A PLASTIC PRODUCTS PLANT LAYOUT DESIGN

by

Mr. Thanakrit Chatlekavanich

A Final Report of the Three - Credit Course
CE 6998 Project

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science
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The Graduate School of Assumption University has approved this final report of the three-credit course, CE 6998 PROJECT, submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer and Engineering Management.

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ABSTRACT

The purpose of this report is to find the best solution by applying the Systematic Layout Planning or SLP. It will be based on the existing operation process.

The study of the SLP helps to guide in the finding of information and other factors that is needed to be considered. These are the five key elements of basic input data, P, Q, R, S, and T, which is necessary to plan this specific plant layout. They will tell us, what the plant is going to produce? In what quantities? How will the manufacturer produce these products? What is needed to support, such as personnel or utilities? And, when and how long will the manufacturer produce which products?

Abba Plastic, a plastic product manufacturer, is chosen to implement the project. SLP was a very good and detailed guidelines for layout planner. The method covers almost all the aspects needed to consider in a layout planning. Time is well spent and results are very effective and efficient. With the help of the software tools available, we can apply it with the theory to create the synergy in the planning process.

The result is satisfactory and scientific. From the viewpoint of the management, it helps to reconfirm that it is a good design because of the strong evidence and mathematical calculation that is tangible and easily understand.

ACKNOWLEDGEMENTS

I am indebted to the following people and organizations. Without them this project would not have been possible.

I wish to express sincere gratitude to my advisor and Dean of Master of Science in Computer and Engineering Management, Dr. Chamnong Jungthirapanich. His patient assistance, guidance, and constant encouragement had led me from the research inception to the research completion. He really cares for us, and stays up very late at night to advise all the students that came to him.

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Above all, I am forever grateful to my parents whose willingness to invest in my future has enabled me to achieve my educational goal.

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I. INTRODUCTION

Abba Plastic is a plastic product manufacturer. The main product is producing plastic packaging.

With the problem of space limitation, the company finds it very difficult in managing the operation. Defect rate is getting higher and higher. Many developments have been slowed down. The expansion of the production is not possible. This causes the loss in opportunity. The company decided to move to a new manufacturing plant. The plant location has already been decided. From past experience, the management team realized that planning of a plant layout is very important. They decided to find the best solution for the plant layout. It will be in the form of process layout.

The purpose of this report is to find the best solution by applying the Systematic Layout Planning or SLP. It will be based on the existing operation process.

1.1 Company's Background

Abba Plastic is a plastic product manufacturer. The main product is producing plastic packaging. Our main products are plastic containers with sizes varying from 100cc to 120 liters. With the annual production capacity of more than 3,500 tons, we are able to serve the demand of many local industries, covering mainly the chemical, petro-chemical, automotive, cosmetic and food industry.

Abba Plastic uses the general-purpose machines, which produce small, medium to large batch of plastic containers. The production process starts with mixing the raw material, which includes the plastic resin and the color pigment. The raw materials will be mixed according to the amount of the production plan. Next the raw materials is transferred to the machines, which we call the blow molding machines. The blow molding machines will be set up by the engineers. Molds will be set up according to the customers' orders. Then the products are produced. Scraps, which weight about fifty percent of the final products, will be removed manually. The products will be transferred to the finishing department, while the scraps will be transferred to the raw material process department. After the products are well finished, they will be transferred to the finished product store ready to be delivered.

From the past experiences, the old factory is facing the problem of space limitation; the company finds it very difficult in managing the operation. Defect rate is getting higher and higher. Many developments have slowed down. The expansion of production is not possible. This causes the loss in opportunity. The company decided to move to a new manufacturing plant. The new plant will be located in Samutsakorn province. The land covers about 22 rais.

1.2 Objectives

With the available space the company decided to build the factory with the following objectives:

(1) To design the layout that ease production, supervision, coordination, and maintenance.

(2) To provide a standard working environment and condition for the aspect of safety and health of the employees.

(3) To minimize the materials-handling costs after considering the aspect of safety of the employee and the quality of the products.

(4) The plant layout has to able to support the expansion in production of at least 10 % annual growth rate within 8 years period.

1.3 Scope

This project will cover only within the overall layout planning of the systematic layout planning. The departments will involve only the production and maintenance departments. The other facilities such as the parking lot, sport club, dining hall and others will be excluded.

The report will be divided into three phases: gather data, overall plan, and conclusion. The first phase, which is gathering data will consist of products, quantities, routings, supporting services, and timing. These are the five key elements of basic input data, which is necessary to plan this specific plant layout. They will tell us, what the plant is going to produce? In what quantities? How will the manufacturer produce these products? What is needed to support, such as personnel or utilities? And, when and how long will the manufacturer produce which products? From this data, it will be processed into useful information to be used to develop layout alternatives.

The second phase is to develop the overall plan. These involve converting the tangible requirements, data, and internal influences into the basic flow patterns for the area. It also indicates the size, relationship, and configuration of each major activity, department or area. The solution will be evaluated upon the factors such as material handling effectiveness, space utilization, safety and housekeeping, flexibility of layout, equipment utilization, working conditions, and others. The techniques that will be used to evaluate the alternatives are list of pros and cons, relative importance or order-of-magnitude ratings, activity relationship chart and diagram, cost comparison, and others.

The last phase is the conclusion. The whole picture will be summarized and topics that are the critical part of the project will be highlighted. Recommendation of the very useful points that the readers can apply to their layout planning.

II. LITERATURE REVIEW

2.1 What Is Facilities Layout?

2.1.1 Definition

Facilities layout means the arrangement of machines, utilities, equipment, storage areas, and work areas, usually within the confines of a physical structure, such as a retail store, an office, a warehouse, or a manufacturing facility, for the flow patterns of materials and people around, into, and within buildings (Norman 1992).

2.1.2 Types of Layouts

There are four basic types of layouts for manufacturing facilities. The four basic types of layouts are process, product, cellular manufacturing (CM), and fixed position.

(1) Process layouts

Process layouts, functional layouts, or job shops as they are sometimes called, are designed to accommodate variety in product designs and processing steps. If a manufacturing facility produces a variety of nonstandard products in relatively small batches, as in a custom machine shop, the facility will probably use a process layout.

Process layouts typically use general-purpose machines that can be changed over rapidly to new operations for different product designs. These machines are usually arranged according to the type of process being performed. For example, all machining would be in one department, all assembly in another department, and all painting in another department. The materials-handling equipment generally consists of forklift trucks, cranes, and other mobile vehicles that allow for the variety of paths followed through the facility by the products produced. Because of their ability to be programmed to fit a variety of products and processing steps, automated guided vehicle systems (AGVS) are also being used in process layouts.

The workers in process layouts must change and adapt quickly to the multitude of operations to be performed on each unique batch of products being produced. These workers must be highly skilled and require intensive job instructions and technical supervision.

Process layouts require ongoing planning, scheduling, and controlling functions to ensure an optimum amount of work in each department and each work station. The products are in the production system for relatively long periods of time, and large in-process inventories usually are present.

(2) Product layouts

Product layouts are designed to accommodate only a few product designs. Such layouts are designed to allow a direct material flow through the facility for products. Auto-manufacturing plants are good examples of facilities that use an assembly line or a product layout.

Product layouts typically use specialized machines that are set up once to perform a specific operation for a long period of time on one product. To change over these machines to a new product design requires great expense and long down times. The machines are usually arranged into product departments. Within one product department several processes, such as forming, machining, and assembly, could be performed. Materials-handling equipment is most often permanently positioned, such as conveyors or crane.

(3) Cellular manufacturing (CM) layouts

In cellular manufacturing (CM), machines are grouped into cells, and the cells function somewhat like a product layout island within a larger job shop or process layout. Each cell in a CM layout is formed to produce a single parts family a few parts all with common characteristics which usually means that they require the same machines and have similar machine settings.

Although the layout of a cell can take on many different forms, the flow of parts tends to be more streamlined when compared to a job shop.

The reasons why a CM layout would be attempted are:

(a) Machine changeovers are simplified.

(b) Training periods for workers are shortened.

(c) Materials-handling costs are reduced.

(d) Parts can be made faster and shipped more quickly.

(e) Less in-process inventory is required.

(f) Production is easier to automate.

In developing a CM layout, the first step is the cell formation decision, the initial decision about which production machines and which parts to group into each cell. Next, the machines are arranged within each cell.

(4) Fixed-position layouts

Some manufacturing and construction firms use a layout for arranging work that locates the product in a fixed position and transports workers, materials, machines, and subcontractors to and from the product. Missile assembly, large aircraft assembly, ship construction, and bridge construction are examples of fixed-position layouts. Fixed-position layouts are also used when special environmental conditions, such as "clean rooms" are required during assembly.

Fixed-position layouts are not common; they are used when a product is very bulky, large, heavy, or fragile. The fixed-position nature of the layout minimizes the amount of product movement required.

(5) Hybrid layouts

Most manufacturing facilities use a combination of layout types. For example, one may basically adopt a process layout with one section of the facility using an assembly line. The departments are arranged according to the types of processes and the product flow through on a product layout.

Although hybrids make the identification of layout types fuzzy, the importance of understanding the characteristics, advantages, and disadvantages of each type of layout should not be underestimated. As more complex production system layouts are designed, the ability to classify these into either product, process, CM, or fixed-position layouts enhances our ability to develop comprehensive and effective layout designs.

2.2 Example of Objectives for Manufacturing Operation Layouts

(1) Provide enough production capacity

(2) Reduce materials-handling costs

(3) Conform to site and building constraints

(4) Allow space for production machines

(5) Allow high labor, machine, and space utilization and productivity

(6) Provide for volume and product flexibility

(7) Provide space for restrooms, cafeterias, and other personal-care needs of employees

(8) Provide for employee safety and health

(9) Provide standard working environment and condition

(10) Allow ease of supervision

(11) Allow ease of maintenance

(12) Achieve objectives with least capital investment

III. TECHNIQUES FOR DEVELOPING AND ANALYZING FACILITY LAYOUTS

Two-or three-dimensional templates or models are the most common facility layout technique used for building floor plan. Analysts slide these models of machines, desks, and other equipment—which are made to the same scale as the building floor plan to various positions. We can achieve a detailed layout in which materials and personnel can flow from place to place with little excess travel with these tools. There is also a lot of computer-aided-design software available in the market. These software helps to reduce time and make design easier.

Other layout techniques differ among four types of layouts—process and warehouse layouts, product layouts, CM layouts, and customer service layouts.

3.1 Planning Process Layouts

The internal arrangement of buildings that use process layouts is usually first analyzed to determine the internal boundaries of operating departments and the external shape of the building. Operations sequence analysis, block diagram analysis, load-distance analysis, and systematic layout planning (SLP) (Muther 1961) are techniques used to develop these layouts. The most suitable method is the systematic layout planning.

3.1.1 Systematic Layout Planning (SLP) (Muther 1961)

In these systems systematic layout planning (SLP) can be used.

SLP first develops a chart to rate the relative importance of each department being close to every other department. The ratings range from the extremes of absolutely necessary to undesirable. The ratings are based on a variety of reasons—type of customer, ease of supervision, common personnel, common equipment, and so on. Next, an initial schematic diagram, similar to the one in operations sequence. But this diagram connects the operating departments with color-coded lines to indicate closeness rating. This initial schematic diagram is modified through trial and error until departments with high closeness ratings are adjacent to one another and department and building space limitations are satisfied.

SLP is quite similar to operations sequence and block diagram analyses in both procedures and end results. The only significant difference between these approaches is that SLP allows many reasons for assigning a closeness rating between departments, whereas operations sequence and block diagram analyses allow a single reason—product or material travel per time period.

The four layout analysis techniques presented—operations sequence, block diagram, systematic layout planning (Muther 1961), and load-distance analysis—can be used whether the analyst is or is not restricted in the building configuration. These analyses begin with the production processes and develop a layout that sets the building configuration. It is more efficient than beginning with the building configuration and then work backward to see how we can fit the production processes into the building.

3.2 The Systematic Layout Planning Pattern (Muther 1961)

Systematic Layout Planning, first developed by Richard Muther, is an organized way to conduct layout planning. It consists of a framework of phases, a pattern of procedures, and a set of conventions for identifying, rating, and visualizing the elements and areas involved in planning a layout.

The strictly "layout planning" phases of any facilities rearrangement involve creating a general overall layout and, a detailed layout plan for each portion of the general overall layout.

3.2.1 Three Fundamentals

Every layout rests on the three fundamentals:

(1) Relationships—the relative degree of closeness desired or required among department, personal and things.

(2) Space—the amount, kind, and shape or configuration of the things being laid out.

(3) Adjustment—the arrangement of things into a realistic best fit. Regardless of products, processes, or size of project, these three fundamentals are always the heart of any layout-planning project. It is therefore logical and to be expected that the pattern of layout planning procedures is based directly on these fundamentals.

