Chapter 4
Layout Planning Approach at a Plumbing Department in a Manufacturing Industry: A Case Study

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Abstract The chapter presents the use of the layout planning approach in the design and installation of the production line. This was carried out in a company dedicated to the manufacture of hydromassage tubs. Diverse problematic situations in an American plant served to make the decision to transfer that production line to a Mexican plant. As a case of study, the systematic layout planning methodology was employed to design the layout of that production line. Diverse phases gave the opportunity to include other methods and tools enriching its process. This iterative and multi-criteria approach permitted to include personnel converging from various departments exhibiting their operational needs. A definitive layout emerged after diverse drafts. It was consequently installed permitting pilot tests to make final adjustments. For 12 months, diverse data were collected to visualize its results, which were associated with diverse criteria. For instance, the layout was installed occupying less area than in previous plant. Moreover, there were reductions in the distance used in material handling, the number of personnel handling the materials and finished goods, and the costs relating to these activities. Similarly, there were an increase in the productivity index and an efficient use of available area. In addition, it allowed the implementation of lean manufacturing.

Keywords Layout planning · Plumbing department · Lean manufacturing · Systematic layout planning

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4.1 Introduction

The project was carried out at the company TP or WW (from here to onwards and for confidentiality reasons, its name and products have been changed). The company was founded in 1977 and has become one of the production leaders of hydro-massage tubs. Currently, it makes an average of 350 units per day. One of its production plants is located in the city of Tijuana, Mexico. Specifically, this plant put the basis to redesign its layout making possible the project. To put on perspective, the production line of tubs involves diverse activities and phases, which starts in the mentioned plant and the final phase and its activities are done in a production plant located in the United States of America (USA). In other words, this means that some processes were done in the Tijuana´s plant and the rest, in the USA´s plant. Within Tijuana's plant, there are different areas that contain activities and processes required in the production of the diverse types of tubs. Particularly, the research was done within the HL area or production line, used indistinctly from here to onwards, and involved the manufacturing engineering and plumbing departments of the plant. As a manner of detail, the area includes different types of plumbing assemblies, which are used in the final phase of the production process. It is important to remark that the company produces at least 50 different models, and the HL area was chosen because it assembles nine models representing the 30% of the total sales. Moreover, 25% of this production initiates in Mexico and is finalized in the USA. In addition, its personnel of both plants is recognized as excellent providers of after sales service to internal and external clients.

Consequently, some substantial changes in the area of the USA's plant have been done in order to satisfy both services, the after sales service and production demands. For instance, the installation of new equipment and uses of diverse materials within the production process have facilitated the satisfaction of both services. Substantial adaptations were also done to meet them. The methods and techniques were changed, and the personnel were trained, among other practices in order to improve the services. However, they do not fully satisfy new challenges consequently of increasing the production demands. So, the managers suggested to attend the production area but to leave outside distribution and managerial issues. In other words, internal aspects of the production line should be considered but external elements should not be left outside (Ning et al. 2010, 2011). For instance, it was discovered that, in general terms, some spaces required in the production line were not adequate for the activities and processes. Additionally, some of these activities and processes pertained to other models diminishing the resources used. Furthermore, the production line included some corridors, shelves, and other warehouses used in other production lines. In a few words, a mixture of activities, processes, and other production elements was uncovered stopping the increase of production rates demanded. In order to make feasible that increase, the use of a holistic viewpoint in this type of internal problematic situations was suggested (Ning et al. 2011). In this line, the managers uncovered diverse problematic situations as a follows:

- Unnecessary transports
- High transportation costs
- Incomplete use of the space
- Waste of materials
- Lack of techniques for designing layouts
- Absenteeism and lack of personnel.

Having this as a background, the managers made the decision to transfer the total production of the HL area, including the majority of the plumbing department personnel of the American plant, to Mexican plant. This decision was supported in statistical information, but it was not considered in this document by ethical reasons. In addition, the decision of transferring that area was another source, the existence of available areas to increase the size of the HL area. There were discovered four potential areas that could shelter it. Previously, the plant was expanded adding diverse spaces and areas to other production lines. Similarly, the relocation of the area could represent the opportunity to reduce its costs. In fact, the company had experience on transference of production lines with this objective in mind. For example, two production lines were transferred in the past from the USA to Mexico. Besides, a new product was developed and the entire production process was established in that plant. However, the managers uncovered the need of use a technique that helps them to design and install efficiently production layouts. It was clear that this type of projects arose from the need to systematize the process of design and installation of production lines using various approaches in the process (Tommelein and Zouein 1993). Specifically, varied tools of industrial engineering and lean manufacturing could be considered within this systematization and could provide differentiators in that process. Nevertheless, it was discovered that some Mexican governmental regulations banned the completely transference of the production process to Mexico. So, the managers made the decision to increase the size of the HL area. This means that some activities were realized in the Mexican plant, and the rest, in the American plant. It is important to remark that, from here to onwards, the term finished goods is related to the products that represent work-in-process products but for the Mexican plant are finalized. This uncovered the necessity of redesign the layout of both areas. Referring to the American plant, the project was made by personnel from that plant. Relating to the Mexican plant, the assignment was done by personnel from varied departments as explained in the next paragraphs and methodology section.

The diverse considerations mentioned before were taken into account in the definition of the objective of the layout planning. This was defined as the discovery of various elements required in the production process within the HL area using various industrial engineering and lean manufacturing tools in order to reduce the travel distances of parts and assemblies and the finished product. Moreover, it included the increase in the productivity of the production line, as a nested objective. In addition, it was expected that the available area should be used effectively in order to meet the production requirements. Although these objectives could be seen as ambitious, there are various tools that should provide what was necessary to achieve them (Xu and Li 2012). Also, it was expected to reduce the costs of distributing materials on the production line and to reduce the areas dedicated to the storage of work-in-process and finished products. This was from the viewpoint of taking advantage of existing resources in the best way as expected (Yang et al. 2000).

Based on these ideas, the managers empathized additional considerations. They were the reduction the costs in the transference, the redesign of the production areas, the reduction of the transportation costs within the production lines, including the reduction of the transportation distance, and finally, the efficient use of the space. These mandatory issues were put on practice in both plants. It was expected, in a similar way, further benefits in terms of increases of productivity, optimization of production resources and efficient use of equipment. However, some of these considerations can cause confusions in the personnel. So, they decided to revise literature relate to layout planning and diverse themes of modern techniques of manufacture. The result of this task is presented in the following section. Similarly, another consideration was the time in which the project should be finalized. The managers suggested 18 months initiating on June 2017. Having this time, the involved personnel added another consideration. It was the redesign of new tools and equipment that will be used in the transport of raw materials and work-in-process and finished products. They saw the opportunity to achieve diverse objectives at the same time in a holistic view point.

