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A Study on Current Layout of Printed Circuits Boards of A Manufacturing Facility

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***Abstract*—Facility layout planning is very essential in the production process because it affects the efficiency of operations. Manufacturing facilities utilize this concept by placing the right equipment in the right place to allow plant operators to process the products effectively. In this case study, the Printed Circuits Boards (PCB) manufacturing process is explained and its manufacturing facility is described. The current layout of the PCB manufacturing facility was studied and analyzed with the objective to improve the product flow and improve the overall efficiency of the production process. Several related departments/machines were found distantly apart from each other. These departments/machines have high in-process flow among them where in-process products are handled and transported manually. This situation caused a risk on the product handling and a longer production time due to transporting the products. The study identified these related departments/machines and recommended some modifications in the facility layout to relocate them closer to each other. Implementing these proposed modifications is expected to reduce transportation time, minimize in-process product handling and with no doubt will improve the product flow and overall efficiency of the production process of the PCB.**

Keywords—PCB; Facility Layout planning; Manufacturing; Optimization;

I. Introduction and Literature review

Facility layout planning (FLP) is very important tool in a production process as it affects the efficiency of operations. Proper layout planning focuses on placing the right equipment in the right place to allow the processing of products most effectively. Moreover, the layout planning is coupled with the right method of arrangement to minimize the distance between various stations and allow delivery within the shortest practicable time. The layout planning process affects all industries, but the level of importance may differ depending on the production cycle design, and the target efficiency. Another consideration that may influence the needed level of efficiency in a facility is the number of workstations and their interdependence. However, modern-day production and manufacturing plants are required to operate in limited spaces, resources, and high completion for the quality and price of products. These factors necessitate the optimization of layout plans. Therefore, conducting a facility layout design and optimizing to the highest, practicable efficiency levels is paramount in production or manufacturing plants.

FLP in manufacturing has become a key point of concern when seeking to retain the profitability of a business. According to Mairesse and colleagues, globalization has significantly increased competition whereby product price is a consequence of many factors including the efficiency and productivity of the manufacturing process. Any inefficient process has a significant impact on the final product cost, which consequentially affects the financial competitiveness of a manufacturing business. In the case of Printed Circuits Boards (PCB) production, the small profit margins per final product necessitate maximum productivity for a business to remain competitive in the global market. For instance, Mohamad and colleagues noted that the profit margin for PCB production business is small and a reduction of inefficiency from 0.6% to 0.3% led to significant improvement in profitability. The small profit margins in electronics manufacturing imply that in case of inefficient production processes, PCB production may become unsustainable. Thus, for business viability and financial success, PCB production processes must adopt facility layout planning techniques that optimize productivity and minimize inefficiencies.

Machine layout planning is a subset of facility planning whereby the machines conducting identical or similar operations are combined into a single work area (Meyers et al.). Notably, an electronic manufacturing facility has detail-sensitive production processes whereby the output items are usually in small quantities with high sophistication. The inherent impact of grouping machines in job shops as a way of improving productivity has been assessed by Meyers, Fred, and Matthew P. Stephens. Moreover, a PCB production line is order-driven production of small batches, which experience strong fluctuations in a given timeline, thus, necessitating the adoption of the most effective, unidirectional flow, and grouping of machines into job shops.

The ease of machine maintenance is a primary objective of a good FLP. According to Tompkins and colleagues, layout modification in a manufacturing facility may reduce the cost of maintenance. In this case, the maintenance schedules designed for given machines may be scheduled in a way that allows maximum productivity. For instance, Wei and colleagues applied a chaos genetic algorithm to optimize machine downtime schedules, which minimized the impact of one machine on the entire production chain. Thus, optimizing the layout of a facility minimizes time wastage, or idle time, which significantly boosts productivity.

II. System Description

A printed circuit board (PCB) is a structural board with electrical circuitry made of metallic traces and planes to support and connect electrical components in electronic devices**.** PCBs are key electronic components used in nearly all electronic devices. Components are mounted and soldered on the metal pads connected to the board circuitry. The components are interconnected, allowing the transfer of electrical signals via a network of copper pathways to meet the mechanical and circuit requirements. The PCB manufacturing process involves complex procedures that ensure that once the product is complete, it will perform reliably in the field (Millennium Circuits Limited). The fabrication processes may differ depending on the number of layers needed and the various structures of PCBs produced. Hence, some PCBs may require more steps during manufacturing than others.

The unique application of each PCB determines the complexity of copper routes. Thus, the structural complexity of the conductive copper routes in a PCB design determines the fabrication steps for producing the board. Cutting back on the manufacturing procedure by skipping some steps could lead to the production of PCBs that do not perform as desired (Flatt). PCBs should perform well in major electronics when the production process is completed correctly.

A. *Description of the process*

Manufacturers employ a variety of processes for producing PCBs – from small workshops where unique PCBs are produced to fully automated production lines where thousands of PCBs are produced daily. Generally, the design and manufacturing of a PCB is a step-by-step process: beginning from the schematic design of a PCB layout to the fabrication and assembling of the boards for packaging and delivery (Robertson and Christopher). Most steps involve computer guidance and machine tools to produce accurate and reliable circuit boards. The complete boards undergo strict quality testing to ensure they function appropriately before packaging and delivery to customers. The detailed steps in the PCB production process are discussed in the following sections.

