While squares were used to illustrate the activities, parallel lines were used to connect the activities to each other. Parallel lines have been changed based on the ranking, which has already determined in the Relationship Chart. The most important rate of relationships (A) was represented by four connecting lines, while E and I were represented by triple and double lines, respectively. After these three relationships were considered seriatim, the O's were inserted as a single line, and the diagram was redesigned to get the optimal relationship fit. Meanwhile, considerable attention was given to ensure that the lines of the connection did not overlap. The goal was to organize the activities based on the closeness rating. According to this, the highest ratings were drawn closest to each other, while the lowest ratings were relatively further from. This diagram demonstrates the theoretical optimized arrangement of activities as prepared without taking into account the real space required for each activity.

As can be seen clearly in Figure 14, the most important relationship in the battery swap machine production process is between the assembly activities. This showed us that while working with real space requirements in the future we need to keep this in mind first. Also, while the relationship between pre-assembly areas is normally not important, pre-assembly 3-4-5 should be close to each other and this requires high attention.

While assembly operations should be near to one another, there is no such necessity for pre-assembly activities since they do not operate with big and massive mainframes like assembly, and also, they do not have a continuous process nature because pre-assembled components are independent of one another.

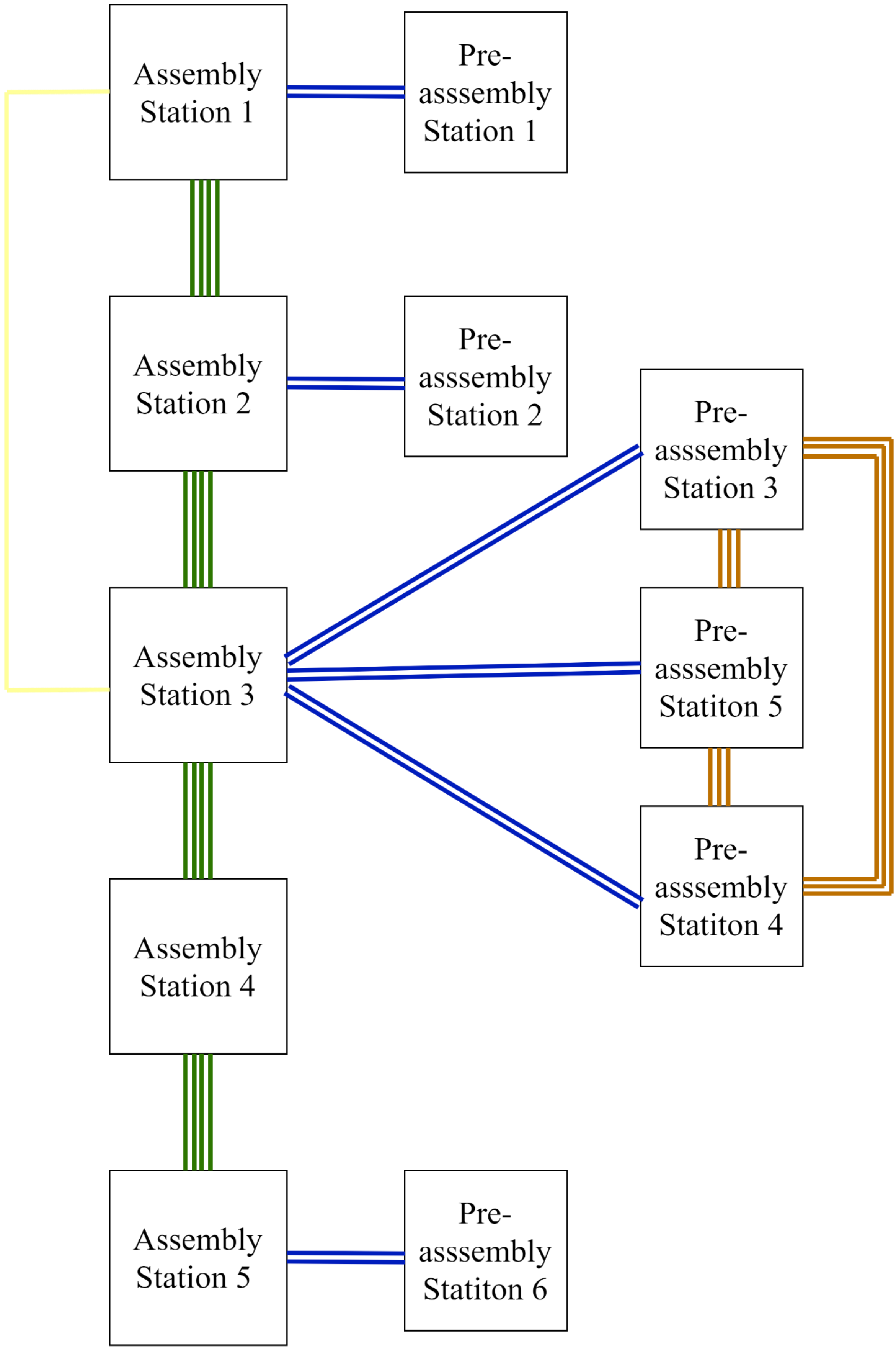

Figure 14.Activity Relationship Diagram of Battery Swap Machine's Production Steps

4.4.4. Creating Detailed Space Relationship Diagram