3.2.2 Data Gathering and Analysis Step

This preliminary data-gathering-and-analysis step is termed Input Data & Activities, and it generally includes the following sequence:

(1) Identify specific elements of input data needed as design criteria for the project at hand.

(2) Project these data into the future. There will surely be many information that involve the layout planner's restructuring information. These information might be available from or supplied by others in the organization.

(3) Seek general approval and top-management endorsement of the input data.

(4) Examine the data for distinctive dissimilarities, using P-Q chart and variations there of to arrive at basic-typed layout and/or definitive bases for dividing, splitting, or combining activity-areas.

(5) Identify and define the activities, or activity-areas, to be used in the subsequent planning.

3.3 The Five Elements (Muther 1961)

Five elements—P (Product), Q (Quantity), R (Routing), S (Supporting Services), and T (Timing)—form the basis for layout planning.

For the layout planner, this sequence of letters is essentially a new alphabetical order. The alphabet no longer begins with A, B; C. From the start, each one of the projects involves P, Q, R, S, and T.

A play on letters, true—but it is the heart and soul of what eventually becomes millions of dollars of new construction, modernization, and plant rearrangement.

With this alphabet, everyone planning new or rearranged facilities has a place to start and starting is sometimes the hardest part of a project.

P Product (Material)

Q Quantity (Volume)

R Routing (Process sequence)

S Supporting Services

T Time (Timing)

3.3.1 Two Basic Elements

Directly or indirectly, these two elements underlie all other features or conditions in layout work. Therefore, facts, estimates, or information about these two elements are essential.

(1) Product, material, or service—what is to be made or produced.

By Product, material, or service we mean the goods produced by the company or area in question, the starting materials which might be raw materials or purchased parts, the formed or treated parts, the finished goods, or service items supplied or processed.

Products may be termed items, varieties, models, styles, part numbers, formulations, product groups, or material classes.

(2) Quantity, or volume—how much of each item is to be made.

By Quantity, or volume, we mean the amount of goods or services produced, supplied, or used.

Quantity may be termed number of pieces, tons, cubic volume, pallet-load, or value of the amount produced or sold.

3.3.2 Other Elements

(1) Routing

After obtaining the product and quantity information, we must study about the routing, or process. The routing refers to how the product or material will be made.

By Routing we mean the process, its equipment, its operations, and their sequence.

Routing maybe defined by operation-and-equipment lists, process sheets, flow sheets, and the like.

The machinery and equipment used will depend on the operations selected to change the form or characteristics of the material. Similarly, the movement of work through the area to be laid out is dependent upon the sequence of the operations. Therefore, the operations involved in the process and their sequence become the body of our key.

(2) Supporting Services

By Supporting Services we mean the utilities, auxiliaries, and related activities or functions that must be provided in the area to be laid out, so that it will function effectively.

Supporting services include maintenance, machine repair, tool room, toilets and locker rooms, cafeteria, first aid, and frequently shop offices, rail siding, receiving dock, shipping dock, receiving or "in area", and shipping or "out area. Storage areas are also considered as a part of the supporting services.

Taken all together, the supporting services often occupy more floor area than the producing departments themselves. Therefore, adequate attention must be given to them.

(3) Timing

Time or timing is other basic key element to unlocking layout problems. By Time or timing we mean when, how long, how often, and how soon.

Time or timing involves when products will be produced or when the layout being planned will operate on one shift only, during harvest season, or on a Christmas rush. Operating times for the producing operations determine how many of a given piece of machinery are required, which in turn determines the space required, man-power staffing, and operation balancing. Urgency of delivery or action is also a part of timing, as are the frequency of lot or batch "run" and the response of supporting services.

Perhaps the most important of all, time affects us—the layout planners. Every layout project takes a certain amount of time to accomplish, and usually there is a deadline to meet.

3.4 Tie-in of P, Q, R, S, and T

We have seen how the pattern of Systematic Layout Planning is constructed. Now let us relate it to the basic input data, P, Q, R, S, and T.

P, Q, R, S, and T underlie most of the calculations needed for layout planning. The preparation of the data for the various boxes in the SLP pattern starts with these five base elements. The product designs and sales forecasts must be woven together and integrated with a P-Q analysis—sometimes called volume-variety analysis or study of product mix. The logical splits and combines of various products or product groups or layout groupings are derived from the P-Q analysis. Specifically, this analysis of product mix, along with analyses of Routing (R), Services (S), and Times (T), often leads us to the actual type of layout. Which actually help to the identification or delineation of the individual activities involved such as areas, machine groups, and work places.

P, Q, and R are then woven together to develop the flow of materials. P, Q, and S are woven together to develop a service activity relationship. From the flow of materials or the activity relationship chart, or a combination of the two.

It is Routing (R), together with Time (T), which essentially determines the machinery and equipment required. Similarly, the services (S) called for are translated into the various service facilities required. The process machinery and equipment and the service facilities are then translated into space requirements. These space requirements are then worked into the SLP pattern as described above.

3.5 Flow of Materials

The third letter of our Key to unlocking layout planning problems is R—Routing. Routing means how an item is made its process. The process is established essentially by selecting the operations and sequences that will best produce P and Q wanted in the optimum operating T—although many other considerations may be involved in the determination.

The routing produces the basic data for analyzing the flow of materials. But before utilizing the routing, the meaningful little word why, the business end of our key. The routing should be examined and proved reasonably right; it should be restudied when the planner feels it can be improved.

3.5.1 Flow of Materials—Heart of Many Layouts

The analysis of materials flow involves determining the most effective sequences of moving materials through the necessary steps of the processes involved and the intensity or magnitude of these moves. An effective flow means that materials move progressively through the process, always advancing toward completion and without excessive detours, back-tracking, or counterflow.

Wherever the movement of materials is a major portion of the process, the flow-of-materials analysis is the heart of layout planning. This is especially true when materials are large, heavy, or many in quantity or when transport or handling costs are high compared with costs of operation, storage, or inspection. In extreme cases of this kind, the desired flow is developed and then diagrammed directly. The space requirements are hung on the flow diagram. Little investigation of supporting services is made, and no activity relationship chart is constructed. The services and other-than-flow relationships are simply picked up as part of the Modifying Considerations.

Therefore, the process of analyzing the materials flow is one of the primary steps that every layout planner should understand and know how to do.

The standard work—simplification check each step in the process routing with these words:

(1) Eliminate—Is the operation necessary, or can it be eliminated?

(2) Combine—Can it be combined with some other operation or action?

(3) Change sequence, place, or person—Can these be changed or rearranged?

(4) Improve details—Can the method of performing the operation or action or its equipment be improved?

Once satisfied with the process routing, the planner can begin flow-of-materials analysis.

3.5.2 The Operation Process Chart

The picture of the materials flow can help to plan the layout. In fact, this necessity to "see the picture" is perhaps the underlying reason that SLP has developed into its present form.

System of sign language is used—equivalent to those used by the mathematician, the chemical engineer, or the procedure analyst. The sign language of process charting is well known to trained industrial engineers. It was originally developed by Frank and Lillian Gubreth.

Process charts provide a systematic description of a process or work cycle involving activities of humans, agents, or objects. It is a schematic or tabular representation of the sequence of all relevant actions or events—circle represents operations, arrow represents transportations, square represents inspections, D represents delays, triangle represents storages and the like, that occur during a process or procedure.

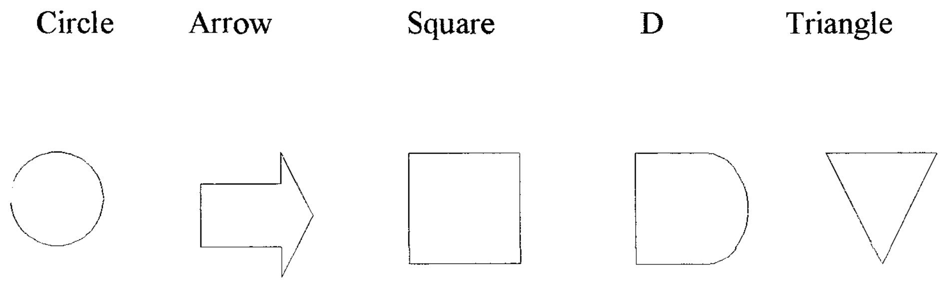


Figure 3.1. Process Chart Symbol.

(1) Intensity of flow

In this connection, we suggest considering two factors which are too often overlooked: the intensity of materials flow, and the outflow of waste, trimmings, and the like.

Flow-of-materials analysis, by our earlier definition, includes both the sequence and the intensity or magnitude of materials movement. If the flow analysis is made in order to arrange operations or activities in the correct relationship to one another, the magnitude of movement, or intensity of flow, over the various routings or paths is the basic measure of relative importance of each route and therefore of relative closeness of operations to one another.

Outflow of waste can be a major part of a layout handling problem. In a plastic bottle production, for example, trim amounts to forty to fifty percent of the tonnage involved. This waste material is often awkward to handle. To overlook this outflow in layout planning can be disastrous.

(2) Measures of intensity

Where materials are similar or more or less homogeneous, then units like pounds or tons, gallons or other cubic volume, or pallet loads are satisfactory measures of the magnitude or intensity of movement. The common calculation is the number of pieces moved per period times the unit of measure per piece. However, when it is necessary to convert from one unit of measure to another, when materials are quite diverse in nature and characteristics, or when there is no common container or handling unit, measurement of flow intensity is more difficult.

3.5.3 Multi-product Process Chart

When there are three or four items to be charted, it is best to make an operation process chart for each one. But when the number of charts becomes many say six to ten, depending on the nature of the products—it is better to use the multi-product process chart, especially if there is no assembly work.

The multi-product process chart brings all items together on one sheet of paper so they can be pictured easily. It lists, down the left side of a sheet, the operations through which the various items pass. Across the top, side by side and each in a separate column, are listed the various products or items involved. This pre-establishes each operation line. The routing of each item is then traced through the pre-identified operations.

3.5.4 Grouping or Selecting

When the number of items involved reaches somewhere around thirty to fifty, some form of grouping or selecting becomes practical.

By combining all or certain items which are alike in design, the planner may have a group with a common or reasonably distinct routing sequence. Items which are alike in process equipment frequently follow the same routing. Seek out these groups by classifying like designs in the former case. For example, similarities in dimension, shape, chemical, or other characteristics, and, in the latter case, by looking for items which begin or end at the same operation or which pass through certain key operations.

It may then be possible to go back and apply the techniques of the operation process chart or multi-product process chart to the flow problem for the group.

Analyses of this kind lead to group-production layouts. Group production is neither line production nor layout by process, but a combination of the two, which retains the advantages of reduced handling and production supervision and control, yet does not cause too much loss of equipment utilization.

Because there is a chance for error in a small sample, it is often better to select "worst-condition" items. Such a selection rests on the precept that if a layout can handle the worst items, it can handle all of them. Therefore, a selection is made of three to five of the items which rate worst in each or several of the following characteristics:

(1)	Heaviest	Most awkward to handle
(2)	Largest	Items with most operations
(3)	Bulkiest	Greatest quantity
(4)	Most fragile	Worst quality problems
(5)	Most hazardous	Most customer complaints
(6)	Costliest	Worst scrap or spoilage record

Selecting items like this oversimplifies the analysis problem since a few rather than all the items involved in the project are considered. Still, sometimes it is a highly practical way to go.

3.5.5 The From-to Chart

Grouping or selecting gives way to the from-to chart when the products, parts, or materials under study are very numerous. The from-to chart is sometimes called a cross chart, and when distance is added to the values, it is termed a travel chart.

After all items have been recorded, the letters or quantities in each box are totaled and the total recorded there. This number, then, represents the degree of traffic flow between each pair of operations or work centers.

The box recordings can be checked by adding down each column and across each line. An error has usually been made if the number of moves into an operation or work center does not equal the number of moves out of that operation or work center.

However, the line totals may not match column totals when more meaningful measures of flow intensity are actually used.

For accuracy's sake, a relative-value chart, using quantity times size or weight or volume of the item for each incidence of movement, should be made. Intensity of flow figures based on realistic quantitative measures are entered in the from-to chart in the manner described above. Usually, the intensity measures for all moves or transports from one activity to another are tallied and the final figure posted on the chart. With the relative-value chart, the planner can see more clearly which activities should be close to one another and how they should be arranged for optimum flow. In the calculation of this data for each box, separate tally sheets or punched cards can be of real value.

At preparing the chart, it is helpful to list all operations or functions involved and to keep the same sequence down the page and across the top. Consistency should prevail, even though nothing may actually come from Shipping, for example, to the operating work centers. It helps to find the correct box and to avoid errors in posting. Moreover, a diagonal line drawn through box 1-1, 2-2, 3-3, etc., will consistently divide the from-to's and the respective to-from's.

If the listing of operations on horizontal lines and vertical columns happens to be in best sequence, then the figures above a diagonal from upper left to lower right corners represents moves toward completion. Figures in boxes below the diagonal show counterflow.