Nevertheless, the achievement of those objectives uncovered several limitations in the project, that were combined with the components of the production system (Jo and Gero 1998). For instance, the redesign of the layout and the installation of the production line should be initially approved by the Engineering Department. This was done by exploring various layouts until the final arrangement was found (Hegazy and Elbeltagi 1999). Once the approval was received, the layout design was presented to other departments to receive feedback and their acceptance. The departments were Maintenance, Production, Human Resources, Finance, among others. Another limitation was the validation of the production line. This served to verify the consistency of the routine activities in relation with the planned activities. Furthermore, this activity aided to engage the internal departments and external companies with the production process. They uncovered the relevance of their activities in that production process. In other words, the validation should serve to create strong relationships between internal and external elements within the production process. One expected consequence should be redesign and fabrication of the diverse equipment and tools that should be employed in the process. The pilot tests could be help on this matter. The recruitment and selection of personnel were other aspects that could be considered within the redesign of the production layout.

The next section presents a review of some topics that were considered into this project. It is followed by the employed methodology. Subsequently, the results are listed emphasizing the objectives achieved. After, the conclusions and recommendations are presented. Finally, the discussion section is exhibited.

4.2 Background

This part presents the main concepts and theoretical foundations creating the foundations of this project.

4.2.1 Layout Planning

The planning of facilities, distribution plant or layout, used interchangeably throughout this document, can be viewed in various ways. It could represent the satisfaction of the production needs of people or organizations that require diverse elements to produce services and goods. Similarly, it could exhibit the opportunity to reorganize the elements in the production process. Moreover, it could show the location of production elements within limited areas, among others (Naqvi et al. 2016). Consequently, in the current literature, there are various definitions of layout planning uncovering the diverse viewpoints in how it could be seen in strong relation with its context of application (Muther and Hales 2015). Consequently, layout planning is considered as the main reason for the plant arrangement in order to optimize the distribution of machines, resources, materials and auxiliary services, so that the value created by the production system is maximized (Martínez Carbajal 2004). Therefore, the transference of the production process from one place to another, it should be used to make changes that could be complicated to do in the initial plant. It creates an opportunity to make changes to correct detected areas of opportunity. One of its objectives is to make efficient the production system. As a manner of detail, it allows the opportunity to eliminate diverse structural aspects and conditions of the production systems (Martínez Carbajal 2004), such as:

- Materials: long distances in transport activities; excessive movements; damaged materials; congested areas for work-in-process products; lost materials; high amount of raw material for delivery; lack of materials, among others.
- Production: unnecessary movements of personnel; materials on the floor (work-in-process products); congestions in corridors; inadequate arrangements of the workplace, among others.
- Production context: accidents; personnel turnover, among others.
- General: disorganized production program; little interest from staff, among others.

Consequently, some of the benefits of having a good distribution plan are the increase of the production rates, the reduction of delays, the saving of areas dedicated to productive activities, the improvement of the materials handling, the reduction of the work-in-process inventories, among other benefits. Specifically, Muther and Rabada (1981) pointed out some advantages of a layout design and installation according to the production needs:

- Reduction of health risks and rise of safety for workers.
- Increased morale and job satisfaction.

- Increase in production rates.
- Reduction of production delays.
- Efficient use of available areas.
- Reduction of material handling.
- Decrement of the production time.
- Markdown of congestion and confusion.
- Among other advantages.

4.2.2 Lean Manufacturing

The term Lean Manufacturing (LM) was coined by a study group from the Massachusetts Institute of Technology (MIT). This group studied and analyzed the evolution of the manufacturing methods of companies in the automotive industry worldwide. They found differences between diverse companies of that industry in terms of how they made their practices more efficient (Reyes Aguilar 2002). The group highlighted the advantages of the manufacturing systems used in the Toyota company. They also uncovered that the company was the best manufacturer in the automotive industry and they had a remarkable leadership in their production practices (Allen 2018). So, this type of manufacturing was called Lean Manufacturing and it represented exceptional manufacturing methods used since 1960. Despite, these techniques exposed good practices, they were improved by Taiichi Onho and Shigeo Shingo (Allen 2018). Specifically, the improvements were done from the viewpoint of minimizing the use of resources in the entire production system and the delivery of goods to the clients. In other words, this means a holistic posture on reducing the costs in the entire system and satisfying the client needs. The reduction of the defects within the production process and the decrement of the delivery time of goods to clients were the principal aims. As a result, the diverse production systems of multiple sectors were aligned to these in order to improve their practices.

In the same way, these considerations have been mandatory in actual companies so that they implement techniques and methods to make possible the achievement of mentioned objectives. In this line, Pineda (2004) suggested that it is important to meet them at operational and tactical levels involving personnel from similar levels using various techniques and tools of LM. Eventually it is expected to obtain benefits, which could be: the reduction of production costs, inventory and lead time; the increase of quality; the reduction of waste, among others.

4.2.3 Kanban as a Visual Tool

The term *Kanban* is related to the administration of visual information within the diverse production areas and processes to reduce confusion on the material handling (Hernández Matías and Vizán Idoipe 2013). On the other hand, Reyes Aguilar (2002) pointed out that Japanese coined the term *Kanban* and has been translated as "signal card". Its use in the production systems suggested the change from normal practices to the visual practice in order to reduce confusion within the processes. The real significance of its intrinsic objective is to improve the practices reducing the errors on material handling. For these reasons, it is common the use of signs within the production processes. The signs take the form of charts, cards, colored lights, colored containers, level lines on walls, etc. The idea is to make possible the easy identification of those signs, which have strong relation with some activities required in the processes. For instance, a sign could indicate that some activities should be done in order to continue with the process. Eventually, the lack of materials in the process could be discovered in the signs employed so that personnel could bring the necessary materials, once they discovered this lack within the production areas. In addition, these activities should be done without the consultation of supervisors expecting the elimination of paperwork and reducing conflicts among personnel, inventories of work-in-process products, among other benefits.

In this line, the *Kanban* provided signals that should suggest the needs for material handling by collecting and transporting raw materials and finished products. Similarly, it is suggested that *Kanban* might avoid overproduction by exposing the necessity of occupying determined equipment to make certain quantity of finished goods. It implied the production of fixed quantities in strong relation with the sales of products. In addition, the use of the signs within the processes served to prevent the production of defective goods by controlling the transportation of quality products as well as to control the inventory in the production areas. For example, the *Kanban* boxes could be used among operations of manufacturing cells or manufacturing cells and processes. This is principally done to regulate differences in the production speeds in order to achieve a constant production flow. In general terms, the process begins with the customer's order; after, it continues with the preparation of the tooling and materials used to produce the goods; and subsequently, a card is generated by the finished product warehouse. This card is the start of the production pointing out the necessity to produce demanded goods. This process is iterative and intuitive (Gutiérrez Garza 2000) and its consideration on layout planning is crucial. It should add production elements so that the manufacturing efficiency should be improved.