1) *PCB production process steps*

Step 1: Designing the PCB

The production process begins with a PCB design. The designer makes a blueprint for the PCB to meet the desired structural and electrical circuit requirements (Khandpur).

Step 2: PCB Printing

After designing a PCB blueprint and checking all design aspects to eliminate potential errors, PCB printing is the next step. The PCB printing process involves the use of a plotter machine, which produces photo films of the panel for PCB imaging and printing (Varteresian). The image, which is a photo negative of the actual PCB, has a black colour for the conductive copper pathways and light colour for the non-conductive areas (Millennium Circuits Limited). For the outer layers, this colour trend is reversed.

The developed film must be stored in a clean room free of dust and other contaminants. For each PCB layer and solder mask, the plotter machine creates a photo negative on a black film. Once produced, the films are aligned correctly with the PCB before registration holes are punched through them. The process is performed on a work table that can be adjusted to achieve the desired alignment (Khandpur). A technician punches the holes once an optimal alignment is achieved. The holes are necessary at this step as they are used as a guide to align the films before imaging.

Step 3: Printing the Conductive Copper Paths for the Interior Layers

The previous step involved the creation of films that are important for mapping out copper paths. In this step, the copper paths on the film are printed on a copper foil to make the actual PCB. The printing process pre-bonds copper on both sides of the laminated piece to serve as the structure for the PCB (Marks et al.). The laminate material comprises epoxy resin and fiberglass and serves as substrate material. This material is the most suitable for receiving copper and making a strong and rigid PCB structure. In addition, the substrate material is dust-resistant, helping meet the high standards of cleanliness required in the fabrication process. The PCB undergoes etching, leaving the blueprint design (PCBCart). Next in the process is to cover the laminated layers with a photosensitive resist film. The film is suitably used at this stage because it contains photo-reactive chemicals that are ultraviolet (UV) light-sensitive. Exposure to UV light causes the chemicals to harden the film. With the resist developed, a technician can perfectly match the blueprint images of the PCB with the photoresist prints.

The proper alignment of the laminate and the resist is achieved by matching the guiding registration holes before exposure to UV light. Passing the UV light through the film causes the photoresist to harden, leaving behind clear copper pathways (Khandpur). The dark ink prevents the UV light from passing through the areas covered by the ink. These dark-inked areas are not meant for copper pathways. As a result, they remain unhardened for easy removal. The remaining traces of photoresist are removed by washing the board in an alkaline solution. After the cleaning and drying processes, the PCB should only have the photoresist on the copper pathways. Before proceeding to the next fabrication step, it is critical to check any errors at this stage.

Step 4: Etching the Inner Layers to Remove Unwanted Copper

The etching process in this step aims to remove extra copper on the inner layers of the PCB. In this process, the copper pathways are covered while the rest of the board is exposed to an etching chemical that removes traces of unwanted copper from the board (Khandpur). The etching removes all exposed copper, leaving only the required copper pathways covered beneath the hardened photoresist layer. After removing the unwanted copper, the hardened resist covering the desired copper pathways is washed off using another chemical solvent, leaving a glittering copper substrate needed for the PCB.

After the inner layers are etched, the board is ready for the resist stripping process. This process removes any remaining resist on the inner layer copper pathways. It is critical to clean the PCB at this stage to remove any unwanted materials that may affect its performance. The layer is sent for inspection of its basic design. The resist stripping step is followed by the post-etch punch process, where the layers are aligned before punching a registration hole. A computer-guided machine performs an optical punch (Varteresian). After punching, the layers are inspected using an automated optical inspection (AOI) technology. Inner layer AOI is a computer-guided examination of the inner layer to identify any resist or incomplete patterns on the board surface. Once the PCB passes AOI, it moves to the next process, which is the

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application of oxide to the inner layer. The purpose of applying oxide is to bond the copper foil with epoxy resin between the outer and the inner layers.

Step 5: Layer Alignment, Lay-up and Bonding

After the PCB layers have been cleaned in step 4, the PCB layers are ready for lamination. However, this process can only proceed after satisfactorily confirming that the layers do not have any defects. The lamination process fuses the outer layer to the original substrate material following the lay-up and bonding steps. A thin copper layer protects the substrate (PCBCart). The PCB layers are first secured on a press table using clamps and fitted using pins to prevent movement that would otherwise cause misalignment.

A technician makes layers in the following order: pre-impregnated epoxy resin – substrate - copper foil - pre-impregnated epoxy resin - aluminum foil. This stack of layers is completed by placing a copper press plate on top before moving it to the pressing machine. On the pressing machine, the layers are pressurized together to form a laminated piece (Coombs). A second laminating machine applies heat and pressure to the laminated stack. The applied heat and pressure melt the epoxy and fuse the materials together (Millennium Circuits Limited). Once the pressing process is complete, the pins and the top press plate are removed to allow for easy removal of the PCB.

Step 6: Drilling

The exact locations of the holes are first identified on the board using an X-ray machine before drilling begins. The board is then secured on the machine using the registration holes to ensure the board remains still during the drilling process. Manufacturers often use a buffer board to ensure a clean bore is achieved and the board remains intact even after withdrawing the drilling machine from the holes. A computer-aided drill is used to drill hairs-width holes, using the file from the original PCB design as a guide. After the drilling process, extra copper left at the edges is removed. The drilled holes house the copper links and, later, are used for the mechanical mounting of the PCB (Coombs). The later mounting of components to the PCB depends on the precision of the drilled holes.