The total traffic or flow between any two activities or work centers is found by adding both the from-to and to-from values for this pair of activities.

Each combination of from-to plus to-from represents a relationship, or relative closeness desired, between the particular pair of operations or activity-areas.

There are various aids to interpreting the chart, once it is made. The boxes are ranked, based on the intensity of flow, starting with the largest and proceeding to the smallest flow. These numbered boxes indicate the order of the most important relationships. Another aid is calculating and recording the percentage-of-total flow intensity that each box accounts for, which yields a measure of the relative importance of the flow between each operation or work center and all others.

3.5.6 Converting Flow of Materials to Simple Convention

Because of the difficulty and time required to compare and visualize a great many numerical values, SLP converts its flow-of-materials intensities into a common rating system. The rating conventions are:

(1) A Abnormally high intensity of flow

(2) E Especially high intensity of flow

(3) I Important intensity of flow

(4) 0 Ordinary intensity of flow

(5) U Unimportant moves of negligible intensity

By grouping his quantified flow-of-materials intensities into this vowel letter scale of values and its cross-indexed number of lines convention, it can more readily find and work with the flow data. He can add a minus sign to each vowel letter (A, A-, E, E-, I, I-, 0, 0-) to give himself half degrees of flow intensity. Mathematically, this gives him a range of accuracy of plus-or-minus six-and-a-quarter percent (±6.25%), which is usually well within the accuracy of the method or unit of measurement of the materials being moved or of the forecast quantities on which the flow-of-materials intensity numbers are calculated (that is, on the P and Q input data).

Converting to the vowel letter convention is a fairly simple problem of calibrating

(1) Identify each route by activity-areas serving as the origin and destination of the move. Always keeping lowest number at left.

(2) Complete a common denominator measurement for the total flow of material, all products or materials in both directions, for each route or pair of activity-areas.

(3) Rank, in descending order of magnitude, the flow intensity for each route.

(4) Plot the intensity of each route on a bar chart or graph.

(5) Divide the bars at logical break points, recognizing that the A's may bracket perhaps only 10% of the highest routes (but the top 40% of intensity values) and that the 0's may bracket intensity values of perhaps only 10% of the largest value (but the lowest 40% of the routes).

(6) Draw division lines to indicate the range of vowel letter ratings, using minus-sign ratings for degrees of flow intensity in between full vowel letters if appropriate.

With these five ranges, or classes, A, E, I, 0, U, of flow intensity—nine if half degrees (minus-sign ratings) are used—each route is put into a simple, realistic, order-of magnitude relationship, ready for subsequent use in comparing closeness desired among the various activity-areas.

3.6 Other-Than-Flow Relationships

In most industrial plants the emphasis is commonly placed on flow of material as the basis for layout arrangement. This has been fully discussed. A flow pattern is determined and diagramed and the rest of the activities are then fitted in and around that pattern. Actually, this is not the best practice as a general rule for layout procedure.

3.6.1 Flow Alone Not Best Basic for Layout

There are several reasons that the flow of material—as determined predominantly by the routing—cannot be the sole basis for layout arrangements.

(1) The supporting services must integrate with the flow in an organized way. This integration results from total analysis-analysis of the reasons that certain supporting activities should be close to certain producing or operating areas. The maintenance crib, the superintendent's office, the locker and rest room, and the transformer bank, all have a relatively preferred closeness to each of the producing areas. They are all part of the layout; they must be planned into it, yet they are not part of the flow materials.

(2) Frequently, flow of material is relatively unimportant. In some electronic or jewelry plants, only a few pounds of material will be transported during an entire day. In other industries, materials are piped, or one skid-load lasts a worker all week.

(3) In completely service industries, office area, or maintenance-and-repair shops, there is often no real or definitive flow of material. Therefore, any general rule must offer a way of relating areas to one another without reference to material flow. And this is true even if we recognize that paper work, equipment, or even people can be considered as the "material" that flows.

(4) Additionally, in heavy materials-movement plants, where the influence of material flow will dominate the layout planning, flow will not be the sole basis for arranging the process operations and equipment. Basically, we chart flow to determine the sequence of operations or which departments should be near one another. But flow of materials is only one reason for this

closeness. There are many others, which may conflict with or at least cause adjustments in the closeness as based on the analysis of flow. The effect of factors like these and the distribution of utilities, the cost of controlling quality, product contamination, and the like must be compared with the importance of material flow and adjustments made as practical.

In any case, some systematic way of relating service activities to one another and of integrating supporting services with the flow of material is necessary. The Relationship Chart is the best method of meeting this need.

In the SLP pattern of procedures, Flow-of-Materials Analysis is based on P, Q, and R. Activity Relationship Analysis draws on P, Q, and S. T (time is involved in both, as in all analyses to some extent.

3.7 The Relationship Chart (Muther 1961)

The relationship chart is a cross-section form where the relationship between each activity (or function or area) and all other activities can be recorded.

The relationship chart shows which activities have a relationship to others. Also, it rates the importance of the closeness between them and supports the rating with coded back-up reasons. These measures make the relationship chart one of the most highly practical and effective tools available for layout planning. It is undoubtedly the best way of integrating supporting services with the operating or producing departments and of planning the arrangement of office or service areas having little or no flow of materials.

The chart itself is almost self-explanatory. Where the activity on down-sloping line 1 intersects the activity represented by up-sloping line 3, the relationship between activity 1 and activity 3 is recorded. In this way, there is an intersecting "box" for each pair of activities involved. The basic idea is how to show which activities should be located close together and which far apart, with all in-between relationships also rated relatively and recorded.

The chart can be likened to a from-to chart which has been folded diagonally so that the from-to and the to-from boxes fall on top of each other. The relationship chart thus shows the total relationship, i.e., in both directions.

The word 'Activity" is a universal term, to designate "things" (other than people and process material) to be located as part of the layout planning. It encompasses, at different levels of planning or in different situations: department, area, function, work center, building, building feature, machine group, operation, and the like.

Closeness is rated according to a value scale A, E, I, 0, U, and X. A indicates closeness absolutely necessary; X indicates closeness is undesirable and the activities should be kept apart. A, E, I, 0, and U each indicate varying degrees of closeness.

3.7.1 The Selection of Vowel Letters

The vowel letters used for closeness rating have been selected with considerable thought.

(1) The letters themselves have meaning. A is for Absolutely necessary; E is for Especially important; I for Important; 0 for Ordinary closeness; U for Unimportant; and X, the accepted symbol for wrong, stands for a negative degree of closeness—not desirable.

(2) A, E, I, 0, and U are vowels most people have memorized in sequence and therefore, easy to remember in the closeness-rating context.

(3) Numbers were not chosen because they imply an accuracy greater than the rating actually has. Moreover, numbers are used to code the reasons and identify the activities. It would confuse the chart to use them also for rating.

3.7.2 Color-coding

Recording ratings and reasons should be done in pencil. But, because letters or symbols become confusing when used in profusion, the charted information can be more readily applied if the ratings are flagged in color. Therefore, each box on the chart should be re-marked with a coded color. The SLP conventions include the following color code:

(1) A - red

(2) E - orange or yellow

(3) I - green

(4) 0 - blue

(5) U - uncolored

(6) X - brown

These colors follow the order of the spectrum so their sequence is easy to remember.

This color coding is done after the original recording in pencil, which saves shifting pencils while making the chart yet allows color to simplify the problem of "reading" the assembled data.

For ease in marking the colors and in reading the chart, and since color represents closeness ratings, not reason(s), the colors are used only in the upper half of each box. Also, in order not to obscure the letter rating already indicated, the colors are drawn in, in three straight lines along the inside edge of each upper-half triangle. The planner may wish to check back on the letter rating; or he may have explanation reference—note letters, asterisks, or other information in the upper half of the box that should not be obscured. And from a practical standpoint, it is much easier to read a photo-reproduced chart if the original pencil letters are clear.

In most projects, nearly half the boxes will have a value of U. To save time and maintain clarity, the planner does not color the "unimportance," although it can be done. However, so as not to overlook any box, always indicate it has been considered by marking a U in the upper half of the appropriate box. This ensures that all relationships have indeed been considered.

3.7.3 SLP Procedure

In practice, the SLP procedure most often calls for the following general sequence of steps:

(1) Develop the intensities of flow for the operating activities.

(2) Rate or classify the intensities between each pair of activities into groupings:

(a) Abnormally high intensities A

(b) Especially high intensities E

(c) Important intensities I

(d) Ordinary intensities 0

(e) Unimportant or negligible intensities U

(3) Then develop a relationship chart for all the service or other-than-flow factors.

(4) Join the flow and other-than-flow ratings and make a combined relationship chart.

When there is no significant flow of material, as in many offices or service areas, no flow-of-material analysis is necessary, and all activities are related to one another only through the relationship chart. The method followed depends on the relative importance of flow of materials versus other-than-flow factors.

3.8 Space Determinations

Once the geographic arrangement of the various activities involved is worked out, the planner must establish the space for each activity. The space, or area, is then fitted to the activity relationship diagram in a Space Relationship Diagram the step 6 in the SLP.

3.8.1 Space Requirements

Basically, there are five ways in which to determine space requirements. Each has its place; all may even be used on the same project. Different methods of determining space requirements tend to check each other, thereby giving more credence to the figures. Moreover very precise methods of space determination may be suitable or required when fixed investment is large. Conversely, in the planning of warehouses or general office areas, there is somewhat less at stake, and accurate details may be more of an exercise in mental gymnastics than of practical use.

The five chief ways of determining space requirements include:

(1) Calculation

(2) Converting

(3) Space standards

(4) Roughed-out layout

(5) Ratio trend and projection

These are arranged generally in the order of greatest accuracy, and probably also in the order of most frequent use.

3.8.2 Machinery and Equipment Inventory

Before the calculation method of determining space requirements can be used, the machinery and equipment involved in the project must be identified. In addition to a record of machinery and equipment, it is highly useful to have a classification system for the equipment. This is generally set up by equipment type, thereby establishing a filing system. At the same time; this allows cross-filing by departmental areas or activities. There are many systems of classification available, and no simple one is universally used. We recommend a letter prefix indicating the class of equipment followed by a numerical system, with suffix letters as appropriate.

Prefix letter(s) indicating the general class or type of machinery or equipment:

(1) W—welding equipment; P—positioners; C—cutting torches and equipment;

(2) L—Lathes Numbers indicating subtype of equipment: Wl-DC arc welders floor mounted; W6—spot welders; W8—gas welding equipment

The classification described above refers only to type of equipment, not identification of a particular piece of machinery or equipment. To identify specific items of equipment an identification or "tag" number should be assigned each.

3.8.3 Calculation Method of Determining Space

The calculation method of determining space requirements is generally the most accurate. It involves breaking down each activity or area into the subareas and individual space elements that make up its total space.

First, determine the amount of area for each space element, then multiply by the number of elements required to do the job, and add any extra space not generally apportionable to any of the elements.

Each element of machinery and equipment is listed and data recorded for the area occupied by the equipment itself, for the operator's work and maintenance area, and for material set-down area-all built into a total area per machine or piece of equipment.

To calculate the number of machines or pieces of equipment needed on any project, the operation times for each part number, the number of pieces per year or per period, and allowances for downtime, scrap, and the like, must be known.

3.8.4 The Converting Method of Space Determination

A second method of determining space requirements is known as the converting, or factoring, method: establishing what space is being occupied at the present time and converting it to what will be required for the proposed layout. This conversion is usually a matter of logic, best estimate, or educated guess.

In using the converting method there is a great temptation merely to jump directly from "what we have now" to "what we anticipate needing." Do not be drawn into this trap. The layout planner must be more discriminating. Adjust the existing space to what is actually needed now and then convert it for each individual area.

It is not uncommon to calculate space requirements for manufacturing areas and then use the converting method for establishing supporting service and storage areas.

3.8.5 Space Standards

The use of pre-established space standards is a practical way to determine requirements for many projects. Basically, once the area requirements for a given machine or space element are established, the planner should be able to use that figure over and over again.

In actual practice, however, this does not always work. In fact, there is great danger in adopting the standards established by someone else unless the planner understands what is involved in the space element, what the working conditions are—or are anticipated to be—and how to refer to and get access to the back-up data underlying the establishment of the standards.

3.8.6 Roughed-out Layout

In some layout projects, calculating or converting is impractical, and no standards are available. If a scale plan of the area is available, if templates or models of the equipment involved are already on hand, and particularly if certain activities are critical or represent very high investment, it may be advisable to rough out detail layouts of certain areas and use them for space requirements. This preliminary detail planning is a perfect example of phases' overlapping here Phase II into Phase III. This method of space determination is expected to be used for critical areas of high investment, relatively fixed equipment, large machinery, or multiple work stations that should line up (as a conveyorized assembly line). What's more, both management and operating supervisors have more confidence in the planner's space requirements when they can see an intended layout.