The diagram was changed to a layout after resolving the first two key difficulties, relations and space. The space required for each activity is restricted, and each activity's relative position is maintained in accordance with the activity relationship diagram. The layout plan was affected by factors such as building characteristics, equipment configurations, utility availability, staff conveniences, processes and controls, access routes, and so on. These are listed in the following and can be seen in the Figure 15:

- Production area is determined before and cannot be adjustable.
- In the pre-determined area, there are some edge columns and 2 pre-installed crane areas.
- Upper edge of production area is not suitable for the material movement and handling because there is another production area at the end of the line.
- Last steps of the production should be located to the right side of the area, to be close as much to the exit of the plant to make the transportation easier.
- Production area should include extra one set of mainframes as a buffer to provide the continuous nature of production.

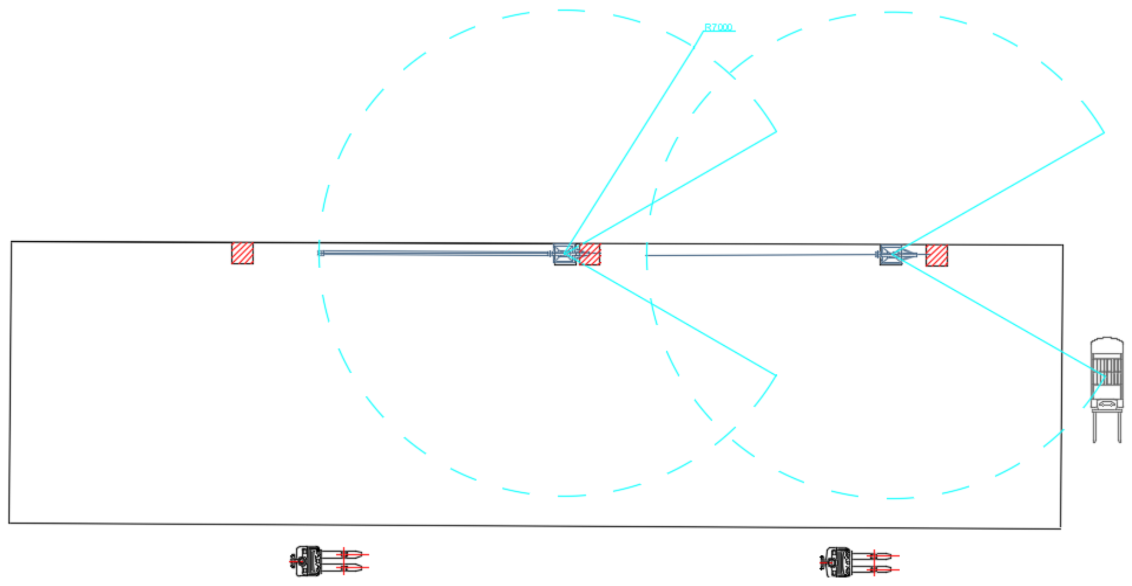

Figure 15. Visual Representation of Limitations of the Production Area

As it is seen in Figures 16 and 17, creating Space Relationship Diagram was not done in an ordinary way. In the normal case, the appropriate superficial area for each activity should be found by considering closeness rating which is determined in the creating Relationship Chart step and real space requirement of each activity. According to possible changes that can be done in the arrangement of layout, some alternatives layouts should be determined without detailing. While considering all the limitations, it could not find any other possibility than putting the assembly area to the left part of the production and the pre-assembly area to the right side. Furthermore, due to the continuous nature of the assembly line does not allows ordering the activities in a different way. For that reason, it has decided to detail the working areas and creating alternatives based on these differences.