4.2.4 Kaizen as Continuous Improvement

The term *Kaizen* is referred to the opportunity to make changes for the improvement of the practices in production. It is also an important part of Lean Manufacturing and represents how organizations employ diverse human aspects for continuous improvement. It focuses on the people and the standardization of production processes (Pineda 2004), in order to recognize people as an important asset of the companies by bringing out as the production element. They add value to the goods, on the one hand, and propose actions and activities to improve the processes, on the other. Consequently, common practices in the current companies are to continuously calibrate their operation involving personnel from all organizational levels employing the point and system approaches. The idea is to put attention to the personnel done their activities and operations so that they look for better practices and make possible them. It represents the organizational culture that reigns in the company. Consequently, there are benefits for the organization and its personnel. Some of them are the increase of the productivity, the control of the production, the reduction of the production cycles, the standardization of the quality criteria and production methods, among others. Hence, it is seen normal that personnel participate in the relevant decision made processes within the companies. The layout planning is one of them and embraces personnel from diverse areas of the organizations. It is common that the teams are created of personnel converging from the majority of areas of the companies. Expected results are layouts in which residues are minimized or eliminated. It is personnel should participate in the design, installation and operation of the production process so that wastes are reduced or eliminated in all phases of the design and installation of the layouts. The benefits could be observed in different periods of time. This could be possible because the majority of the personnel involved in the processes were acknowledged (Gutiérrez Garza 2000).

4.2.5 Systematic Layout Planning (SLP)

In order to carry out the layout planning, diverse aspects in its design were considered. Initially, a revision of the current literature was done and various methodologies were found (Monga and Khurana 2015). Each of them provided different approaches to design layouts. This means the diverse necessities of layout planning, which have strong relationships with the diverse contexts of utilization (Naik and Kallurkar 2016). Each company needs particular layouts that can give them technological advantages. For instance, companies from similar sectors usually have different layouts. They permitted to discover how their objectives might be achieved. In other words, the disposition of the diverse production elements might be a clear signal in how those elements are connected to achieve the organizational goals. However, the majority of the approaches converge in looking for the best layout to achieve organizational goals. So, it was found that the Systematic Layout Planning Plant (SLP) could be useful to achieve the aim of layout planning in the considered context.

Moreover, this methodology has multiple benefits in its application providing flexibility in the design and installation of layouts. In other words, it has practicality when it is applied and gives advantages over others. Moreover, it suggests a systemic procedure that includes multiple criteria, and the same time, it also delineates activities for layout design in new facilities and/or layout redesign in utilized facilities (Muther and Rabada 1981). The basis of the methodology is to put on perspective and emphasize that layouts are prepared to achieve organizational goals. Specifically, it incorporates as triggers the flow of materials, information, human needs, among other elements within the companies. Consequently, the layout planning process establishes diverse phases and techniques that should help on organizing the production elements. This could be seen in the disposition of the facilities to achieve the organizational goals. To do so, it allows the identification, valuation and visualization of all elements involved in the processes and their relationships (Muther and Rabada 1981). Furthermore, it provides details facilitating the adjustment of those elements to minimize the transportation of information, materials, and products in process as well as to foresee the use of the areas of the layouts, the risks and comfort within the production areas. In other words, the methodology helps on taking care of the relevant elements of the systems so that it permits the achievement of organizational goals (Muther and Hales 2015). Thus, it was found that this methodology could aid with the achievement of an efficient layout. Then, it was found that it is required to implement the methodology in certain phases as follows:

- Phase I: Localization. In this phase, the location of the plant that should be distributed is decided. Here, it was suggested to find a place that has a competitive geographic position satisfying those relevant factors, which were weighted as crucial to the organization. Moreover, in the case of a redistribution, the phase is aligned to use the existing area or assigned area with this objective in mind. For instance, it could be normal the redesign of layouts on existing production areas in order to open new production areas. The companies move their processes to other areas within their buildings in other type of situations. The efficient use of the areas is important to the organizations.
- Phase II: General Distribution Plan. This phase is distinguished by finding patterns of the transportation of information, materials and products in process so that it permits the creation of the basis of the physical location of the production elements. The quantification of the area required by each element, the relationships between those elements, and the particular configuration of them are indicated in this phase. These indications are in general terms and particular questions related to the disposition of the elements are not answered. Its result could be sketches o diagrams presenting the needs of the diverse areas in the organizations and the relationships between them.
- Phase III: Detailed Distribution Plan. This phase is characterized by the study and preparation in detail of a distribution plan. It is a continuation of the previous phase and it is suggested to develop the layout with personnel from the diverse areas of the organization. Specifically, it includes the analysis, definition and planning of the areas where the jobs, machinery or equipment should be installed or placed. The consideration of requirements and facilities to operate those areas are estimated to satisfy the discovered needs.
- Phase IV: Installation. The last phase is distinguished by the installation of the system elements into the designated areas. The physical movements and adjustments are made in order to collocate the elements. It included the installation of equipment, machines and facilities. The result of the phase is the materialization of the layout. Particular adjustments and details are made in order to achieve the solicited layout.

4.2.5.1 Process Mapping

This methodology allows the discovery of certain elements of the products adding value so that companies should guide and redefine their efforts to reinvent their products and production process in order to offer valuable goods (López Cuevas and Briceida Noemí 2013). It starts with the elaboration of the process map or Value Stream Mapping (VSM). This map allows the planning and identification of the inputs and outputs of the production elements to improve the design and operation of the process. Thus, the main objective is to establish coherent strategies to satisfy the needs of the internal and external clients. Similarly, the methodology allows to systematically measure the internal progress on accomplishing the client needs. Furthermore, it highlights the main obstacles and opportunities that might arise in the process considering all steps in the production process, delivery of goods and post-sales services (Cabrera Calva 2014). In other words, this methodology helps to understand in detail the need to improve the production process considering its elements and services provided to internal and external customers.

4.2.5.2 Spaghetti Diagram

This is a tool that helps on visualizing and defining different types of waste within the processes. Its emphasis is in the transportation activities of materials, products in process and finished goods (Cabrera Calva 2014). To do so, it is necessary to create a plant layout and draw the diverse transportations and trips that are done by diverse production elements in study. Each of these elements is drawn into the layout exhibiting the distances traveled within and/or between different areas. So each element used a distinctive color to facilitate the quantification of distances as well as to discover the mix of routes into the transportations. As this diagram is a graphical tool, the flow of the elements served to uncover the unproductive activities and put the grounds to redesign the process (Cabrera Calva 2014). Consequently, the name of the spaghetti diagram comes from the mix of the colored lines as a whole and exhibiting similar appearance as a plate of spaghetti. However, the color of the lines indicates the various routes that follow the diverse production elements exposing the risks and wastes into it. Consequently, the use of the diagram is primarily used to visualize the routes of materials, products in process and finished goods into the process; to detect diverse types of waste within the transportation activities, and to provide the basis for the optimization of transportation of production elements, the increase of the productivity and the reduction of waste (López Cuevas and Briceida Noemí 2013).

4.2.5.3 Flow Process Chart

Flow process charts are used to describe the transformation processes in production systems (Niebel and Freivalds 2004). Furthermore, they help to develop strategies to improve the effectiveness or efficiency of them since they allow the visualization of all required activities emphasizing those that aggregate value to products. Similarly, it permits to distinguish those activities that are unnecessary and constitute costs. For instance, transportations, storages, delays and inspections represent costs under this approach. Consequently, the analysis of processes should give an ample visualization of the effect of each these activities on the process. The chart offers a clear description of the activities required to make goods. Moreover, it graphically presents the entrance of materials, the use of machinery and equipment, the transformation processes, the order of the activities required in the manufacturing process and the relationships between the activities and the production elements (Niebel and Freivalds 2004).