"Minimum area required" in square feet is established as left-right and front-back dimensions including table travel, overhang, and service doors open; plus at least 45 centimeters on three sides for cleaning or adjusting the machinery plus 60 centimeters on the operator's side.

These figures are then multiplied by a factor based on the anticipated space required for setdown space, access ways, and departmental service areas. The factor ranges from 1.3 for normal layouts to 1.8 where handling and stocking of material in the department is a real problem. The total estimated area for the department equals the sum of the minimum areas required for all the machines times the concentration-or-dispersion factor.

Almost any plant or office can set-up this kind of space standards. The organization of the data for ready reference and the estimating of the factor value are the important practical limitations to this method.

3.8.7 Ratio Trend and Projection

The ratio trend and projection method is limited to general space requirements. It is perhaps the least accurate of any of the five methods. Still, in terms of long-range planning, it may be fully adequate, especially in areas of offices and general storage, where equipment is movable, fixed investment is relatively low, and the property can be used for more than one purpose.

The ratio trend and projection method establishes a ratio of square feet to some other factor, square feet per person employed, for example, or square feet per man-hour per year.

3.8.8 Safety Consideration for Space Determination (National Safety Council: USA 1992)

There are safety aspects needed to consider during the space determination. The following factors are:

(1) The appropriate area for the aisle and the road in the plant or factory

(2) Emergency exit for the accidents such fire or natural disasters

(3) Space for the ease of maintenance.

(4) For the aspect of safety and health of the employees

The appropriate area should be big enough for the trolley or forklift can reach the machine. Here are the standard widths of the aisles.

Table 3.1. Standard Width of Aisles.

Types of work	Width of the Aisle (Meters)
One-way aisle for 2-wheel trolley	Not less than 75 centimeters
One-way aisle for 4-wheel trolley	Width of the trolley + 50 centimeters
Two-way aisle for 4-wheel trolley	Width of two trolleys + 90 centimeters
Manual pallet-lifter	1.50 meters to 2.40 meters
1-Ton Forklift	2.40 meters to 3.00 meters
2-Ton Forklift	3.00 meters to 3.65 meters
3-Ton Forklift	3.65 meters to 4.25 meters

Emergency exits are legally stated that there must be at least two different exits, each located at a different direction. The width of the exits door must be at least 1.10 meters and 1.70 meters for factory that have more than 50 employees. The employee must not be working further than 45 meters away from the nearest exits.

The distance between each machine must be at least 80 centimeters in length for the ease of maintenance and safety.

The machine should be situated as near to the source of sunlight as possible, such as, as near to the windows as possible to reduce luminaries expense. The machine should be situated within the area that the crane can work easily. Consideration of the air ventilation to reduce the heat produced by machine is also important. These should include the sound pollution in the production department. All these are the for the health and safety aspect of the employees.

3.8.9 Hazard Color Code (National Safety Council: USA 1992)

Red: Used exclusively in connection with fire prevention and fire fighting equipment.

Orange: Indicates dangerous points of machinery which can cut, crush, shock, or otherwise injure.

Yellow: The universal signal for caution. It is used most often to mark areas when there are tripping, falling, storing against, or being-caught-in-between hazards.

Green: The basic safety color. It should be used to indicate the location of first-aid equipment, gas masks, safety deluge showers, and safety bulletin boards.

Blue: A cautionary color It is a specific warning against starting equipment that is being repaired. It may be used as a general cautionary aid around such equipment as elevators, boilers, scaffolding, ladders, and so forth.

Purple: Indicates the presence of radiation hazards. Tags, labels, signs, and floor markers are made with a purple-and-yellow color combination.

Black, white, or black and white combinations: Indicate traffic and housekeeping locations such as stairways, dead ends of aisles, and the location of refuse cans.

3.8.10 Space Requirements versus Space Available

As often as not, a layout planning project is more restricted by space limitations than any other factor—except investment money. Reduced investment funds themselves usually result in reduced space available whenever modernization of buildings or new construction is involved.

Regardless of cause, the planner seldom has—and probably should not be permitted to have—all the space he wants. This means compromising or balancing what is determined as space required with what can logically be made available.

The problem of balancing space requirements against space available is really three problems:

(1) Will the total amount of space available be adequate?

(2) Will the divisions of space available, such as buildings, floors, rooms, match in amount the various areas that each department, activity organizational group required?

(3) Will the character or condition of the available space or space divisions be suitable for the work required to be done in the various areas?

Balancing total amount is usually a simple matter of adding and comparing. If the area requirements will not fit, the requirements must be trimmed or squeezed. Rather than making a single percentage reduction for all areas involved, make the required reductions in the areas where the least hurt to total company operation will result. This means rating each area in order to establish which must retain its amount and which can afford to be reduced.

To calculate the number of machines or pieces of equipment needed on any project, the operation times for each part number, the number of pieces per year or per period, and allowances for downtime, scrap, and the like, must be known.

In calculating machines required, certain precautions must be taken.

(1) Part of a machine obviously can not be purchased. Generally the planner must go to the full, or next full, machine, when a fraction of a machine is required.

(2) One hundred percent good work is not possible. We must decide how much we expect in spoilage and make an allowance in determining the number of machines.

(3) Known or anticipated capacity—reducing delays—whether due to the operator avoidable delays or to the operating practices of the plant unavoidable delays—must be incorporated, if they have not been built into the figures as a delay allowance when the operating times per piece were established.

(4) Machine utilization, due to change-over or set-ups, failure of utilities, repair, or maintenance, is an important factor in all plants and must be compensated for on an individual machine basis.

(5) Peak conditions of quantity—if not already built into the requirement figures—should be allowed for. Actually, these may vary from machine to machine, depending upon the critical nature of the operation, whether or not the work is tightly scheduled, and whether or not the work can be put on alternate machines or sent outside to subcontract shops. If the machine is

already operating on two or three shifts, the possibility of solving this problem by overtime is unlikely.

(6) In balancing production lines, the planner must account for the fact that extra machine capacity may be available for use by other areas, but that because it is segregated for use in the production line, it may not be practical to move other materials in and out of the machine.

(7) Where only a small portion of an additional machine is required, an attack on methods improvement or simplifying the job may reduce operating time sufficiently to avoid the investment in an additional machine which would be used only a small portion of the time.

3.8.11 Procedure for Determining Space

(1) Identify the activities areas or features involved, using the same numbering and terminology as for charting and diagramming.

(2) Identify the machinery and equipment involved or at least the general type of machinery and equipment—both operating and supporting.

(3) Determine for the operating activities:

    (a) The area requirements, based on the plan—for P, 0, and R, and the operating times involved.

    (b) The nature or condition required for each area of operating space.

(4) Determine for the supporting activities:

    (a) The area requirements, based on the plan—for P, 0, and S, and the times involved.

    (b) The nature or condition required for each area of the supporting space.

(5) Recap the amount and condition of the space required and balance this against the space available or possibly available.

(6) Adjust, rebalance, and refine as necessary.

3.9 Space Relationship Diagram

3.9.1 Fitting Space

In fitting space to the diagram, the planner again has the flow and/or the activity relationship alternatives. That is, he can:

(1) combine the space with the flow diagram only

(2) combine the space with the activity relationship diagram; or

(3) combine the space with a combined flow and other-than-flow relationship diagram.

The method chosen, again, depends upon the relative importance of materials flow and the relationship of supporting services.

When working from the activity relationship diagram—either service only or combined flow and other-than-flow—proceed in a similar way. Enlarge each activity symbol into its specific size, on cross-section paper, at a convenient scale. Retain the same geographical arrangement of the activity relationship diagram. Each area is adequately identified to refer to the previous charting and diagramming.

3.9.2 Method of Fitting of Spaces

This joining and fitting of the spaces involved can be done in two ways:

(1) By sketching to scale, on cross-section paper, various alternative combinations of fits and configurations of the activities involved

(2) By moving unit-area blocks of space—the actual areas being represented by an equivalent number of movable blocks.

The advantages of sketching on cross-section paper are: immediate availability; a record of each alternative tried; and a plan that can be reproduced conveniently.

The advantages of the unit-area block method, on the other hand, are: the space need be counted into blocks only once and not for each sketch; time is saved because only one coding need be marked on the blocks; and the physical replicas of space can be used to interest operating people, top management people, and others who are hesitant to look at drawings but willing to help physically manipulate "their" area.

3.9.3 Drawing of Diagram

When drawing the diagram, generally apply the following:

(1) Retain the same identifying symbols, numbers, and other conventions as used in prior charting and diagrams.

(2) Retain the same geographical arrangement as the activity relationship diagram—impose the space on top of each symbol. You will have time later to join, rotate, take the reverse image, or otherwise adjust.

(3) Spread out the activities so the relationship lines can be drawn in. You will find the diagram easier to read if you extend the relationship lines to run inside each block of space.

(4) Draw generally compact and rectangular blocks at first, except where shape is a requirement or an odd number-of-squares count makes it easier to distort the rectangle. You will shape the areas as you fit them together later.

(5) Try to avoid letting relationship lines touch areas other than the ones they connect. This practice sometimes does lead to congestion of the lines, in which case, it is best to draw them straight through another area but as dotted lines.

(6) Work in black and white, for both speed and fidelity in reproduction. When diagram is complete, make the areas stand out by coloring them in total or by edge-of-area border, or by shading with a black-and-white shading code.

SLP incorporates the use of the IMMS—approved standard for color coding and indexed with it for black-and-white shading the tincture code of heraldry.

For those unskilled in the advanced techniques of layout planning, pencils and cross-section paper are the most practical materials to use.

3.9.4 Unit-area Blocks for Space Planning

The theory of unit-area space planning is based on the concept that any space or area can be shaped into almost any form if it is divided into small enough increments or units. Any major area, department, or plant space divided into very small units of space, can be rearranged in an infinite number of ways—just as any design of wall or house can be made from the standard-size brick or building block.

Unit-area blocks are similar to areas blocked on cross-section paper except that they are generally larger, are free to move, and are heavier than paper. In using them for space planning, the procedure is as follows:

(1) Divide all areas required for various activities or departments being planned into a common basic unit of area.

(2) Prepare blocks equal in number to the areas allowed for each activity and identify the blocks by marking on them.

(3) Arrange these area units into fits and configurations based on the activity relationship diagram or space diagrams roughed out on paper based on the relationship diagram.

(4) Substitute large blocks for small and vice versa as needed or helpful, making sure not to change the space representing each activity by losing blocks or miscounting during substitutions.

Rearrange the unit-area blocks into as many layouts of the space involved as seems warranted. Much of this rearranging will be done as the modifying consideration

3.10 Multi-Story Layout

The best layout should be within the same floor. But some layout planner may face the problem of space limitation. The theory of multi-story layout is suitable for the plant layout that has more than one story high. This process will be done after the space relationship diagram has been formed.

The optimum solution is to find the alternative that the total activity area of each story is being divided as equally as possible with the least number of relationships being broken. Some layout might include the other requirements or limitations beside the relationships, which if not honored will also affect the results.

To find the optimum solution, the total activity area of each story must not exceed the given space of each story. The relationships are broken when the related activities or departments are to be separated on different floor. The requirements or limitations are not honored when the activities or departments are not situated as required. Points will given for each broken relationship and unhonored requirements. The solution with the least points is the optimum solution.

IV. IMPLEMENTATION OF SYSTEMATIC LAYOUT PLANNING

4.1 The Selection of Techniques for Developing and Analyzing Process Layout

From the production process of the factory, we can conclude that Abba Plastic is a process layout manufacturing facility.

The internal arrangement of buildings that use process layouts is usually first analyzed to determine the internal boundaries of operating departments and the external shape of the building. Operations sequence analysis, block diagram analysis, load-distance analysis, and systematic layout planning (SLP) are techniques used to develop these layouts.

We choose SLP technique because SLP is quite similar to operations sequence and block diagram analyses in both procedures and end results. The only significant difference between these approaches is that SLP allows many reasons for assigning a closeness rating between departments, whereas operations sequence and block diagram analyses allow a single reason—product or material travel per time period. From the experience the ease of production, supervision, and maintenance can help to reduce the cost in production. With the SLP technique, the company can design the plant layout that fit in every objectives of the project.

4.2 The Systematic Layout Planning Pattern

Systematic Layout Planning is an organized way to conduct layout planning. It consists of a framework of phases, a pattern of procedures, and a set of conventions for identifying, rating, and visualizing the elements and areas involved in planning a layout.

The strictly "layout planning" phases of any facilities rearrangement involve creating a general overall layout and, subsequently, a detailed layout plan for each portion of the general overall layout.

4.2.1 The Five Elements

Five elements—P (Product), Q (Quantity), R (Routing), S (Supporting Services), and T (Timing)—form the basis for layout planning.

(1) Product—By product the company means every material that is handled in the production process. Start from raw materials which consist of plastic resin and color pigment; the service items supplied such as the plastic molds, maintenance spare parts and equipment; the formed or treated parts, which is the pre-finished products; the waste in the form of plastic scraps from the production process; and the final products after going through the finishing process.