Step 7: PCB Plating and Copper Deposition

After drilling, the PCB is cleaned in readiness for plating and copper deposition. All the panel layers are fused together before they pass through a series of cleaning chemicals. During the chemical bathing process, a thin copper layer is deposited in the holes and on the uppermost layer. Once bathed and covered with a copper layer, the holes no longer expose the substrate material in the boards (Varteresian). The entire process is computer-controlled.

Step 8: Imaging the Outer Layer

The PCB boards undergo another photoresist process in this step. However, unlike earlier, the photoresist is only applied on the outer layers of the board that need imaging. The entire process occurs in a clean room free of contaminants (PCBCart). Once prepared, the boards are exposed to a yellow light with minimal UV exposure to preserve the photoresist layer. The PCB panel is then secured in contact with a stencil using pins to protect black ink transparencies before exposing it to UV light. The light hardens the photoresist, and areas left unhardened are removed in a machine.

The process is the inverse of that of the inner PCB layers. After the outer layers receive a photoresist coating and are imaged, they are plated using the same process as the plating process on the interior layers in step 7 (Millennium Circuits Limited). However, the outer layers are plated using tin, unlike copper for the inner layers, to protect the copper of the outer layer. The final process is to inspect the PCB to ensure no underside photoresist remains from the previous step.

Step 9: Final Plating and Etching

In this step, the PCBs return to the plating line, where a thin layer of copper is electroplated on the exposed areas of the boards. Extra copper from the previous step is removed by applying another layer of tin plating (Clark). In the final etching, the outer layer is etched for the last time. During the etching process, the tin guard plays an important role in protecting the copper from etching out. All unwanted copper is etched out using a copper solvent. The ink colours for the inner and outer layers are inverted; the non-conductive areas on the outer layers of the board are represented by dark ink, while light ink is used to indicate the conductive copper areas of the board (PCBCart). Hence, the applied light ink helps cover and protect the copper. Unwanted copper is removed before moving to the next step.

Step 10: AOI and Solder Masking Application

In this step, an optical inspection of the outer layers is conducted to ensure that the fabricated PCB satisfies the design requirements. AOI is also performed to ensure that there are no traces of extra copper left on the board. The overall purpose of the AOI procedure is to ensure that the final board has proper electrical connections for the desired electrical performance. Thorough cleaning of the PCB is important prior to the solder masking process. Further exposure to UV helps identify areas where solder masks should be removed (PCBCart). Curing is the last process in this step, where the PCB is left in the oven for some time to dry. The mask is useful in preventing copper damage that can result from oxidation and corrosion.

Step 11: Surface Finish and Silkscreen Application

It is desired that the fabricated PCBs have high solderability. This is achieved through the chemical plating of the PCBs using gold or silver. Some manufacturers use hot air-levelled pads as part of the PCB surface finish process to produce uniform pads. The process produces a surface finish (Coombs). Vital information is printed on the PCB surface in a process known as silkscreen application. Such information may include the manufacturer's logo, part numbers, and other important marks (PCBCart). After silkscreen application, the PCB undergoes the coating and curing stage before continuing to the inspection, electrical testing, and cutting phases.

Step 12: Electrical Testing, Profiling, and Route Out

Advanced electrical testing methods, such as Flying Probe Testing, are used to test the electrical performance of each PCB. First, the shape and size of individual boards are determined from the original panel design to guide the routing process by creating scores on the board. The next step is to cut out the PCBs from the original panel using a CNC machine, a

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V-groove, or a router. Profiling and V-scouring using either technique allows the boards to pop out from the original panel without breaking (Millennium Circuits Limited). After cutting and separating the boards, they are ready for final quality inspection, packaging, and delivery.

Step 13: Quality Inspection, Packaging, and Delivery

After the individual PCBs are separated from the original panel, the next procedure involves conducting the final inspection before the boards are packaged and shipped for delivery to customers. Visual and automated inspection procedures are conducted to confirm that the PCBs are clean, conform to the original design, and function properly (PCBCart). Packaging and delivery are the last stage of PCB manufacturing, where the PCBs are sealed, placed into containers that protect them from physical damage, and shipped to the customer.

2) Description of the process flow

The PCB manufacturing flow chart is shown in Figure 1. The entire production unit consists of six teams. The flowchart shows the tasks in each process, from material preparation to packaging and delivery, and the teams performing each task.

The production process has already been described in details in the previous section. The production steps are assigned to various teams in the PCB manufacturing facility, which the study is conducted at, these teams are:

Team 1: The Photo-Tooling process team

This team performs the following processes in the processing flow chart: Film plotting process, inner and outer layers laminating and printing processes, and solder masking process.

Cleanliness does matter in these processes. Therefore, the team is responsible for the Clean Room in the layout (shown in Figure 2). The Clean Room is kept free of dust particles and is temperature and humidity-controlled.

Team 2: The Mechanical Process Team

The PCB production process involves various mechanical processes. This team is responsible for material preparation, pressing, drilling, and final routing.