4.3 Methodology

This part presents the techniques and tools used in the design and installation of the layout utilized in the production line. As mentioned in the last section, the SLP methodology was considered the basis to outline the activities that define the solicited layout in the production line. It is important to remark that its phases were reinforced with the utilization of other tools so that the design of the layout concentrates other tools from LM and Industrial Engineering. The administration suggested a holistic viewpoint in which these tools should be enrich the process of layout design. Other tools were exploited, but they were omitted. The company authorize their use in the project with the condition that were omitted in this report. These tools gave technological and competitive advantages. Some of these were qualitative and quantitative criteria granting a particular character to the project. This is in line the use of the SLP methodology, which can be utilized to make all kinds of plant layouts in deep relationship with the context of adoption (Muther and Hales 2015). It suggested the steps which were adapted to the observed needs. It is because some tools and designs were developed for the exclusive practices of this company. So, ethical and confidentiality aspects were considered.

4.3.1 Phase I: Localization

The start of project was the consideration of both HL areas in the American and Mexican plants. It was found that in the Mexican plant, the HL area can be closed and a new area will be destined to this production line. Four areas were offered and analyzed until one of them was chosen to install the production line. On the other hand, the HL area in the American plant served to create the foundations of that line. The occupied area of the line was 5061 square feet (sq. ft.). Figure 4.1 presents the area occupied by the HL production line, which contains diverse production elements as warehouses, corridors, workstations, etc. A brief description of these are disclosed

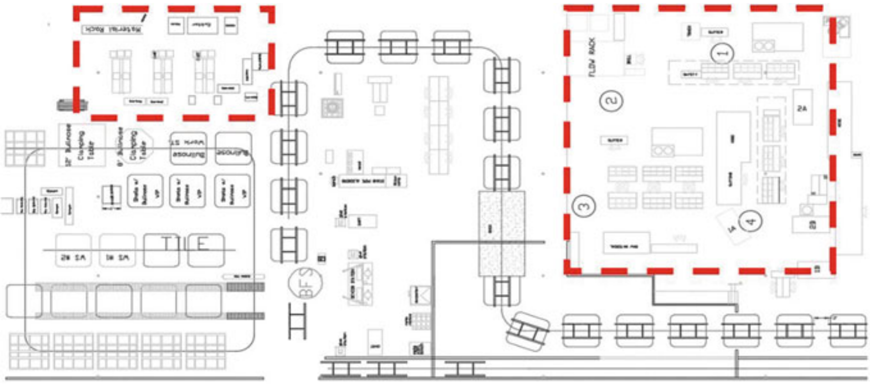

Fig. 4.1 Initial layout

after. Note: the figures used along this document are general representations of the developed technical drawings. The utilized drawings were a scale representation of all production elements involved in the production process and considered in this project.

The relevant data of the production elements in the HL area were:

- Number of workstations: 23; occupied area by each workstation: 32 sq. ft.; occupied area: 736 sq. ft.
- Number of temporary warehouses: 24; occupied area by each storage: 32 sq. ft.; occupied area: 768 sq. ft.
- Other elements as corridors, equipment, among others: 3557 sq. ft.
- Occupied area in the HL area: 5061 sq. ft.

Using these data as background, the offered areas in the Mexican plant were analyzed. In order to define a convenient area in the plan, diverse criteria were defined to help on the process of choosing it. In the process, diverse personnel converging from different departments were consulted. They listed four criteria that should be satisfied. The location of the production line, the distance from raw material warehouse to production areas, the appropriate area and number of corridors, and the distance from the production line to the shipping warehouse were the factors considered as relevant. They are explained below.

- **Location**: This criterion was associated with the use of the size of the area employed in the American plant, which was 5061 sq. ft., as an initial point of reference. The idea was to exploit less area in the new production line. As mentioned before, four areas were offered to house that line. Figure 4.2 presents the location of offered areas in the plant and the Table 4.1 exhibits the size of each area and the compliance of the criterion.

- **Distance to warehouse**: This criterion was associated with the distance between the production line and the raw materials warehouse. It was because the process

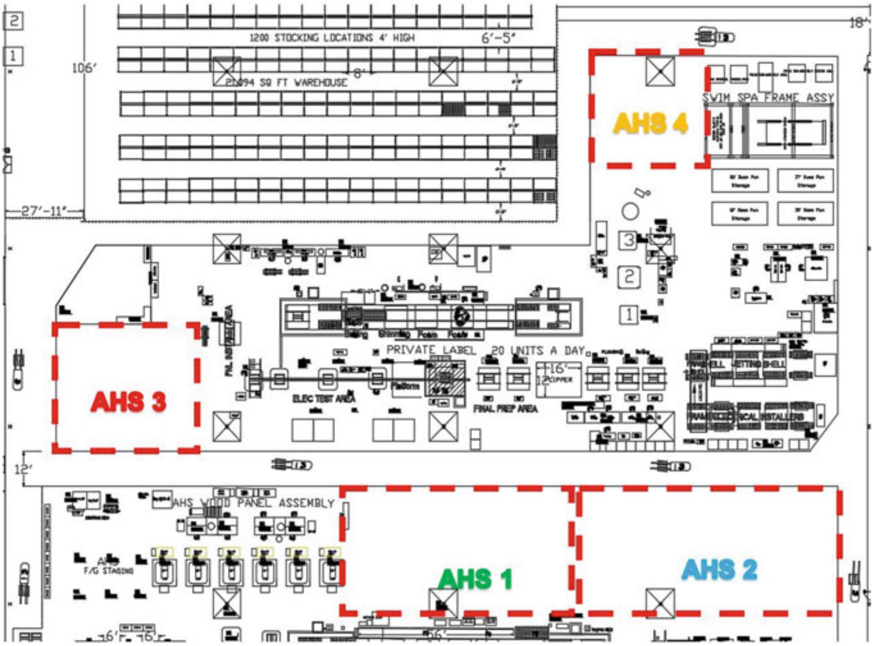

Fig. 4.2 Proposed locations

Table 4.1 Proposed locations

Location	Surface (sq. ft.)	Criterion
AHS 1	3557	✔
AHS 2	3516	✔
AHS 3	2064	✔
AHS 4	1638	✔

requires large quantities of raw material and was found that the distance between these locations was 920 feet (ft.). So, the aim was to reduce it so that the total distance traveled should also decrease. Table 4.2 presents the distances between these locations and the compliance of the criterion.