(2) Quantity—For the plastic products of the company, it is a very bulky product. The final product can be 8 times bigger than the raw materials in storage space. Therefore the volume here will be in the term of pallet loads.

(3) Routing—As mentioned in the background, the production process starts with mixing the raw material, which include the plastic resin and the color pigment. The raw materials will be mixed according to the amount of the production plan. The raw material is transferred to the machines, which will be set up by the engineers. Molds will be set up according to the customers' orders. From here, the picture is that material, man and molds are moved or transferred to the fixed position machines. Then the products are produced. The products will be transferred to the finishing department. Scraps will be transferred to the raw material process department. After the products are well finished, they will be transferred to the finished product store and are ready to be delivered.

(4) Supporting Services—Includes maintenance store room, machine repair, tool or mold shop, toilets and locker rooms, meeting rooms, raw material store (or "in area"), finished product store (or "out area).

(5) Time—This manufacturing facilities is planned for round the clock production. Which means that 24 hours a day, 7 days a week period throughout the year. The plant has to be able to support the expansion in production of at least 10 % annual growth rate within 8 years period.

4.3 Tie in of P, Q, R, S, and T

Product—Raw material that consists of plastic resin and color pigment can be calculated in the pallet load. With the present production demand, the daily pallet load of raw material is an approximate 29-pallet load. The raw material is packed in a 25 kilograms plastic bag. 1 pallet load can hold 40 plastic bags.

Mold will be transferred to the machines by the overhead crane, one mold at a time with about 20 trips a day.

There are about 100 different products in the company. We use the method of grouping according to the size of the products. There are 4 main groups used in the calculation, 1-liter container, 5-liter container, 30-liter container, and 120-liter container. All of the pre-finished products and the final products are moved by the use of 1-ton forklift. The details are as follows: 1 liter container will be packed in a 90 containers pack, 5 liter container in a 50 containers pack, 30 liter in a 12 containers pack, and 120 liter in 7 container pack. Each pallet can hold 20 packs, 14 packs, 10 packs, and 8 packs respectively. And everyday, the workers have to make approximately 7 trips, 33 trips, 49 trips, and 20 trips respectively from the production department to finishing department, and from finishing department to the finished product store.

The scrap will be put in the plastic bags which 1 pallet can hold about 20 bags and takes about 55 trips a day.

Table 4.1. Product Data.

Product	**Detail**	**Pack of**	**Pallet load**	**Trips/Day**	**Methods**
Raw Material	Plastic resin	25 kgs pack	40	29	Forklift
Supporting Service	Mold	1 Piece	1	20	Overhead Crane
	Spare parts	2 Pieces	1	2	Forklift, Pallet
Pre-Finished Product	1L	90 Containers	20	7	Pallet
	5L	50 Containers	14	33	Pallet
	30L	12 Containers	10	49	Pallet
	120L	7 Containers	4	20	Pallet
Scrap	Small Piece	1 Fill Plastic Bag	20	55	Pallet
Finished Product	1L	90 Containers	20	7	Pallet
	5L	50 Containers	14	33	Pallet
	30L	12 Containers	10	49	Pallet
	120L	7 Containers	4	20	Pallet

4.4 The From-To Chart

4.4.1 Converting Flow of Materials to Simple Convention

SLP converts its flow-of-materials intensities into a common rating system. The traditional rating conventions are:

(1) A Abnormally high intensity of flow

(2) E Especially high intensity of flow

(3) I important intensity of flow

(4) 0 Ordinary intensity of flow

(5) U Unimportant moves of negligible intensity

But we add a plus and minus sign to each vowel letter (A, A-, E+, E, E-, I+, I, I-, O+, O, O-) to increase the intensity of the flow and call it in degree of closeness. Degree 1 represents the highest intensity of flow and Degree 11 represents the lowest intensity of flow.

The degree of importance will be the same as the flow of material relationship.

(1) A is for absolutely necessary

(2) A- is for less than absolutely necessary

(3) E+ is for more than especially important

(4) E is for especially important

(5) E- is for less than especially important

(6) I+ for more than important

(7) I for important

(8) I- for less than Important

(9) O+ for more than ordinary closeness

(10) O for ordinary closeness

(11) O- for less than ordinary closeness

(12) U for unimportant, and

(13) X, the accepted symbol for wrong, stands for a negative degree of closeness-not desirable

Table 4.2. Modify Rating Conventions.

Alphabet	A	A-	E+	E	E-	I+	I	I-	O+	O	O-
Degree	1	2	3	4	5	6	7	8	9	10	11

4.4.2 Department

The plant layout has to consists of the following departments:

(1) AUX—Auxiliary : Supporting Equipment

(2) FGS—Finished Goods Store : Store of finished products

(3) FIN—Finishing Department : Process the finishing touch of the containers

(4) MAN—Maintenance Store : Store for spare parts, tools, and equipment

(5) MET—Meeting Room : Room for meeting

(6) MOD—Mold Shop : Department for repairing of machines, and molds

(7) MOS—Mold Store : Store of plastic molds

(8) OFF—Office : Department of administration

(9) PRD—Production Department : Production Area

(10) QCR—QC Room : Room for the quality test of sample products

(11) RAW—Raw Material Store : Store for plastic resin and color pigment

(12) REC—Receiving : Entrance for receiving raw materials

(13) RES—Rest room : Lavatory and lockers

(14) RMP—Raw Material Process : Process the scrap parts into used plastic resin and mixing of raw material.

(15) SAF—Safety Room : First aid room

(16) SAM—Sample Room : Store for finished product sample for quality control

(17) SHP—Shipping : Exit for the finished product for delivery

4.4.3 The Flow of Material

From the process, we estimated that the flow of raw material from the receiving to the raw material store is approximately 610 pallet loads a month. The flow of raw material from raw material store to raw material process department and from raw material process department to the production department is approximately 870 pallet loads a month respectively. And the flow of material from the production department to finishing department, from finishing department to finish goods store, and from finish goods store to shipping decks is approximately 3,270 pallet loads a month. The scrap will flow from the production department to the raw material process department approximately 1,650 pallet loads a month. The recycle material will flow from raw material process department to the raw material store approximately 300 pallet loads a month. Molds will be transferred to and from the mold store and the machines situated in the production department approximately 1,200 trips a month.

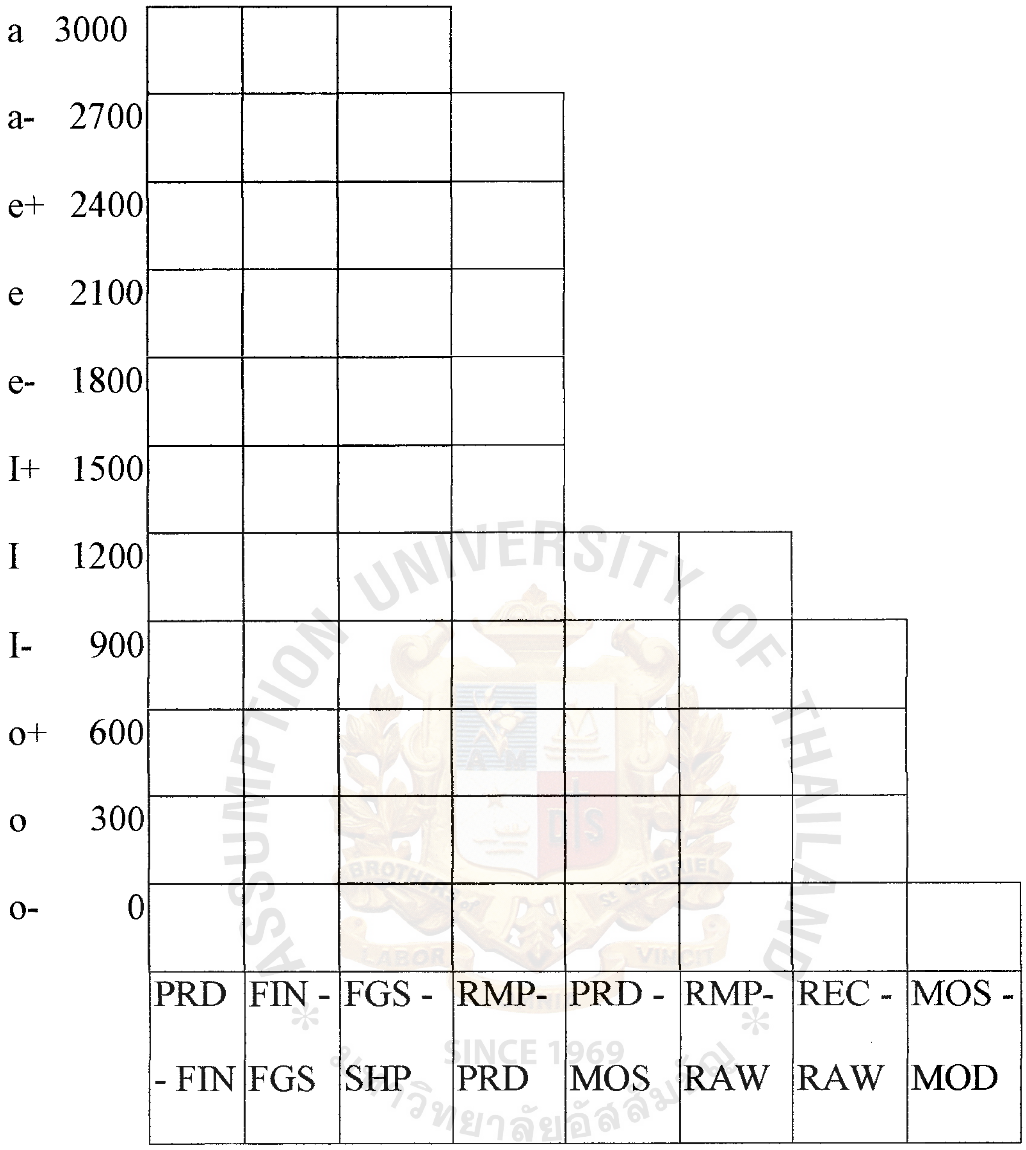


Figure 4.1. Flow of Material Rating.

4.3.4 The Other Than Flow Relationship

The Quality control room is "more than important closeness" to the production department for ease of inspection and production control. It is "important closeness" to finishing department for ease of inspection, to office for ease of production control, to meeting room for ease of coordination. It is "less than important closeness" to sample store for ease of production control. It is "more than ordinary closeness" to mold shop for ease of inspection, and to safety room for safety. It is "ordinary closeness" to raw material store and raw material process department for ease of inspection.. It is "less than ordinary closeness" to the rest room for fringe benefits.

The production department is "important closeness" to maintenance store, and auxiliary for ease of maintenance, to meeting room for ease of coordination, and to safety room for safety. It is "more than ordinary closeness" to the office, mold store, and sample room for the ease of production control. It is "less than ordinary closeness" to the rest room for fringe benefits.

The meeting room is "important closeness" to the finished goods store, and office for ease of coordination. It is "ordinary closeness" to the mold shop and finishing department for ease of coordination and to rest room for fringe benefits. It is "less than ordinary closeness" to sample room, raw material store, and raw material process department for ease of coordination and to safety room for safety.

The raw material process department is "more than ordinary closeness" to the raw material store for ease of production and to safety room for safety. It is "ordinary closeness" to the maintenance store for ease of maintenance. It is "less than ordinary closeness" to rest room for fringe benefits. And it is "not desirable closeness" to the office because of the noise problem.

The mold store is "important closeness" to the mold shop for the ease of production control. It is "ordinary closeness" to the maintenance store for ease of maintenance.

The finished good store is "important closeness" to the office for ease of logistic control. It is "more than ordinary closeness" to the safety room for safety. It is "less than ordinary closeness" to rest room for fringe benefits.

The finishing department is "more than ordinary closeness" to the safety room for safety. It is "ordinary closeness" to the maintenance store for ease of maintenance. It is "less than ordinary closeness" to rest room for fringe benefits.

The safety room is "more than ordinary closeness" to the raw material store, maintenance store, office, and mold shop for safety. It is "less than ordinary closeness" to rest room for fringe benefits.

The rest room is "less than ordinary closeness" to maintenance store, office, sample store, and moldshop for fringe benefits.

4.3.5 Combined Relationship

The rating of the flow of material and the other than flow are combined into the combined relationship chart.

Here is the summary of the relationship of each department.

Production department is "absolutely necessary closeness" to the finishing department for the flow of material. It is "less than absolute necessary closeness" to the raw material process department for the flow of material. It is "especially important closeness" to the mold store for the flow of material and the ease of production control. It is "more than important closeness" to the quality control room for the ease of inspection and production control. It is "important closeness" to maintenance room and auxiliary for ease of maintenance, to meeting room for ease of coordination, and to safety room for safety. And it is "more than ordinary closeness" to office and sample room for ease of production control.