Team 3: The Chemical Process Team

The chemical process team performs all processes in PCB production involving the use of chemicals. The responsibilities of the team include inner layers treatment process, inner and outer layers etching process, inner and outer layers photoresist stripping process, and outer layers tin stripping process

Team 4: The Plating Process Team

This team performs all the processes on the plating line of the PCB production process. These processes include black oxidation process for the inner layers, outer layers plating through holes process, pattern plating process for the outer layers, and outer layers gold plating process.

Team 5: Quality Control Team

PCBs are the basic assembly of any electronic device. They directly affect the functions and performances of all electronic devices. Failure to pay close attention to the quality of the PCBs produced can present problems for the development process, ranging from the inability to manufacture the boards to premature failures in electronic devices. Hence, the need to produce high-quality and reliable PCBs. Quality control in PCB manufacturing covers three important aspects: validity of the design, manufacturability of PCBs, and testability and normalization (PCBCart 2022B). Team 5 is responsible for checking all the boards through the process and the final product inspection (electrical testing and final inspection) to ensure that the boards meet the technical requirements and function according to design before packaging and delivering the product to the customer. They constantly check the design drawings, manufacturing capabilities, and procedures. The team also inspects the final products to ensure that the PCBs meet the highest applicable standards.

Team 6: Assembly Team

The work of the assembly team in the PCB production process is to assemble the final PCB products. The team amounts various electronic components on the PCB depending on the field of the application.

Team 7: The Chemical Lab Team

The work of the chemical lab team in the PCB production process is to prepare and carry out Chemical Analysis for the chemical process and plating lines.

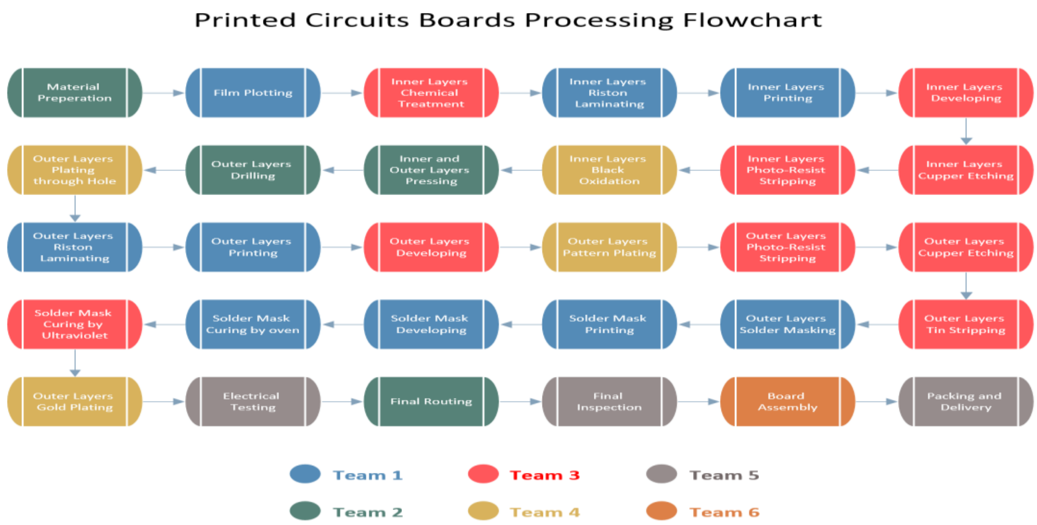

Fig. 1. PCB Processing Flow Chart.

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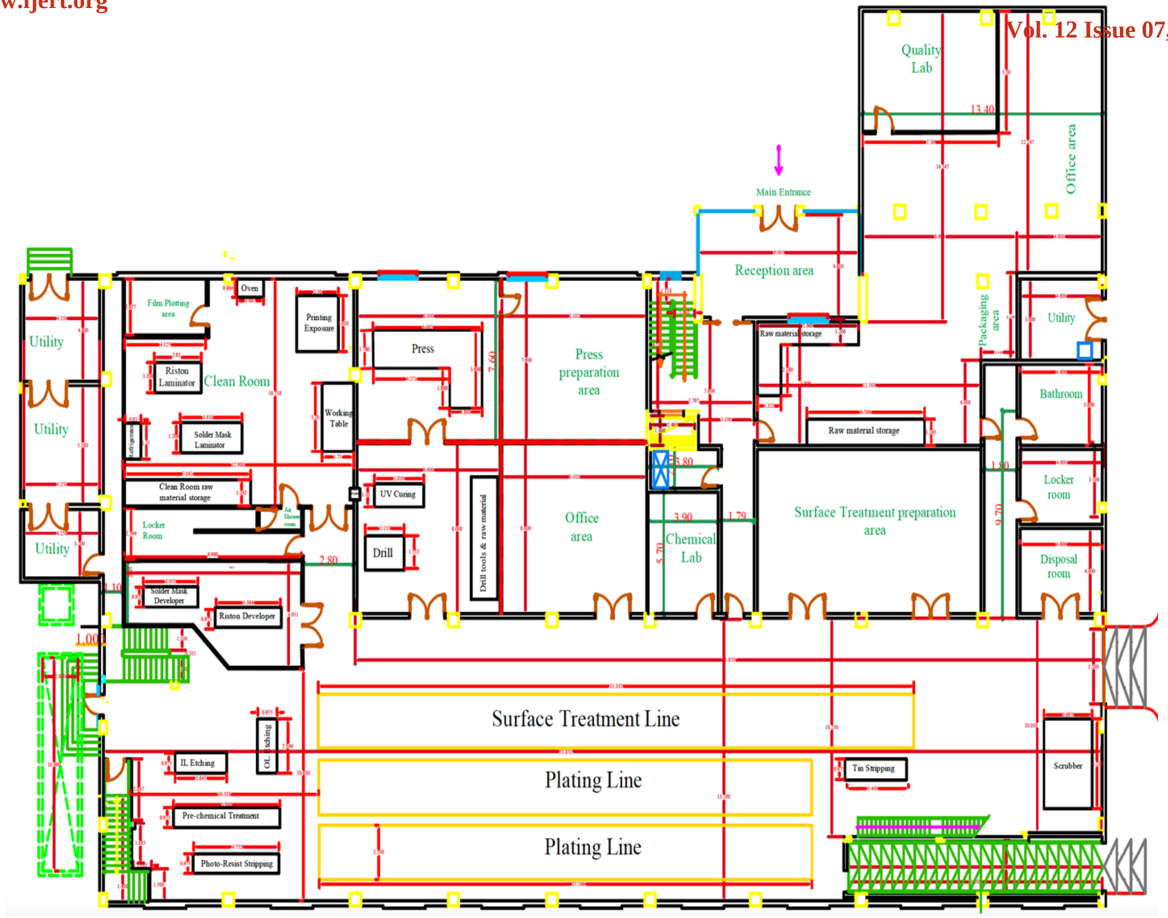