While considering all these limitations, two possible alternative layouts were created. It did not make sense to create and work on more alternatives because it is not possible to relocate assembly areas. As a result, the only places that may be altered are the pallet storage and pre-assembly sections.

The major goal while designing the first alternative layout was to be nearer to the assembly area and provide better communication between pre-assembly and assembly area employees. As a result, even if there is no direct necessity between them, every possible work area and palletized materials are positioned relatively close to the assembly area.

In the second alternative layout, while the aim was to provide a more flexible working environment for the pre-assembly area workers, it was to reduce the confusion of choosing the necessary place to get the necessary raw materials for the assembly area employees.

When we examine both alternatives, we will notice that in both cases, they are placed side by side, taking into account the "absolutely necessary" relationship between the assembly areas. In addition, the "especially important" relationship between pre-assembly stations 3,4 and 5 and each "important" relationship between associated pre-assembly and assembly stations are provided. This general overview clearly indicates that without detailing the layout, it will not make sense to evaluating alternatives by only considered pre-determined activities.

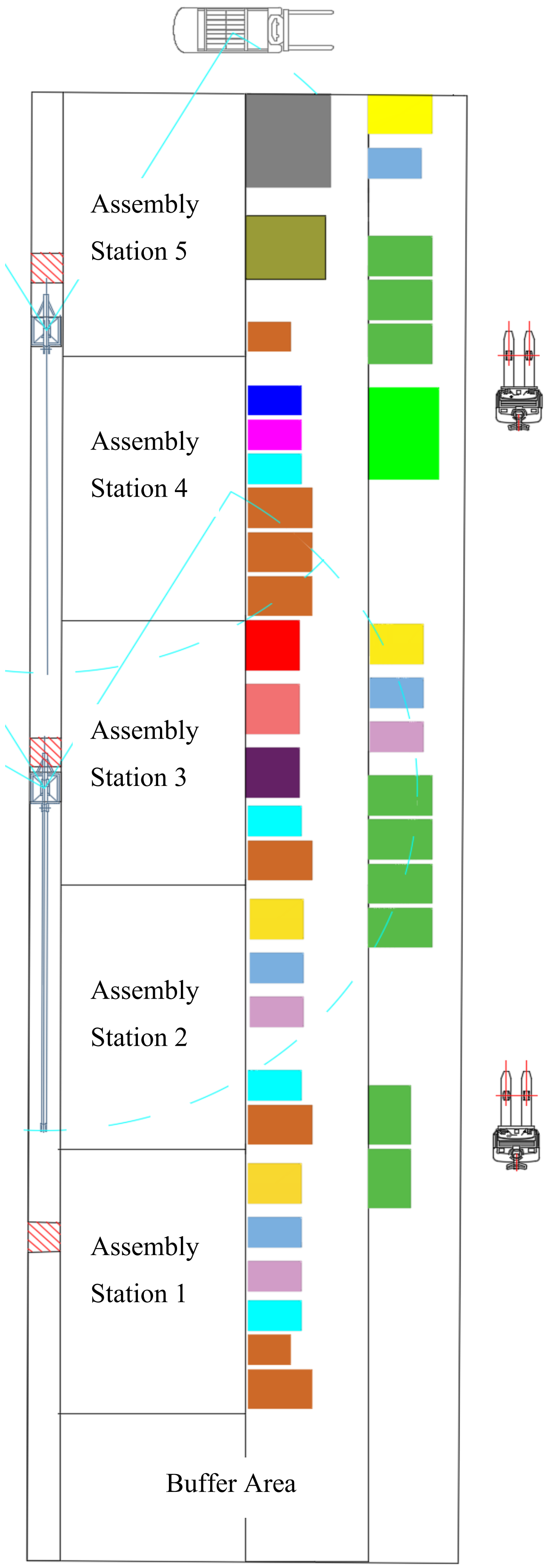

Figure 16. Alternative Layout 1

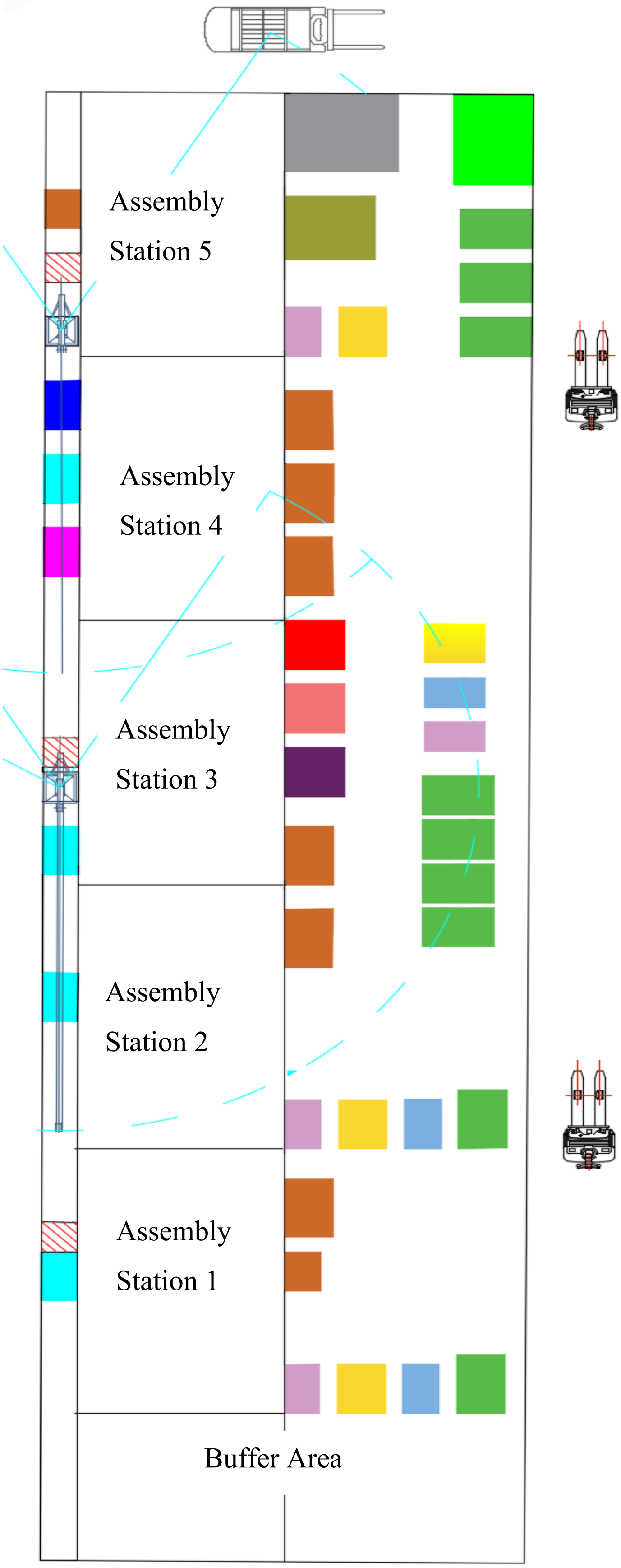

Figure 17. Alternative Layout 2

While the detailed alternative layouts can be found in Figures 15 and 16, the index of activity areas and equipment are listed in Table 9.