Table 4.2 Proposed locations and distance to warehouse

Location	Distance to warehouse (feet –ft.)	Criterion
AHS 1	397	✔
AHS 2	428	✔
AHS 3	245	✔
AHS 4	460	✔

Table 4.3 Proposed locations and quantity of corridors

Location	Corridors	Criterion
AHS 1	2	✖
AHS 2	3	✔
AHS 3	2	✖
AHS 4	2	✖

Table 4.4 Proposed locations and distance to the shipping warehouse

Location	Distance to shipping warehouse (ft.)	Criterion
AHS 1	430	✔
AHS 2	450	✔
AHS 3	278	✔
AHS 4	493	✖

- **Corridors**: The criterion was correlated with the size of the corridors because there was a necessity to transport continuously raw materials and work-in-process inventories. In addition, the consideration to use the existing corridors around the production line was another examined factor. Both factors were glued into this criterion to reflect the imperative need to have sufficient area to transport materials and to give access from diverse locations. In the American plant, three corridors with enough area satisfied these needs. Table 4.3 shows the number of corridors and the compliance with the criterion using the number of corridors as minimum condition.
- **Distance to the shipping warehouse**: This criterion was associated with the distance between the production line (specifically the final assembly station) and the shipping warehouse. It was because the product was voluminous and complex for transportation and was found that the distance between these locations was 920 feet (ft.). So, the aim was to reduce it so that the total distance traveled should also decrease. Table 4.4 presents the distances between these locations and the compliance of the criterion.

Based on the obtained results, it was decided to exploit the AHS 2 location. This location met all indicated criteria. That is, the existing area in AHS 2 location was less than the one used previously; the distances from this location to raw material and shipping warehouse were less that those traveled previously, and the appropriate area and number of corridors in this location were similar to the previous line.

4.3.2 *Phase II. General Distribution Plan*

Two diagrams were employed in this phase and were generated within the American plant. One was employed to describe the materials flow and the second one, to uncover the personnel movements. They put the basis to study the convenient materials flow and personnel movements. Particularly, the flow process chart exhibited all activities required in the production process. Table 4.5 shows a summary of these activities. With this chart, the designers carefully studied the entire process and discovered those activities that could be eliminated without affect the process. Furthermore, the diagram helped on in an intermediate level the transportation of materials and finished goods as well as the relationships between the activities permitting to realize a draft to the layout. The emphasis was in the traveled distance of the raw materials and finished products and certain difficulties on these transportations (Muther and Hales 2015).

On the other hand, the spaghetti diagram was used to visualize the personnel movements into the production line and to the diverse warehouses. Moreover, the discovery of the movements permitted to measure of their distances. The uncovered activities in the flow process chart aided with the creation of the spaghetti diagram. The purpose of each activity in the production process was uncovered allowing the planning of the reduction of the activities and when I was convenient, the cutback of the distances of movements. In other words, these activities put the basis to redesign the entire production process to propose a new one. An extraordinary discovery was that in the actual plant, the production was fragmented in two areas. This was one cause of the excessive distance in transportations and personnel movements. The average distance that personnel traveled each workday was 35,000 ft. Thus, additional problematic situations were exposed: lack of communication and some activities overlapped. Figure 4.3 presents the developed spaghetti diagram.

Another aspect contemplated in both diagrams was the design and construction of vehicles which will be adopted within the production process. On the one hand, the size and form of them allowed some changes in the methods employed in the diverse activities. On the other, the size and form granted specific characteristics that were implied onto the redesign of the size of corridors, warehouses, workstations, among other elements. It is important to remark that the transportation of raw materials and finished goods were manually transported. Their fabrication also boosts the implementation of LM tools.

During the design of the layout draft, personnel with strong relation with the production process were invited to participate. So, contributions from operators and supervisors representing the Production Department were valuable as well from

Table 4.5 Summary of the process flowchart

Activity	Quantity
Operations	3
Transport	6
Inspection	1
Delay	0
Warehouse	3
Total	13

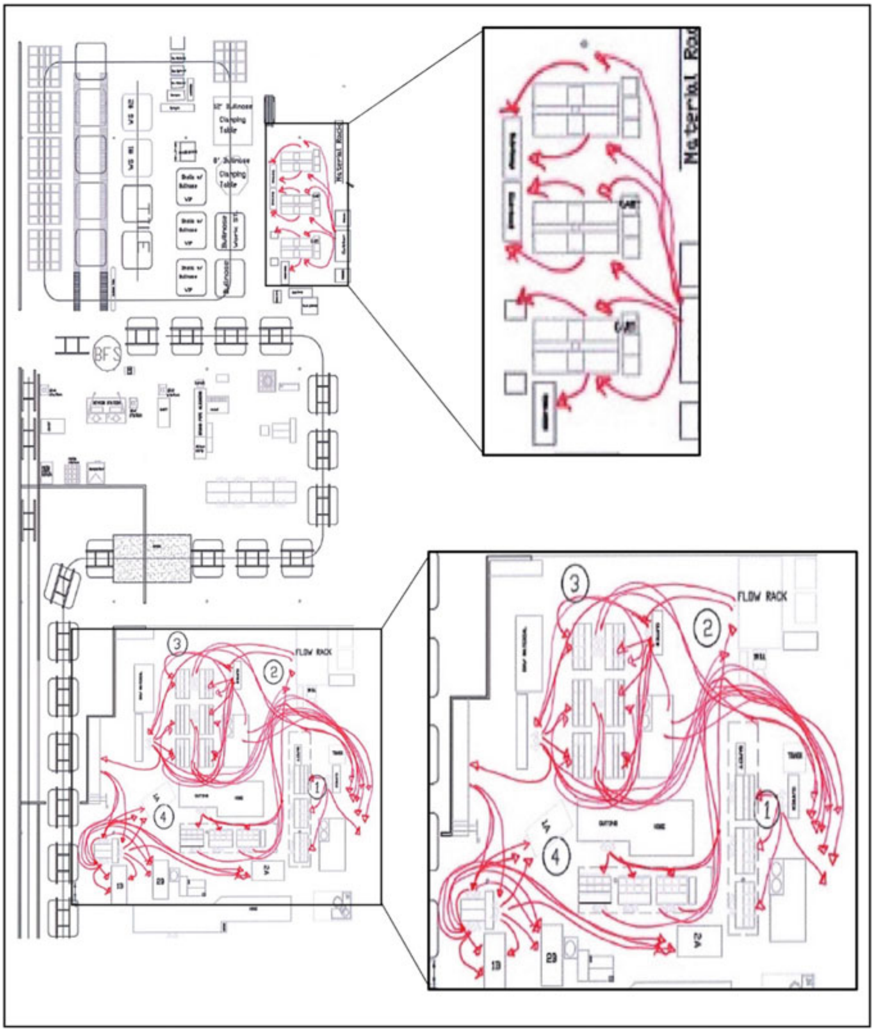

Fig. 4.3 Spaghetti diagram

personnel of the Maintenance, Hygiene and Safety, Engineering and Administration departments. In this particular task, various tools were adopted in order to catch their contributions. The *paper doll* tool was exploited because its flexible for proposing the initial and subsequent layout drafts until the final version of the layout was generated. The representation of the area and production elements were made using a commercial software of CAD. Their representations were made to scale for easy manipulation and two proposals were developed. This act was manually done because the company did not have appropriate software to do in a simulated environment. Moreover, Muther and Hales (2015) suggested the use of the activity-relationship

Table 4.6 Summary

Criterion	Proposal 1	Proposal 2
Available area (sq. ft.)	3516	3516
Number of employees	27	23
Cutter (piece)	5	4
Transport vehicle (piece)	4	15
Area for warehouse (sq. ft.)	564	462
Traveled distance (ft.)	22,000	17,000

and space-relationships diagrams in this phase; however, they were mixed with other tools presented before. This enriched the process and the layout and its implications were aligned to future tasks as the implementation of LM.