Fig. 2. Current Layout of the PCB manufacturing workshop

B. *Description of the Facility Layout*

PCB manufacturing is a design and development process with several steps, including requirements analysis, functional and detail design, product testing, and documentation. The current layout of a Printed Circuits Board facility in the field of research and development (R&D) is a "Functional (Process) Layout." While this type of layout has advantages, limitations may emerge in the process layout. The functional layout can be seen in how workers and equipment are positioned. This type of layout configures the workplace according to the process organization. The manufacturing processes are grouped according to the function, equipment, or technology used (Swamidass). A functional layout in production focuses on value stream, processes, and flow. The facility layout design of the current PCB manufacturing workshop is shown in figure 2.

All activities and processes should be established and organized based on the PCB production process to create flow throughout the facility. In addition, the production resources, i.e., machines, equipment, and labor, should be assigned to the same work area where different teams are required to perform similar tasks. This arrangement of processes and resources reduces movement between workstations, thereby cutting time wastage (Meyers et al.). The different work areas of the PCB facility include the clean room, press preparation area, surface treatment preparation area, chemical lab, surface treatment and plating lines area, quality lab, and packaging area. Cleanliness is critical in the PCB manufacturing process since dust particles may interfere with the fabrication process and the functioning of the electronic equipment in which the PCB will be used (Tulkoff et al.). The clean room has photo-tooling process equipment to help team 1 complete the PCB production processes assigned to the team. Team 2, responsible for mechanical processes, works in the material preparation area, press preparation area, drilling area, and final routing area. Unlike in the clean room area, where team 1 completes most of their tasks, the work areas for team 2 are in different locations in the facility.

Fig. 3. The Clean Room area

Most of the equipment and processes carried out by the chemical process team are located adjacent to the clean room and the plating line. This work area houses the solder mask developer, Riston developer, etching process equipment, and equipment for pre-chemical treatment and photoresist arranged as shown in figure 4. All the chemicals used in the production process are prepared in the chemical lab, located near-central to other areas of the workshop.

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Fig. 4. Chemical Processes area

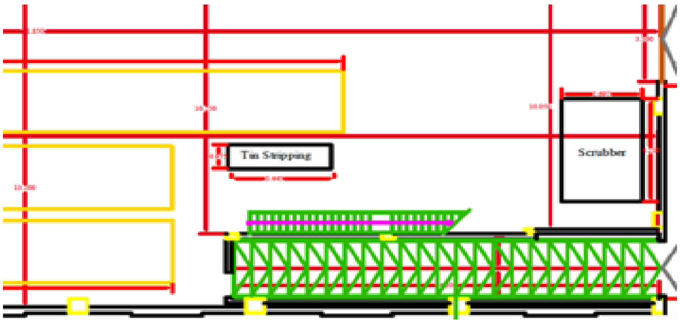

Fig. 5. Tin Stripper and Scrubber system area

The Tin Stripping process follows the plating process, and the process area is located on the other side of the plating Line. The scrubber system to remove any industrial exhaust gases is also located in the same area (see figure 5). The plating process team uses the plating line for PCB plating at various points of the production process. Boards from the drilling section are prepared for the plating process. The Plating process is repeated with conductive materials as part of the finishing process. The plating line can perform only two processes at the time from the process list; inner layers black oxidation, plating through holes, pattern plating and gold plating.