Represented area/equipment	**Colour**
Assembly station working area	
Assembly station screw area	
Assembly station 4 label printing area	
Assembly station 4 adhesive area	
Pre-assembly station working area	
Pre-assembly station buffer storage area	
Pre-assembly station screw area	
Pre-assembly station 3 working area	
Pre-assembly station 4 working area	
Pre-assembly station 5 working area	
Bubble wrap packaging machine area	
Packaging storage platform	
Ready-to-packaging storage	
Assembly station raw material pallet	
Pre-assembly station raw material pallet	

Table 9. Colour Index of Area/Equipment

4.4.5. Evaluating Layout Alternatives

The distance of material transportation is considered during the design of different layouts, which influences the cost of material handling in the battery swap machine manufacturing. It is possible to conclude that, despite alternative layouts 1 and 2 have analogous positions, there are some changes in the details. Before choosing the best option, we can easily say that both alternatives are better compared to the existing layouts. The reasons behind this are that decreased distanced between assembly stations and pre-assembly stations, and between raw materials that are used during the assembly and assembly station, making it easier to select and get the screw parts, providing a better communication channel between the employees who are worked pre-assembly and assembly areas.

Several factors are defined to compare the two alternatives with the project manager and plant manager's cooperation. For each of these factors, weighted values ranging from 1-3 with an increasing importance effect were determined. These can be seen in Table 10.