Quality control room is "important closeness" to finishing department for ease of inspection, to office for ease of production control, and to meeting room for ease of coordination. It is "less than important closeness" to sample room for ease of production control. It is "more than ordinary closeness" to mold shop for ease of inspection and to safety room for safety. It is "ordinary closeness" to raw material store and raw material process department for ease of inspection. And it is "less than ordinary closeness" to rest room for fringe benefits.

Finished goods store is "absolutely necessary closeness" to the finishing department and shipping deck for the flow of material. It is "important closeness" to meeting room for ease of coordination and to office for ease of logistic control. It is "more than ordinary closeness" to safety room for safety. It is "less than ordinary closeness" to rest room for fringe benefits.

Raw material process department is "less than especially important closeness" to the raw material store for the flow of material and the ease of production control. It is "ordinary closeness" to maintenance room for ease of maintenance. It is "less than ordinary closeness" to meeting room for ease of coordination. It is "more than ordinary closeness" to safety room for safety. It is "less than ordinary closeness" to rest room for fringe benefits. And it is "not desirable closeness" to the office because of the noise problem.

The meeting room is "important closeness" to office for ease of coordination. It is "ordinary closeness" to the mold shop and finishing department for ease of coordination and to the rest room for fringe benefits. It is "less than ordinary closeness" to sample room and raw material store, for ease of coordination, and to safety room for safety.

Mold store is "more than important closeness" to the mold shop for the flow of material and ease of production control. And it is "ordinary closeness" to maintenance room for ease of maintenance.

Raw material store is "less than important closeness" to the receiving deck for the flow of material.

The finishing department is "more than ordinary closeness" to safety room for safety. It is "ordinary closeness" to the maintenance store for ease of maintenance. It is "less than ordinary closeness" to rest room for fringe benefits.

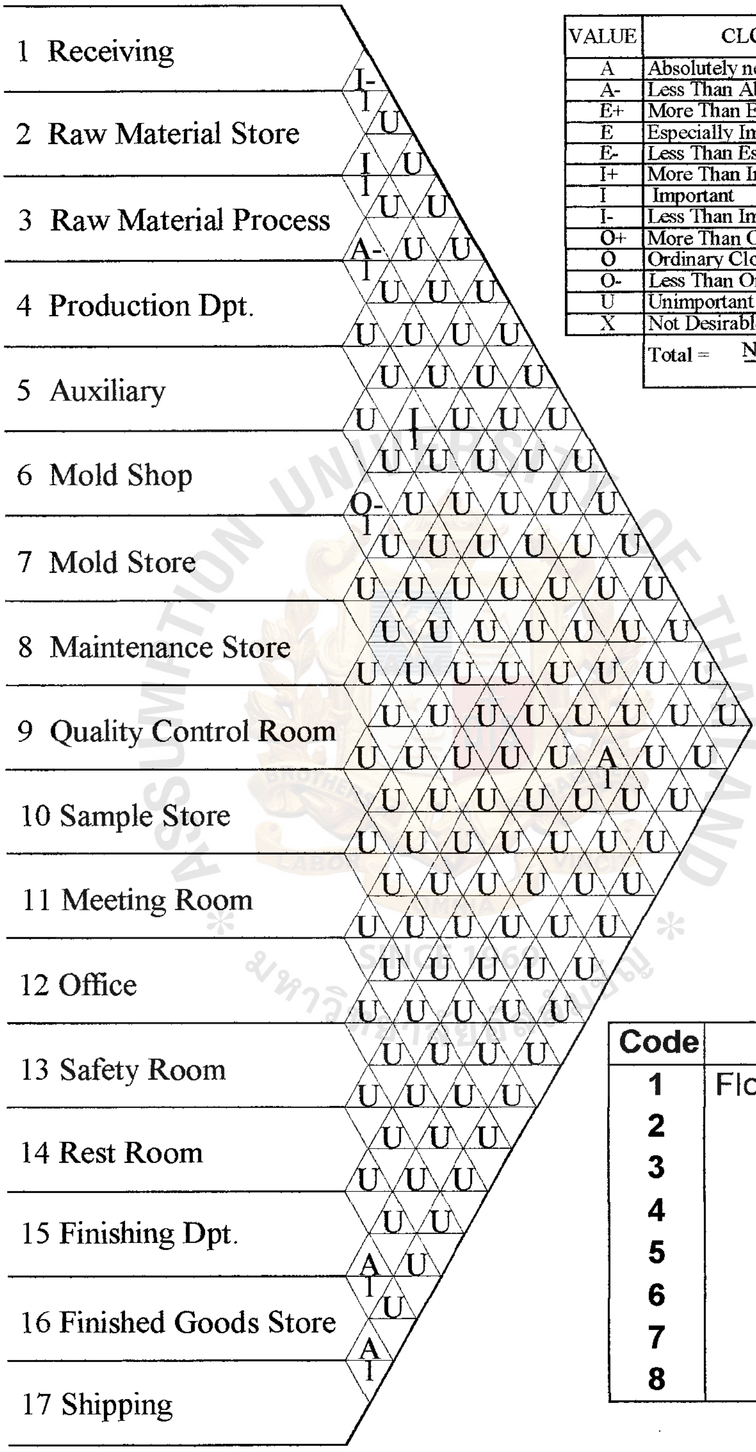
The mold shop, maintenance store, and the sample store are "more than ordinary closeness" to safety room for safety. They are "less than ordinary closeness" to rest room for fringe benefits.

The auxiliary is "not desirable closeness" to the office because of the noise problem.

Relationship Chart

Plant(Company) CTP
Charted by T.C.
Date 21 May 2000
Reference Flow of Materials

Project New Plant Layout
With etal.
Sheet 1 **of** 3



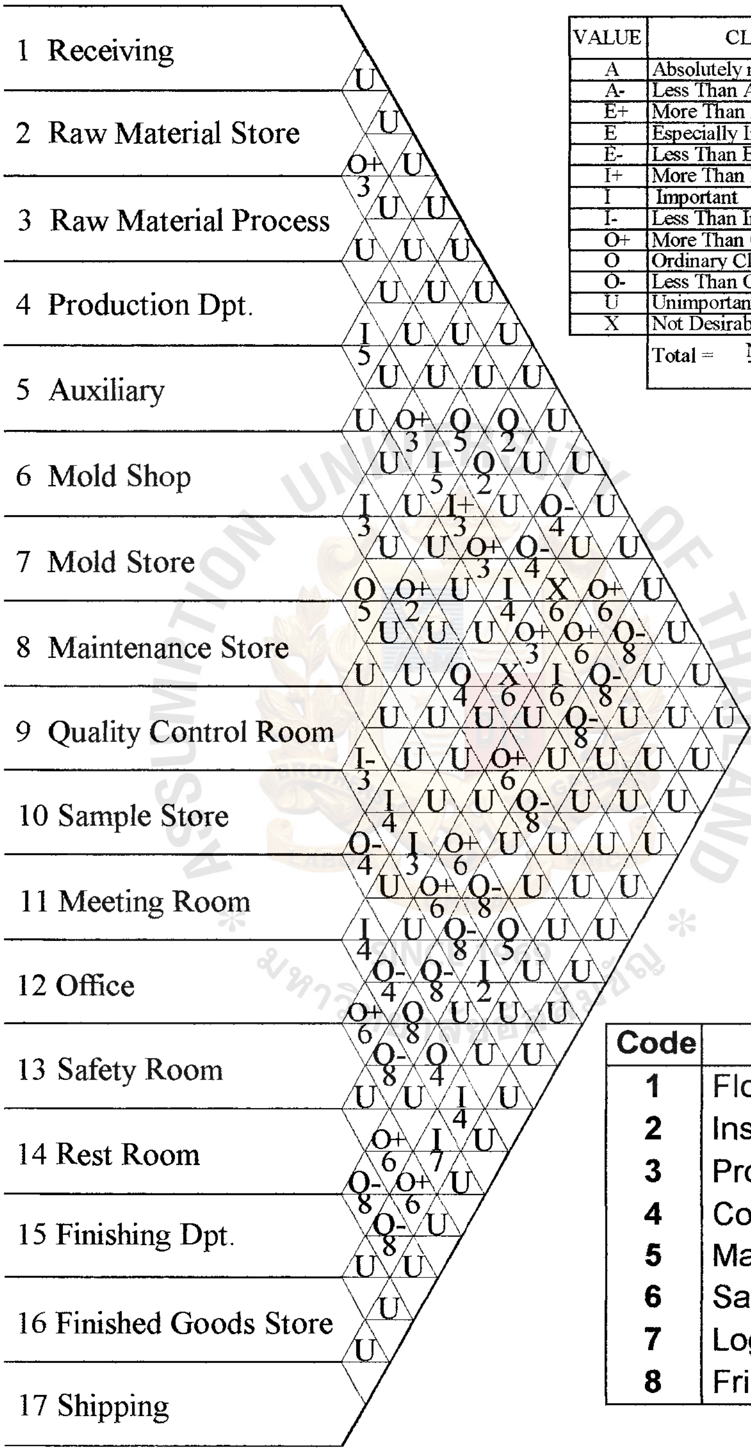
VALUE	CLOSENESS	No. of Ratings
A	Absolutely necessary	3
A-	Less Than Absolutely necessary	1
E+	More Than Especially Important	0
E	Especially Important	0
E-	Less Than Especially Important	0
I+	More Than Important	0
I	Important	2
I-	Less Than Important	1
O+	More Than Ordinary Closeness	0
O	Ordinary Closeness	0
O-	Less Than Ordinary Closeness	1
U	Unimportant	128
X	Not Desirable	0
	Total = $\frac{N*(N-1)}{2}$ =	136

Code	Reason
1	Flow of Materials
2	
3	
4	
5	
6	
7	
8	

Figure 4.2. Flow of Materials.

Relationship Chart

Plant(Company)	CTP	**Project**	New Plant Layout
Charted by	T.C.	**With**	etal.
Date	21 May 2000	**Sheet**	2 **of** 3
Reference	Other- than- flow		



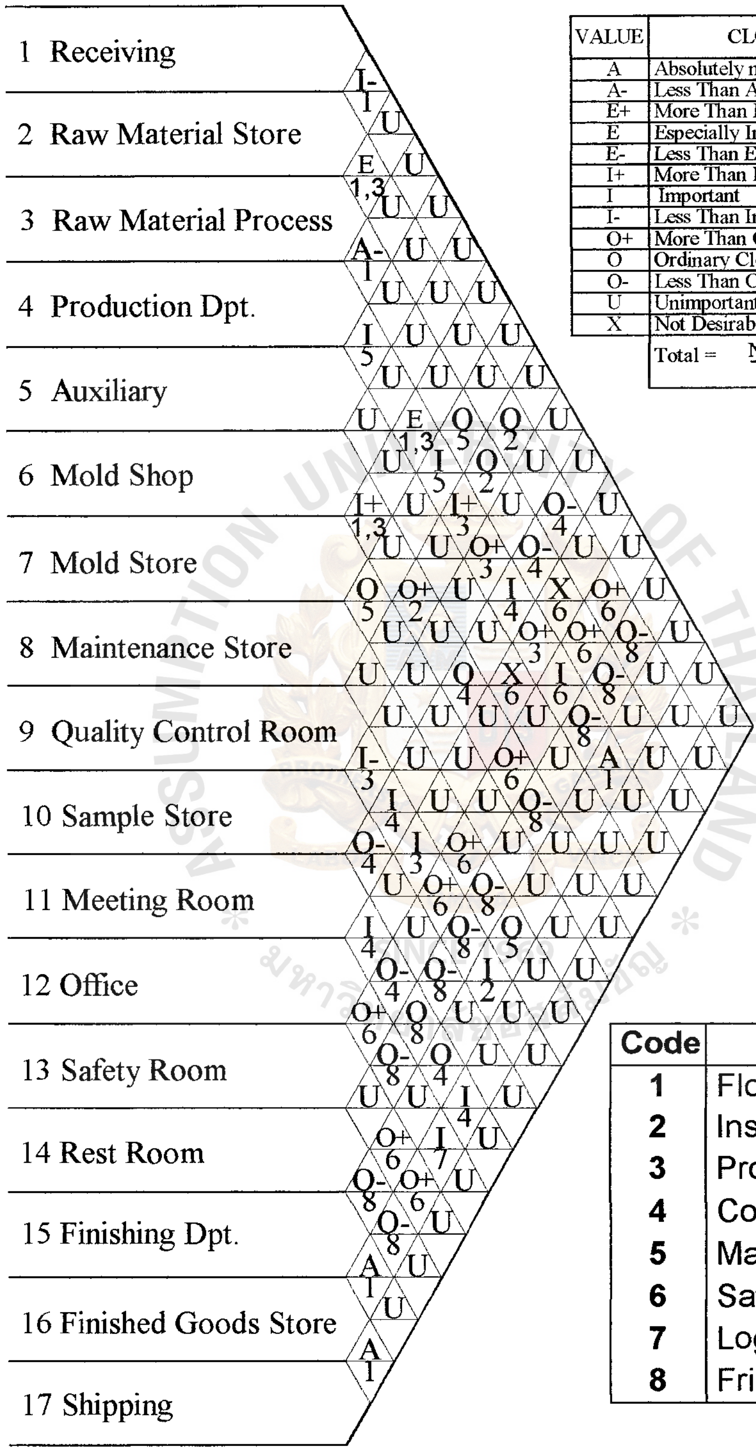
VALUE	CLOSENESS	No. of Ratings
A	Absolutely necessary	0
A-	Less Than Absolutely necessary	0
E+	More Than Especially Important	0
E	Especially Important	0
E-	Less Than Especially Important	0
I+	More Than Important	1
I	Important	11
I-	Less Than Important	1
O+	More Than Ordinary Closeness	13
O	Ordinary Closeness	8
O-	Less Than Ordinary Closeness	14
U	Unimportant	86
X	Not Desirable	2
	Total = $\frac{N*(N-1)}{2}$ =	136

Code	Reason
1	Flow of Materials
2	Inspection
3	Production Control
4	Coordination
5	Maintenance
6	Safety
7	Logistic Control
8	Fringe Benefit

Figure 4.3. Other Than Flow.