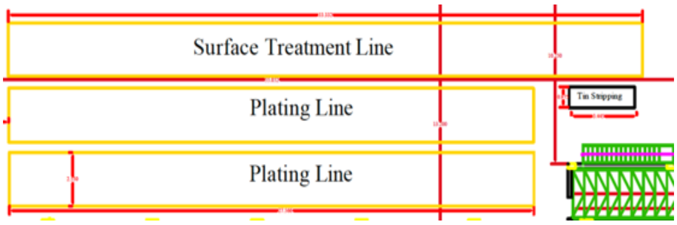

Fig. 6. Surface Treatment and Plating Lines area

The quality lab and packaging areas are on the far left of the workshop layout. Quality checks and final visual inspection are the last steps in the manufacturing process before the products are shipped for delivery. The quality control team works from the quality lab to ensure that the PCBs meet the desired quality before proceeding to the next process and that the final product after the assembly process is of high quality.

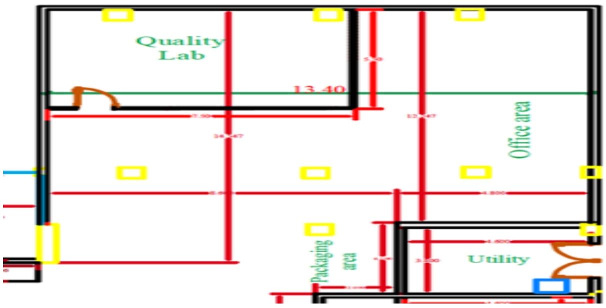

Fig. 7. Quality Lab and Packaging area

The current functional layout needs reorganization to achieve greater value streams, processes, and flow. The two approaches to achieving lean production in this layout are: (i) installing machines and equipment for a particular process in one area with different areas and teams assigned to each type of equipment, and (ii) creating a product-oriented layout in which the machines and equipment are placed in a sequence similar to that of the production processes (Swamidass). Re-arrangement will allow each team of workers to work together in a work area or create flow-oriented work sub-sections to support other teams in the production process.

III. Data Collection

The PCB production lines and machines consist of more than one process in different stages of the production chain, and each requires preparation process to be done such as chemical lab analysis. For instance, the plating line performs four different processes: Inner Layer Black Oxidation, Plating through Holes, Surface Pattern Plating, and Gold Plating. The PCB manufacturing companies usually provide at least a machine or production line for each process, so the production order will wait in queue because the machine is busy performing a different process. Due to unavailability for dedicated machine for every process, some orders are processed by the same machine, In this situation, these orders that need to be processed by the same machine they wait for their turn on a first come first served (FCFS) basis. Thus, data was collected as per batches running in the production.

The study started by gathering the number of orders over the past 3 years. Then, as per the production plan in the company, we selected the month with the highest number of orders to be run in the production as a batch to calculate the overall production time.

TABLE I. Distripution of Orders Over 3 Years

Month	No. of orders per year			Total no. of orders
	2020	*2021*	*2022*	
Jan	3	5	3	11
Feb	10	8	9	27
Mar	5	7	16	28
Apr	1	2	1	4
May	1	2	-	3
Jun	-	1	-	1
Jul	13	2	1	16
Aug	5	2	21	28
Sep	8	9	5	22
Oct	4	14	27	45
Nov	5	11	4	20
Dec	8	3	2	13
Total	**63**	**66**	**89**	**218**

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The highest number of orders received was in Oct 2022 (27 orders). To study the overall production, the number of layers for each order should be considered as it affects the inner layers' process. Another factor that should be taken into account is the number of production panels.

TABLE II. OCT 2022'S ORDERS AS PER PRODUCTION PANELS AND NO. OF INNER LAYERS

Type of order (as no. of layers)	Total no. of orders received	No. of production panels per order	Total no. of production panels	No. of Inner layers per order	Total no. of Inner Layers
4 layers	7	2	14	1	14
6 layers	2	2	4	2	8
8 layers	8	2	16	3	48
10 layers	5	2	10	4	40
12 layers	2	2	4	5	20
14 layers	2	2	4	6	24
16 layers	1	2	2	7	14
Total	**27**		**54**		**168**

Thus, the experiment was run as per the above table. About 27 orders run in the production with a total of 54 production panels which have 168 inner layers. When calculating the total time of the PCB process, the production should be separated into 2 phases due to quantity type change. Phase 1 is Inner layer process, which in this trial equals to168 Inner layers, and phase 2 is the panel production, which equals to 54 production panels. Phase 2 starts after pressing the inner layers for each order in the Pressing process. Few points to be considered before calculating the overall production process:

- The quantity unit for the production is Inner layers for phase 1 (Film plotting – Pressing) and Production panels for phase 2 (Drilling – Final Inspection).
- The machines: (Pre-chemical Treatment, Riston Laminator, Riston Developer, Inner Layer Etching, Photo-resist Stripping, Outer Layer Etching, Tin Stripping, Solder Mask Laminator, Solder Mask Developer) are Conveyor system machines and the difference between the production pieces is set to 20 sec.
- The Plating Line consists of tanks and transporters to carry the production pieces and dip them into the tanks required for the operation. The sequence of tanks differs from process to another and the capacity of each tank differs as well from one process to another.
- The PCB process start with inner layers production**.** Then, these inner layers are pressed together and sandwiched by the two outer layers to produce a panel. Each panel produced has a different number of PCB boards as requested by the customer. Some panels can have more PCB boards than the ordered quantity by the customer; the reason behind that is the size of the board and the panel. If the PCB size is small and extra unused area on the panel remains, more PCB will be produced on the panel, even if it is more than the quantity ordered by the customer. These extra PCBs will be used to replace the PCBs that did pass inspection in the customer order or it will be stocked to fulfill future orders. In some cases, two orders can be merged in one production panel if they have the same specifications, and the board size is small. On the other hand, some orders have big board sizes so that the panel can have only one board, in this case, more production panels should be processed to meet the customer requirements.