Since the process of layout design was challenging, diverse criteria were considered a quantitative and objective approach to choose an option that met the criteria. As mentioned before, in this phase a mix of diverse tools was crucial to develop a layout that satisfied the needs of the implied departments. The available area for install the production line, the number of required employees, the number of cutters as manual tool, the number of vehicles that fit within the corridors transporting raw materials and finished goods, the area assigned for warehouse and the average distance traveled per workday were the criteria scrutinized. The use of the spaghetti diagram was essential to quantify the traveled distance per each option. Table 4.6 presents the results obtained by each proposal and the compliance of the criteria. The proposal 2 was chosen by exhibiting better conditions for being a suitable layout, which is presented in Fig. 4.4 and was denominated layout draft.

4.3.3 Phase III. Detailed Distribution Plan

The third phase of the project consisted on defining in detail aspects related to the transportation of raw materials and the finished goods, the inventory systems to control their transportation, and the vehicles that should be utilized on it. Referring to the vehicles, these should be used to transport the raw materials in the plant and to put the basis in the design of the corridors and in the final arrangements of the production elements. Furthermore, they should be used to transport the finished goods from the Mexican plant to the American plant. As mentioned in the Introduction section, the finished goods are referred to the work-in-process inventories that have to be finalized in the American plant. For these reasons, the vehicles were designed and constructed having this goal in mind. Related to the inventory systems, the phase served to design and implement varied actions and tasks in conjunction with the design of the vehicles and how they should be exploited within the routine work. For instance, the inventory management and its control techniques were implemented, so that they similarly allowed the operation of diverse operational techniques to forecast the needs of materials and diverse resources in the production process. They tried to

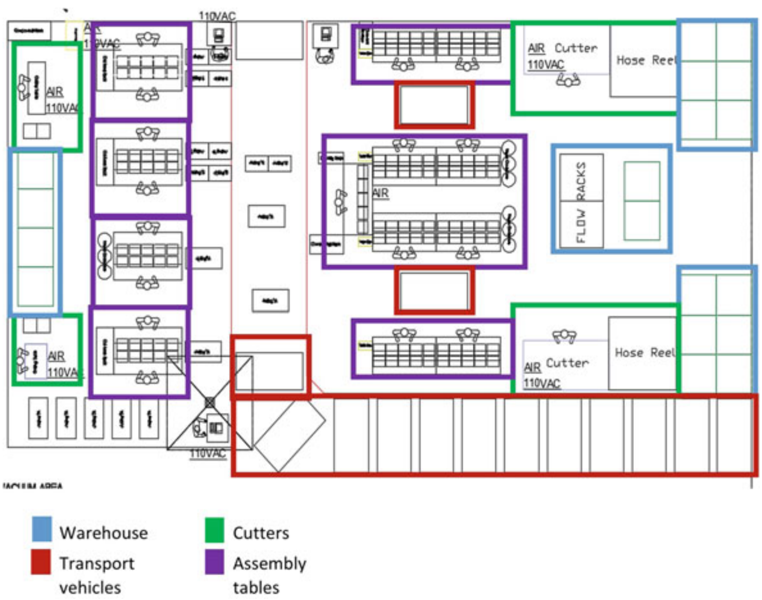

Fig. 4.4 Layout draft

make the production system efficient. Table 4.7 presents the number of vehicles used and considered in the plant layout in strong relationships with the expected production rates in both plants. The name of the models was changed for confidentiality reasons.

Another contemplated aspect related to the use of the vehicles was the area demanded by them. So, the desired size of the corridors was in connection with size of the vehicles and the considered area for them in the layout draft. This phase of the layout design went from the plane to the space. Although, it is preferable to design layouts in space, sometimes there are limitations such that plane design

Table 4.7 Summary of transport vehicles

Model	Capacity of operations	Required vehicles
A	15	8
B	13	9
C	18	6
D	18	4
E	24	4
F	24	4
G	32	3
H	32	3
I	20	2
Total	43	

is sufficient (Muther and Hales 2015). However, the designers explored the space using the constructed vehicles to have data from the context where they should be operated. Consequently, they helped on pondering barriers in risk areas, limitation of work areas, ramps, among other aspects of the production area. Once this process was completed, final adjustments were done to the layout draft and the installation plan was defined, which were the results of this phase.

4.3.4 Phase IV. Installation

The phase 4 was the materialization of the personnel needs from the diverse departments involved in the production process. The convergence of diverse personnel verifying that yours needs were satisfied was the particular characteristic of the stage. Layout designers and potential users were engaged on the installation of the production elements so that additional changes were done in the layout. This gave certainty that personnel were complete satisfied and the aim of the transference were achieved. Particularly, the operational needs were priority at the moment of install the equipment and tools. For instance, the installation of the electrical power, the compressed air intakes, air and steam extractors, among others were a challenge because they should be met technical requirements. Figure 4.5 presents the main operational needs within the production line.

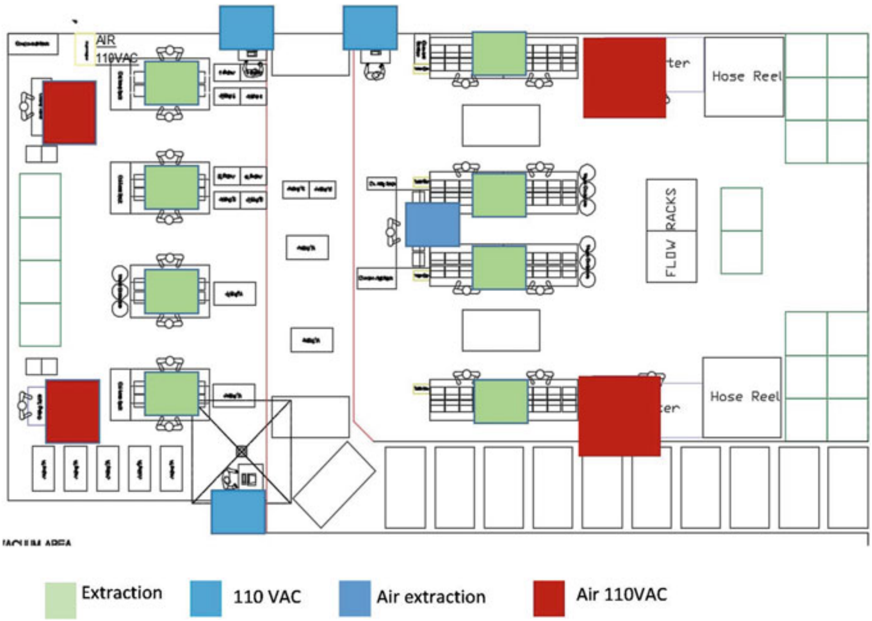

Fig. 4.5 Operational needs

Once the installation of the equipment, tools and the rest of the production elements finalized, the personnel considered that the production lines was ready to start the production. Nevertheless, diverse technical and pilot tests and observations were made so that they tuned the last details found in the production line. This means that with the obtained results were found many areas of opportunity or changes to make within the layout. The changes were not big into the layout but these had notable impact in the production flow. For example, some arrangements and dispositions of determined equipment were necessitated. Moreover, the size of temporary warehouses was increased and some depots were replaced. Figure 4.6 presents the last layout draft and the final layout.