Relationship Chart

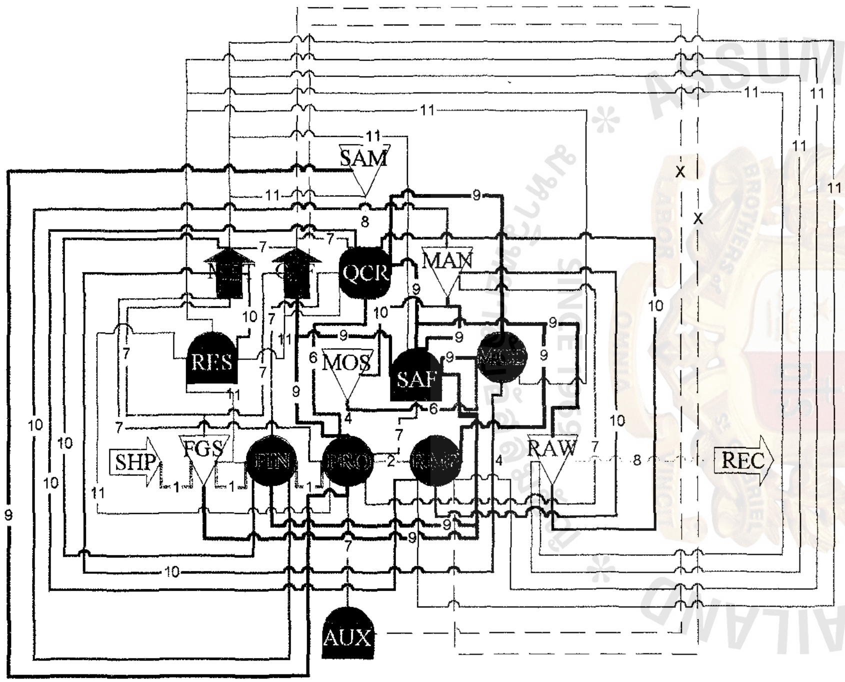
Plant(Company)	CTP	**Project**	New Plant Layout
Charted by	T.C.	**With**	etal.
Date	21 May 2000	**Sheet**	3 **of** 3
Reference	Combined		



VALUE	CLOSENESS	No. of Ratings
A	Absolutely necessary	3
A-	Less Than Absolutely necessary	1
E+	More Than Especially Important	0
E	Especially Important	2
E-	Less Than Especially Important	0
I+	More Than Important	2
I	Important	10
I-	Less Than Important	2
O+	More Than Ordinary Closeness	11
O	Ordinary Closeness	8
O-	Less Than Ordinary Closeness	14
U	Unimportant	81
X	Not Desirable	2
	Total = $\frac{N*(N-1)}{2}$ =	136

Code	Reason
1	Flow of Materials
2	Inspection
3	Production Control
4	Coordination
5	Maintenance
6	Safety
7	Logistic Control
8	Fringe Benefit

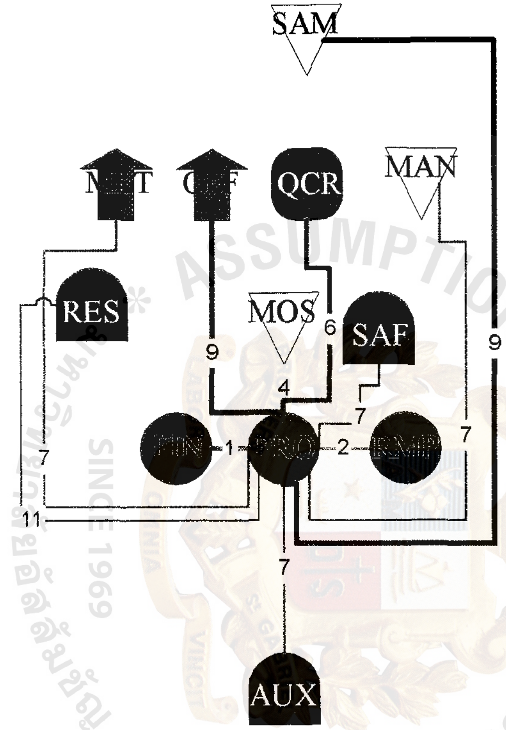
Figure 4.4. Combined Relationship Chart.



VALUE	CLOSENESS	Degree
A	Absolutely necessary	1
A-	Less Than Absolutely necessary	2
E+	More Than Especially Important	3
E	Especially Important	4
E-	Less Than Especially Important	5
I+	More Than Important	6
I	Important	7
I-	Less Than Important	8
O+	More Than Ordinary Closeness	9
O	Ordinary Closeness	10
O-	Less Than Ordinary Closeness	11
U	Unimportant	0
X	Not Desirable	X

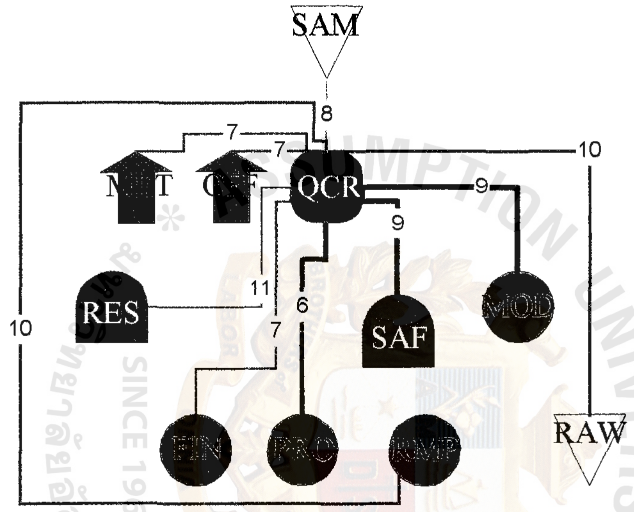
Symbol	A	A-				I+	I	I-	O+	O	O-	X
Degree	1	2	3	4	5	6	7	8	9	10	11	x

Figure 4.5. Activity Relationship Diagram.



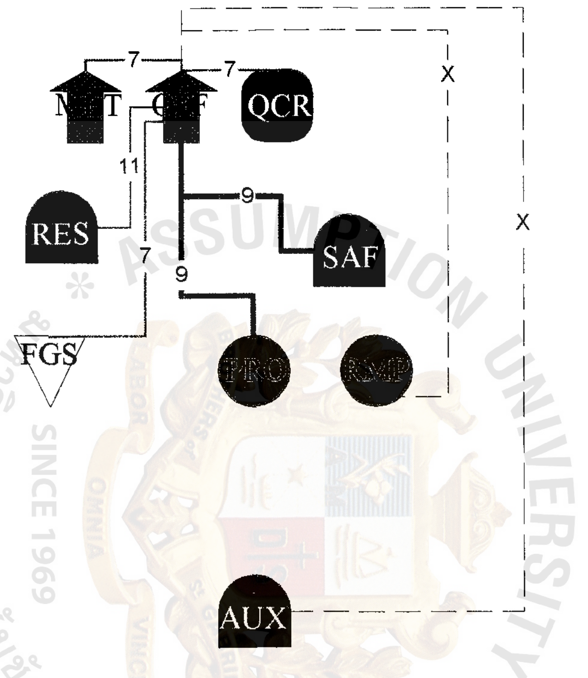
Symbol	A	A-				I+	I	I-	O+	O	O-	X
Degree	1	2	3	4	5	6	7	8	9	10	11	x

Figure 4.6. Activity Relationship Diagram for Production Department.



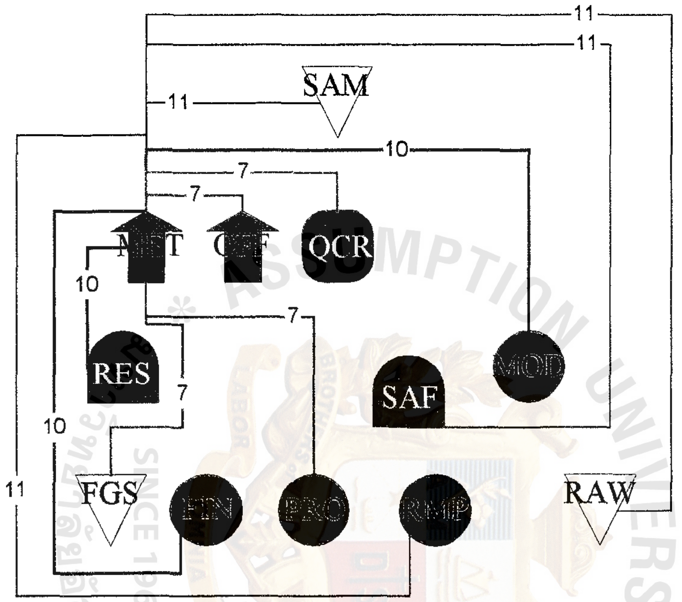
Symbol	A	A -				I+	I	I-	O+	O	O-	X
Degree	1	2	3	4	5	6	7	8	9	10	11	x

Figure 4.7. Activity Relationship Diagram for Quality Control Room.



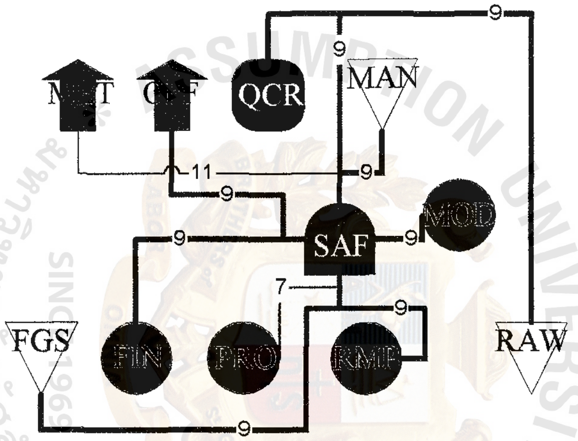
Symbol	A	A -				I+	I	I-	O+	O	O-	X
Degree	1	2	3	4	5	6	7	8	9	10	11	x

Figure 4.8. Activity Relationship Diagram for Office.



Symbol	A	A	-			I+	I	I-	O+	O	O-	X
Degree	1	2	3	4	5	6	7	8	9	10	11	x

Figure 4.9. Activity Relationship Diagram for Meeting Room.



Symbol	A	A-				I+	I	I-	O+	O	O-	X
Degree	1	2	3	4	5	6	7	8	9	10	11	x

Figure 4.10. Activity Relationship Diagram for Safety Room.

4.5 Space Requirements

Basically, there are five ways in which to determine space requirements. The five chief ways of determining space requirements include calculation, converting, space standards, roughed-out layout, and ratio trend and projection.

These are arranged generally in the order of greatest accuracy, and probably also in the order of most frequent use.

4.5.1 Calculation Method of Determining Space

The calculation method of determining space requirements is generally the most accurate. It involves breaking down each activity or area into the subareas and individual space elements that make up its total space.

There are 4 main sizes of blow molding machine, 1.500-liter machine, 5-liter machine, 30-liter machine, and 120-liter machine. The blow molding machines are the main production machines. The machines used in the raw material process department are the mixer and the grinder. The mixer is used to mix the two raw materials, the plastic resin, both new and recycle, and the pigment. The grinder is used to grind the scrap or defect part into small pieces that is about the same size as the new plastic resin. The other machines are the lathes and the milling machines use in the mold shop for mold making, repair, and maintenance. The forklift, the crane, and the finishing machines, which are used to level the opening of the containers.

(1) Space determination

Here is the data for the machine footprint.

Table 4.3. Machine Footprint.