The production time for each process is calculated using a stopwatch, and the production process time is shown in the tables below:

TABLE III. PHASE 1 (INNER LAYERS) PRODUCTION TIME

Process (Phase 1)	Process Time one inner layer (sec)	Process Time for 168 inner layers (sec)	Transportation Time to next Stage (sec)	Machine Capacity	The flow for the next batch
Films Plotting	150	41,400	-	Unlimited	One by one
Material Preparation	50	13,800	50	Unlimited	One by one
Inner Layer Prechemical Treatment (@ 0.90 m/min)	358	63,484	45	Unlimited	The second IL after 20 sec
Inner Layer Riston Laminating	80	14,275	10	Unlimited	The second IL after 5 sec
Inner Layer Printing	270	45,360	25	Unlimited	One by one
Inner Layers Developing (@ 1.2 m/min)	195	36,100	10	Unlimited	The second IL after 20 sec
Inner Layer Etching (@ 0.54 m/min)	327	58,276	10	Unlimited	The second IL after 20 sec
Inner Layer photo-resist stripping (@ 0.9 m/min)	255	46,180	5	Unlimited	The second IL after 20 sec
Inner Layer Black Oxidation	900	75,600	30	2 IL at the time	One by one (2 Inner layer at the time)
Pressing - (Press Cycle: 195 min - Lay up: 10.2 min)	12,300	68,148	15	21 panels at the time	One by one (21 panels at the time)
Total Time	14,885	462,623	200		
Total Production Time (sec)		**462,823**			

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TABLE IV. PHASE 2 PANELS PRODUCTION TIME

Process (Phase 2)	**Process Time for one production Panel (sec)**	**Process Time for 168 IL (sec)**	**Transportation Time to next Stage (sec)**	**Machine Capacity**	**The flow for the next batch**
Drilling	900	48,600	15	Unlimited	One by one
Plating through holes	6,000	95,700	45	4 panels at the time	The second batch after 15 min (Max 2 batches in the system- 8 panels)
Outer Layers Riston Laminating	80	4,585	10	Unlimited	The second Panel after 20 sec
Outer Layers Printing	270	14,580	25	Unlimited	One by one
Outer Layers Developing (@ 1.2 m/min)	195	11,590	20	Unlimited	The second Panel after 20 sec
Pattern Plating	5,400	48,600	5	6 panels at the time	One by one (6 panels at the time)
Outer Layers photo-resist Stripping (@ 0.9 m/min)	255	14,830	10	Unlimited	The second Panel after 20 sec
Outer Layers Etching (@ 0.96 m/min)	205	12,130	60	Unlimited	The second Panel after 20 sec
Outer Layers Tin Stripping (@ 0.9 m/min)	198	11,752	75	Unlimited	The second Panel after 20 sec
Solder Mask Lamiating	190	10,525	10	Unlimited	The second Panel after 20 sec
Solder Mask Printing	360	19,440	25	Unlimited	One by one
Solder Mask Developing (@0.9 m/min)	309	17,746	25	Unlimited	The second Panel after 20 sec
Solder Mask Curing by Oven	3,600	3,600	40	60 panels	all panels at the same time
Solder Mask Curing By UV	120	6,745	15	Unlimited	The second Panel after 20 sec
Gold Plating	5,400	48,600	65	6 panels at the time	The second batch after 60 min (Max 2 batches in the system - 12 panels)
Electrical Testing	480	25,920	60	Unlimited	One by one
Final Routing	900	48,600	60	Unlimited	One by one
Final Inspection	720	38,880	-	Unlimited	One by one
Total Time	25,582	482,412	565		
Total Production Time (sec)		**482,988**			

TABLE V. TOTAL PCB PRODUCTION TIME

Production Time	**Production Time (sec)**	**Production Time (min)**	**Production Time (hr)**	**Production Time (day) for 8 hrs shift**
Phase 1	462,823	7,714	128.5	16.1
Phase 2	482,988	8,050	134.2	16.8
Total	**945,811**	**15,764**	**262.7**	**33**

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IV. Results and Discussion

From the data above, we can tell that there is transportation time between the processes, and in some cases, this transportation can be avoided. For instance, machines, such as, Riston Developer, Inner Layer Etching, Photo-resist Stripping, Outer Layer Etching, and Tin Stripping, are conveyor system machines and their processes are sequential; Riston developer, Inner Layer Etching, then Photo-resist Stripping are sequential and Photo-resist Stripping, Outer Layer Etching, then Tin Stripping are also sequential too. We will focus on the idea that the relocating of the machines to reduce the material handling and the transportation time will benefit the facility through a reduced production time.