Factors	**Weight**
F1- Less material handling needs	3
F2- More flexible and organized working area	2
F3 - Better communication & easiness of supervision	1

Table 10. Layout Evaluation Factors and their Weights

Evaluation points between 1 and 5 were given for each consideration. In order to determine the total value of each considered factor for the alternative layout, all the determined values of each consideration were added and multiplied by the weighted factor value. This process repeated for all factors and when the factors summed, the total value of that alternative calculated. Table 11 indicates these calculations and determined considerations.

There are some points that should be carefully understood in these 'consideration/relationship' elements. As it is seen the Figures 16 and 17, assembly areas and pre-assembly 3,4, and 5 are always located in the same locations. Furthermore, as it is seen in Figure 14, in the case of placing all these activities/stations in the same place, the only comparable part is the relationship between assembly areas and their relevant pre-assembly areas. While combining this situation with the detailed layout alternatives by considering the raw materials storage areas and needed extra equipment/places for the pre-assembly and assembly stations, 'consideration/relationship' elements were determined.

As a result of the comparison, alternative 2 selected as the best alternative. It was considered as the most promising layout in terms of providing a more flexible and organized working area for the employees by enhancing working conditions besides adding value to the company and reducing material handling need.

Consideration/Relations \ Factor	Alternative 1			Alternative 2		
	F1	F2	F3	F1	F2	F3
Assembly 1 - Pre-assembly 1	5	4	5	5	5	4
Assembly 1 - Assembly 1 Raw Materials	4	4	-	5	5	-
Pre-assembly 1 - Pre-assembly 1 Raw Materials	4	5	-	5	5	-
Assembly 2 - Pre-assembly 2	5	4	5	5	5	4
Assembly 2 - Assembly Raw Materials	4	4	-	5	5	-
Pre-assembly 2 - Pre-assembly 2 Raw Materials	4	5	-	5	5	-
Assembly 3 - Pre-assembly 3	5	5	5	5	5	5
Assembly 3 - Pre-assembly 4	5	5	5	5	5	5
Assembly 3 - Pre-assembly 5	5	5	5	5	5	5
Assembly 3- Pre-assembly Merged	3	3	3	3	3	3
Assembly 3- Assembly 3 Raw Materials	5	4	-	3	3	-
Pre-assembly 3 - Pre-assembly 3 Raw Materials	4	4	-	4	4	-
Pre-assembly 4 - Pre-assembly 4 Raw Materials	4	4	-	4	4	-
Pre-assembly 3 - Pre-assembly 5 Raw Materials	4	4	-	4	4	-
Pre-assembly Merged - Pre-assembly Merged Raw Materials	5	5	-	5	5	-
Assembly 4 - Assembly 4 Raw Materials	4	4	-	5	5	-
Assembly 5 - Pre-assembly 6	3	3	3	5	5	5
Assembly 5 - Assembly 5 Raw Materials	5	5	-	5	5	-
Pre-assembly 6 - Pre-assembly 6 Raw Materials	4	4	-	5	5	-
	246	**162**	**31**	**264**	**176**	**31**
	439			**471**		

Table 11. Comparison of Alternative Layouts

5. Conclusion

Improving the manufacturing plant layout is a common problem for every industry and has increased attention due to the need of enhancing productivity. Despite the general view that SLP is an established procedural technique for developing new facility layouts, it may also be used to improve current layouts as it happened in this study. Muther's SLP procedure was used in this work to address a production layout problem considering inconsistencies between the labour cost project by project and to satisfy the increased demand.

Despite the fact that SLP provides sequential phases for developing layout, it is often regarded as a slow and time-consuming approach. This paper's case study of the battery swap machine production line took a few months to illustrate the current situation and suggest the new layout. This study attempts to demonstrate the implementation of a simplified SLP methodology as well as a simpler approach in layout selection criteria based on the qualitative methods. The redesigned layout successfully improved the facility's overall productivity. The results show that the significant amount of distance improvement, which lowers the lead time and promotes value creation through more finished product production, has gotten. The suggested layout also stresses improved integration of the battery swap machine production activities and thereby its stations.

The selected alternative was applied, and the new production batch has started there. A time study was conducted, and one set of battery swap machines was produced within 29.5 hours. This clearly indicates that a 26% improvement is provided with the new layout. Apart from the new layout, applying lean production principles has provided some additional improvement to the process.

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