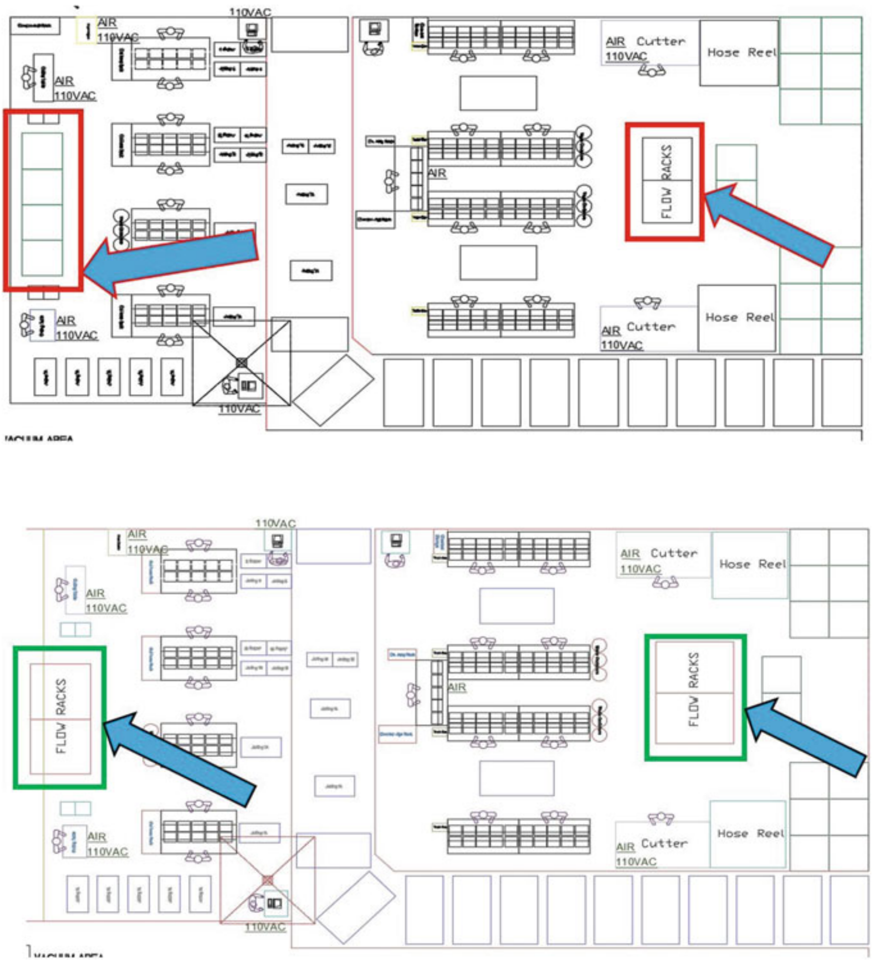

Fig. 4.6 Last layout draft and final layout

4.4 Results

This project was an iterative process in which the results of one phase were the inputs of the following phase. Each of the presented phases utilized the results of previous phases in order to advance in the achievement of its aim. In this form, the layout planning approach exhibited a multi-criteria path acceding similarly to multiple viewpoints coming from various origins. The idea was to start a production process in a designated place. Consequently, the proposed objectives were achieved. They converge in the design and installation of the HS production line. To do so, multiple tools were employed within the four phases included in the SLP methodology. Additionally, distinct tools were adopted to accomplish the multiple objectives indicated by the managers. In the following figure and tables, the representative results are disclosed exposing previous and actual status of the production line in order to compare quantitatively both layouts and the impact in performance and productivity. Initially, Fig. 4.7 presents previous (or initial) and actual layouts of the production lines. Both layouts exhibit the diverse routes following by the raw

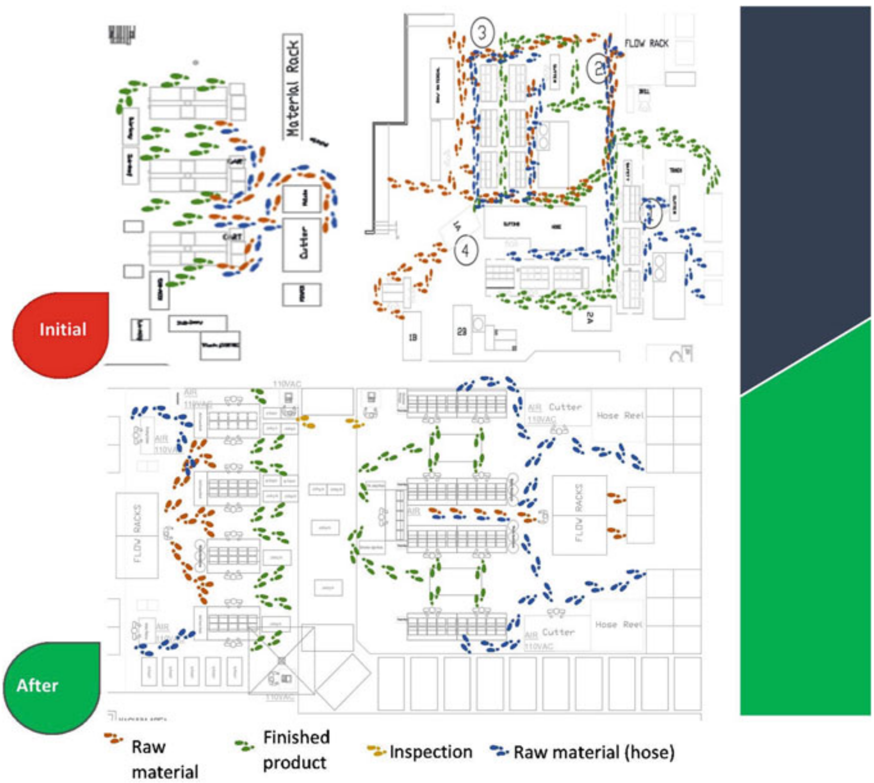

Fig. 4.7 Comparative of initial and final layouts

materials, the finished products, the inspection activities, and the approaching of raw materials to the production lines. This figure was requested by the administrative authorities to graphically and intuitively show differences between both layouts.

Moreover, various indicators were developed to be able to evaluate iteratively the layout through the phases of its design and installation. For instance, one employed index was the traveled distance so that it permitted to explore other indicators as the productivity and the transportation costs of raw materials and finished goods within the production line. It is important to notice that costs were defined and associated with the salary perceived by the personnel carrying out activities of transporting materials and finished products in the production line. Similarly, productivity was related to the result obtained in basis of the efficient utilization of resources within the production process. Another aspect was the entire duration of the project. Initially, managers considered 18 months to finish it and they started on June 2017 focusing in the general tasks of preparation the design and installation of the layout. However, it was delayed and phase 1 was activated on February 2018. And the final phase finished on December 2018. The pilot tests were done during the next two months. Subsequently, managers considered that the production line was in the condition to be exploited. During the following twelve months, diverse data were collected so that permitted to evaluate its performance uncovering a clear visualization of the implied trends on its routine use. The averages of the results are presented in Table 4.8.