As per PCB manufacturing facility's current layout, it was found that lots of materials movement among several departments that are distantly located apart of each other. These departments are: Chemical Processes, Mechanical Processes and Quality Control department. In the Chemical process department, Pre-chemical is located away from the raw material storage. Also, the Riston developer is located a way from the IL Etching and Photo-resist Stripping. In addition, the Photo-resist Stripping, the OL Etching and the Tin Stripping are located away of each other. Similarly, The Drilling machine is located in the Mechanical Process department is far from the Quality Control Lab, where the Electrical Testing, Final Routing by the Drilling and the Final Inspection processes are performed sequentially. Therefore, these machines have to be relocated to be closer to each other to minimize transportation time and product handling movements based on the relationships among these departments/machines and the size of product movements among them.

The first step should move the Drilling machine from its' current location to a new place near the QC Lab so the transportation between the Electric testing in the QC Lab and the Routing Process then back to the QC Lab again for the Final Inspection will be reduced. The second step is to move the Pre-chemical Treatment equipment to the current Drilling area after the Drilling machine is moved to improve the Inner Layers Chemical Treatment process. These two steps should reduce material handling and transportation time for every part that will be transported between Pre-chemical and raw material storage and the Final Routing process and QC Lab. With these proposed modifications, the flow of material and in-process PCBs will be very smooth and efficient between Material Preparation to Inner Layers Printing's process.

The next equipment to be moved should be the Riston Developer, the IL Etching and the Photo-resist Stripping to the vacant site near by the Pre-Chemical Treatment in the current Drilling area after removing the wall between the Drilling area and the Office area next to it. The current office area should be moved to the second floor where the other offices are located. This would ensure a smooth process from Inner Layers Developing, Inner Layers Copper Etching, and Inner Layers Photo-Resist Stripping. This step will ensure that members of Team 3 will work in the same area and reduce both the transportation time and minimize in-process product handling.

The Chemical Lab should be moved to the area where IL Etching, Pre-Chemical Treatment, Photo-resist Stripping and OL Etching was, so it gives us the space to move the OL Etching and Tin Stripping equipment in the same area with the Photo-resist Stripping after moving the Chemical Lab. This will ensure reduced material handling from Outer Layers Photo-Resist Stripping, Outer Layers Copper Etching, to Outer Layers Tin Stripping. According to Kareem et al., minimizing material handling would minimize the production of defective products. Shorter manufacturing lead times are not only an ingredient for improving productivity, but also enhancing business performance (Han et al.). The UV curer should be moved close to the Clean Room area in the same place where the Riston Developer was. This will ensure a smooth flow of in-process PCBs from the Outer Layers Solder Masking to Solder Mask Curing by the Oven and UV since most of Team 1 members are stationed in that area. The process is expected to reduce the transportation time and material handling by team 1 operators. The remaining processes can stay in their current location because they are properly located in relation to each other. Therefore, all these proposed modifications are expected to reduce the transportation time and material handling of the products among the machines/departments that are currently located apart from each other. It will also improve the efficiency of the overall manufacturing process of the PCBs from the start of the production until the end.

V. Conclusions and Recommendations

Facility layout planning is an essential technique in the production process as it improves efficiency in manufacturing facilities. Facility planners should position the right equipment in the right places to ensure the smooth movements of the products. In this study, the current layout of a PCB manufacturing facility was thoroughly studied and analyzed to improve the overall efficiency of the production process. Several departments and machines within departments that are highly related to each other were found distantly apart from each other. This improper location of these related departments/machines have made the overall production process inefficient. These inefficiencies were represented by transporting and handling the in-process products manually through the far distant among these departments/machines. Based on these findings, recommendations were made by the study to move these related departments/machines locations closer to each other. Also, it was recommended that some current departments to be relocated to other areas within the facility to free their current location in order to carry out the recommended relocation of the manufacturing departments/machines of the PCB production process. Implementing these proposed modifications would reduce transportation time, minimize in-process product handling and with no doubt will improve the product flow and overall efficiency of the production process of the PCB.

In manufacturing, lead times describe the amount of time it takes to complete specific processes, including processing an order, manufacturing a product, or delivering orders. Ivanov and Jaff observed that a shorter manufacturing lead-time (MLT) is an invaluable source of competitive advantage as it allows a business to respond quickly to the customers and, as a result, improve its image and profitability.

As additional enhancements, to optimize the current layout, the following recommendations should be considered:

- The chemical process machines should be assembled close to each other to act as one conveyor. For instance, the panel or layer of the output of the Riston Developer

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is the input of the inner layer etching of the production by passing the finished panels or layers to the following process and not wait to finish the whole batch. This proposed concept is shown in figure 8.

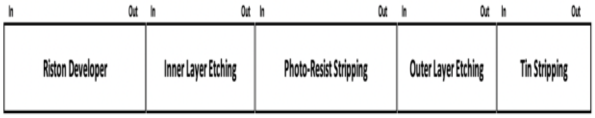

Fig. 8. Proposed arrangement of the Chemical Process Machines.

- Second, machines that are handled by the same team should be assembled in one area as possible. This will prevent team members from moving around the workshop to complete their tasks. Restricting the movement of employees will facilitate safety in the workplace. For instance, a member skilled in photo-resist stripping will be safer if they are prevented from handling the drill. Workplace safety is beneficial to any organization or plant as it increases the workers' capacity to deliver better. Every manufacturing plant should prevent accidents in their premises.

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