Furthermore, other indicators helped to visualize other benefits as a result of the layout design and installation. These were closely related to SLP methodology. For example, as mentioned in the phase 2 section, the vehicles used to transport raw materials and finished goods were also redesigned and built to suit the actual layout. 11 different types of vehicles were constructed and adapted to the production process. Moreover, various fixtures were designed and constructed to aid the diverse operations within the process. Their aims were to reduce the damaged during the operations and to reduce the errors in the assembly operations. Table 4.9 shows the total occupied area, the number of used fixtures and the staff operating the process in both plants.

Table 4.8 Summary of the final results

Indexes	Initial	Final
Traveled distance (ft.)	35,000	17,000
Personnel transporting materials	4	2
Productivity (%)	74	104
Area of warehouses (sq. ft.)	629	458

Table 4.9 Summary of other results

Indexes	Initial	Final
Area used (sq. ft.)	5061	3516
Fixtures (pieces)	7	12
Personnel	27	23

4.5 Conclusions and Recommendations

The design and installation of a layout were the objective of this project and were solicited as a part of the production transfer from an American plant to a Mexican plant. The transfer was based on trying to solve various problems detected in the American plant. The initial goal of it was to transfer the entire process, but administrative regulations forced to the company to transfer diverse activities to the Mexican plant and the product should be finished in the American plant. For practical reasons, the managers considered the work-in-process inventories from the Mexican plant as finished goods. The process of the layout design and installation was a challenge, and the SLP methodology helped to direct efforts to achieve that objective. That methodology was an iterative process in which diverse tools were employed in order to enrich it. Additionally, this process aided in the implementation of LM, but it was not presented in this chapter. Referring to the methodology, the results of the diverse phases served as inputs of the subsequent phases. This allowed the involvement of personnel converging from the diverse areas that conform the company. It also boosted a holistic viewpoint along the entire process. The personnel agreed to share their needs in order to be added to the layout design, which subsequently impacted in the installation of the facilities.

Furthermore, the iterative path of the SLP methodology included a multi-criteria approach in which diverse goals were reached during that process. One of them was the use of the existing area in the Mexican plant, which met the criteria in reference to the necessary area to install the production line. In fact, one available location with less area met the criteria. The company saved approximately 30% of the area used initially. Another goal was related to the traveled distances of the transportation of raw materials and finished goods. The layout design should reduce these to minimal quantities. The obtained results exhibited that it was possible to reduce 50%. Similarly, this result impacted in other aims as presented after. For instance, the productivity in the production line increased approximately 30%. On the other hand, the costs were reduced in the same line and 50% of them were cut benefiting the company. The costs were associated with the personnel performing the transportation activities. So, the costs were reduced because fewer employees were hired to perform those activities. Furthermore, new types of vehicles were designed and constructed in consideration of the proposed layout. The 11 models met diverse criteria having as basis on the dimensions of the size of the corridors and the areas where they should be utilized. Moreover, the number of fixtures employed in the process was increased in order to give competitive advantages to the production process. These had effect on other benefits as reduction of scrap and human errors.

In short, the initial objectives were achieved and exceed the expectations that were initially outlined. The formed team who carried out the project was result of a mix of backgrounds, experiences, and knowledge that converged in it. The viewpoint was respected until the end of the project. Similarly, it worked well into the diverse phases of the endeavor involving in the same form personnel from other departments. This way helped on listen to individuals that expose their operational needs permitting to subsequently satisfying them in the form of an efficient layout. The results obtained in the diverse indicators uncovering the achievement of multiple objectives outlined. The majority of them was associated with the production flow so that productivity was increased and the costs were reduced.

However, it is important to comment that this process had many challenges along its diverse tasks. It was possible by exploring different sources of information and knowledge. This also provided an opportunity to probe the necessity to develop experiences, skills, and additional knowledge in order to achieve the proposed goals. These principally took the form of social skills, interpersonal communication, systematization of processes, and use of technological tools. Referring to the technological tools, the process was done using rudimentary tools employing considerable resources. For instance, the personnel were summoned every week in order to manifest their advances, on the one side; and these meetings were made in person, on the other. This represented the movement of personnel to the Mexican plant. In addition, only one software was utilized to develop the diverse proposed layouts. Thus, it is proposed to do financials studies in order to measure the benefits on buying software to conduct virtual meetings and to simulate the diverse proposed layouts in order to reduce the duration of future projects. The virtual and augmented reality technology would be options in this line.

Related to the systematization of processes, it was associated with the organization and ordering of the generated information along the project, which contributed with the awareness of all type of happened situations that, what factors were crucial, the results obtained and the lessons learnt along the project. This should result on the creation of a knowledge society in which the personnel can be exposed to the generation and sharing of knowledge so that it should improve these kinds of projects. It is relevant to remark that it could include the development of interpersonal communication and the social skills. For instance, the leadership adopted along the project can open favorable circumstances to increase the interpersonal communication and social skills. This can be visualized as contrary to the use of technological tools in the communication; nonetheless, these tools can be used in determined situations and not in crucial state of affairs. Here, the leadership can create the guidelines when the technology can be employed and when not. In conclusion, information, knowledge, and personnel can be the difference in the success of the project. These factors must be carefully monitored to see the performance within the project since their deviations can mean delays or non-compliances on it.

4.6 Discussion

The design and installation of a layout were the principal objective of this project. Initially, the motivation of the design and installation of the layout were to use the existing area in a Mexican plant. So, with this motivation in mind, it was inferred that the principal motivation to do those activities were based on the efficient use of the actual resources the company has. This was similar to other authors had exposed in the current literature (Naik and Kallukar 2016; Monga and Khurana 2015). Moreover, the SLP methodology was utilized to achieve the stated objective. To put on practice, many tasks were required to do. They were challenging and demanding in which many viewpoints were added. For instance, many researchers have found that other tools should be incorporated to the methodology in order to enrich the process (Fahad et al. 2017; Naqvi et al. 2016; Liao et al. 2015; Wiyaram and Watanapa 2010). It also allowed to include quantitative and qualitative approaches giving a holistic view. Furthermore, the methodology granted the utilization of a multi-criteria path where diverse aims were reached during the phases of the methodology. Thus, the process was iterative grating the convenience of exploiting the path to consummate various aims at the same time (Fahad et al. 2017), including pure quantitative approaches (Krajčovič et al. 2019; Li et al. 2018). It also reiterated the principal motivation of design and install layout, the efficient use of the resources. Finally, the results obtained were associated with the motivation, the methodology, the tools utilized, and the multi-criteria path. They can generally take quantitative forms in order to offer objectivity to the entire process (Naik and Kallukar 2016). To sum up, the efficient achievement in the design and installation of the layout had in basis its motivation, the employed methodology, the use of diverse tools within the process, and the inclusion of a multi-criteria approach. The results should exhibit them in strong relation with the context where the layout approach is applied.

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