Machine	Type	Number of	Width (Meter)	Length (Meter)	Height (Meter)
Blow Molding	1.5 Liter	7	2.10	2.90	2.35
	5.0 Liter	15	2.70	3.75	2.70
	30 Liter	12	2.70	4.60	3.00
	120 Liter	2	4.20	6.20	5.00
Granulator	1/2 Ton	4	2.50	3.00	2.00
Mixer	2 Ton	6	3.00	3.00	2.10
Cooling tower	100 Ton	2	3.45	1.95	2.60
Chiller	100 Hp	2	2.95	3.95	1.90
Air compressor	60 Hp	4	1.76	0.70	0.99
MDB		2	4.30	1.00	2.20
DB		4	2.30	0.70	2.00
Milling		4	2.00	2.30	2.30
Lathe		8	1.60	2.80	1.50

Table 4.4. Office Equipment Footprint.

Office	Type	Number of	Width (Meter)	Length (Meter)	Height (Meter)
Table	1	42	0.75	1.20	0.75
	2	14	0.75	1.80	0.75
	3	13	1.00	3.00	0.75
Chair	1	210	0.50	0.60	0.75
Shelf	1	160	0.50	1.00	2.00
	2	20	0.80	1.50	2.00

Table 4.5. Other Equipment Footprint.

Equipment	Type	Number of	Width (Meter)	Length (Meter)	Height (Meter)
Forklift	1-2-Ton	3	1.10	2.90	2.10
Pallet	1-Ton	600	1.00	1.20	0.15
Finishing	20 cm	15	0.80	1.00	1.20
	60 cm	1	1.20	1.50	1.50
Working Table	1	34	0.80	1.00	0.65
	2	2	0.80	1.20	0.75
Mold	1.5 Liter	20	0.30	0.30	0.40
	5.0 Liter	42	0.40	0.40	0.45
	30 Liter	36	0.60	0.60	0.70
	120 Liter	6	0.80	0.80	1.20

4.5.2 Machine and Equipment Requirement Calculation

At present, the estimated monthly production demand of the 1-liter container, 5-liter container, 30-liter container, and 120-liter container are 196,000 containers, 351,000 containers, 91,000 containers, and 8,500 containers respectively.

A = number of years

Here is the example of the calculation,

$\text{Demand}_A = \text{Demand} * (1 + \text{growth rate})^{(A-1)}$

For demand of 196,000 with the growth rate of 10% per year for the next 8 years, the calculation A = 8, growth rate = 0.10, Demand = 196,000. If we apply this information into the formula, the result will be exactly 381,948.55 and rounded up to 382,000 units.

With the annual growth rate of 10%, the expected monthly production demand in the next 8 years of the 1-liter container, 5-liter container, 30-liter container, and 120-liter container will be approximately 382,000 containers, 684,000 containers, 178,000 containers, and 17,000 containers respectively.

Each machine capacity varies indirectly to the size of the machine. The machine capacity of 5-liter machine, 30-liter machine, and 120-liter machine is approximately 66,000 containers, 52,800 containers, 16,500 containers, and 9,900 containers respectively.

MAC = Machine Actual Capacity, MFC =Machine Full Capacity, DFR = Defect Rate

MAC = MFC– (MFC * DFR)

Here is the example of the calculation.

For the machine actual capacity of 1.500-liter machine with the 10% allowance of defect rate and downtime and the machine full capacity of 66,000 units, MFC = 66,000, DFR = 0.10, therefore MAC is 60,000 units.

The monthly production capacity of the 1.500-liter machine, 5-liter machine, 30-liter machine, and 120-liter machine is approximately 60,000 containers, 48,000 containers, 15,000 containers, and 9,000 containers respectively. This figure is estimated from the past data of 10% allowance of defect rate and downtime.

With the two calculations of the demand in the next 8 years and the machine's actual capacity, we can find the number of machines required by dividing $Demand_A$ by MAC. MR = Machine Required.

$MR = Demand_A / MAC$

For example $Demand_8$ of 1.500-liter machine is 382,000 units and MAC of 1.500-liter machine is 60,000, is 6.37. But you can not buy 0.37 of the machine, therefore, you have to round up to the whole figure. Therefore the number of machines required for 1.500-liter machine is 7 machines.

From the calculation, we can conclude that the total number of 1.500-liter machine, 5-liter machine, 30-liter machine, and 120-liter machine needed for the next 8 years are 7 machines, 15 machines, 12 machines, and 2 machines respectively, as shown in the Table 4.6.

The formula can be applied to all the other machines and equipment.

The Finishing machine with 20 cm width has the MFC of 95,000 units per month, and the Finishing machine with 60 cm width has the MFC of 25,000 units per month. The Finishing machines with 20 cm width are used for finishing the 1.5-lite containers up to 30-liter containers. While the Finishing machine with 60 cm width is used for finishing the 120-liter containers. From the data, the volume of the 1.5-liter containers up to 30-liter containers are 638,000 units per month and the 120-liter containers are 8,500 units per month. With the 10% growth rate, the volume will be 1,244,000 units and 17,000 units in the next 8 years respectively. With the DFR of 10%, the number of machines required for Finishing machine with 20 cm width and the Finishing machine with 60 cm width are 15 machines and 1 machine respectively, as shown in the Table 4.7.

The machines used in the raw material process department are the Granulator and the mixer. The Granulator are used to recycle scarp and defect plastic parts into reuse resin. And the mixer is used to mix the raw material, which consists of the plastic resin, reuse resin and the pigment. The volume of the recycle scrap is approximately 140 tons per month and the volume of the raw material needed to be mixed is approximately 415 tons per month. The MFC of the Granulator is 100 tons per month and the mixer is 200 tons per month. By applying these information into the formula, the volume of the recycle scrap and the raw material needed to be mixed will be 275 tons and 820 tons respectively. With the DFR of 20%, we can conclude that the number of machines required for Granulator and the mixers are 4 machines and 6 machines respectively, as shown in the Table 4.8.

Table 4.6. Machinery and Equipment Requirement Sheet in Production Department.

Identification Data			Production	Demand 8	MFC	MAC		MR
Product Identification Number	Name or Description	Function	Volume per Month (Demand)	Volume per Month A = 8	Capacity per Month (Containers)	Down Time and Defect Rate (DFR = 10%)	Number of Machine Calculated	Number of Machine Required
B1.5	Blow Machine 1.5L	Production of 1.5 liter Containers	196,000.00	382,000.00	66,000.00	60,000.00	6.37	7.00
B5	Blow Machine 5L	Production of 5 liter Containers	351,000.00	684,000.00	52,800.00	48,000.00	14.25	15.00
B30	Blow Machine 30L	Production of 30 liter Containers	91,000.00	178,000.00	16,500.00	15,000.00	11.87	12.00
B120	Blow Machine 120L	Production of 120 liter Containers	8,500.00	17,000.00	9,900.00	9,000.00	1.89	2.00

Table 4.7. Machinery and Equipment Requirement Sheet in Finishing Department.

Identification Data			Production	Demand 8	MFC	MAC		MR
Product Identification Number	Name or Description	Function	Volume per Month (Demand)	Volume per Month A = 8	Capacity per Month (Containers)	Down Time and Defect Rate (DFR = 10%)	Number of Machine Calculated	Number of Machine Required
F20	Finishing - 20 cm	Finishing of 1.5-30 liter Containers	638,000.00	1,244,000.00	95,000.00	86,363.64	14.40	15.00
F60	Finishing - 60 cm	Production of 5 liter Containers	8,500.00	17,000.00	25,000.00	22,727.27	0.75	1.00

Table 4.8. Machinery and Equipment Requirement Sheet in Raw Material Process Department.

Identification Data			Production	Demand 8	MFC	MAC		MR
Product Identification Number	Name or Description	Function	Volume(Ton) per Month (Present)	Volume per Month A = 8	Capacity per Month (Containers)	Down Time and Defect Rate (DFR = 20%)	Number of Machine Calculated	Number of Machine Required
G1	Granulator 1/2 Ton	Recycle Scrap into Reuse resin	140.00	275.00	100.00	80.00	3.44	4.00
M2	Mixer 2 Ton	Mix the Resin and Pigment	415.00	820.00	200.00	160.00	5.13	6.00

4.5.3 Machine and Equipment Area Requirement Formula

To find the total area requirement of each machine and equipment, you have to consider the footprint of the machine or equipment, the maintenance area, the operators working area, the material set-down area, and the aisles area required.

(1) Footprint

For the machine footprint, the information needed is the left-right dimensions, and the front-back dimension. FP = Footprint, L = Left-right dimension, and W = front-back dimension. Multiply L to W and you will get the footprint of the machine or equipment.

$$FP = L * W$$

For example, the 1.500-liter machine has the L = 2.10 meters, and W = 2.90 meters, therefore, the footprint of the1.500-liter machine will be 6.09 square meters.

(2) Maintenance area

For the maintenance area, each machine needs at least 80 centimeters away from the next machine, and 50 centimeters away from the wall. MA = Maintenance area. The formula for calculating the maintenance area is:

$$MA = ((L + 0.80) * 0.50) + (W * 0.40 * 2)$$

For example, the 1.500-liter machine, by applying this formula, the maintenance area will be 3.77 square meters.

(3) Operator working area

The operator working area consists of the operating equipment, which are the table, and the working area. The table sizes are 1 meter in length and 80 centimeters in width. The working area for the operators to move about is 80 centimeters in diameter. OWA = Operator working area, L_t = the table length, W_t = the table width, W_o = Operator working diameter. The formula for calculating the operator working area is:

$$OWA = L_t * (W_t + W_o)$$

For example, the 1.500-liter machine, $L_t = 1$, $W_t = 0.80$, $W_o = 0.80$, input the data into the formula, OWA = 1.60 square meters.

(4) Material set-down area

The area of material set-down area consists of the raw material, pre-finished product, and scrap. Each type of material are put in the pallet with the size of 1 meter by 1 meter. MSA = Material set-down area, RM = Raw material, PFG = Finished goods, SC = Scrap and defect products.

Therefore, the area of material set-down area formula is:

$$MSA = RM + PFG + SC$$

(5) Aisles area requirement

The aisle area requirement is calculated by the percentage of the total net area or the sum of the footprint, maintenance area, operator working area, and material set-down area. For the data, the percentage used in the department with machine and equipment is approximately 45% allowance area of the total net area.

ASL = Aisles required area,

TNA = Total net area, and

AA= Allowance Area.

The formula of calculating the ASL is:

$$TNA_M = (FP + MA + OWA + MSA)$$

$$ASL = TNA * AA$$

For example, the 1.500-liter machine, FP = 6.09, MA = 3.77, OWA = 1.6, MSA = 3, therefore, the ASL of the 1.500-liter machine is 6.51 square meters.

(6) Total area requirement

The total area requirement is the sum of TNA and ASL. TAR = Total area requirement, which formula is:

$$TAR = TNA + ASL$$

4.5.4 Machinery and Equipment Area Requirement Calculation in Each Department

(1) Machinery and equipment area requirement calculation in production department

In the production department, there are 5 different machines, the 1.500-liter machine, 5-liter machine, 30-liter machine, 120-liter machine, and the Distribution Branch. The left-right, and front-back dimensions are 2.10 meters by 2.90 meters, 2.70 meters by 3.75 meters, 2.70 meters by 4.60 meters, 4.50 meters by 6.20 meters, and 2.30 meters by 0.70 meters respectively.

The table with the size of 1 meter by 80 centimeters is used with of 1.500-liter machine, 5-liter machine, and 30-liter machine. While the 120-liter machine use the table with the size of 1.20 meters by 80 centimeters.

The raw material set-down consists of 3 types, the raw material, the pre-finished goods, and the scrap.

The number of machines required consists of seven 1.500-liter machines, fifteen 5-liter machines, twelve 30-liter machines, two 120-liter machines, and 6 distribution branches. The allowance area for the aisles is

45%. The TAR for the production department is 1,110.59 square meters, as shown in the Table 4.9.

(2) Machinery and equipment area requirement calculation in raw material process department

In the raw material process department, there are 3 types of machinery and equipment. The Granulator for recycling the scrap and the defect products, the mixer for mixing the raw materials, and the 2-Ton-forklift for material handling. The left-right, and front-back dimensions are 2.50 meters by 3.00 meters, 3.00 meters by 3.00 meters, and 1.10 meters by 2.90 meters respectively.

For this department, no operating equipment is needed, only the operators working area. The material set-down area consists of 2 types, for the pre-process materials and for the post-process materials, which both are put on the standard pallet with the dimension of 1 meter by 1 meter.

The number of machines required consists of 4 Granulator, 6 mixers, and 1 2-Ton-forklift. The allowance area for the aisles is 45%. The TAR for the raw material process department is 230.35 square meters, as shown in the Table 4.10.

(3) Machinery and equipment area requirement calculation in finishing department

In the finishing department, there are 3 types of machinery and equipment. The finishing machines with 20 cm width are use for finishing the 1.5-lite containers up to 30-liter containers, the finishing machine with 60 cm width is use for finishing the 120-liter containers, and 1-Ton-forklift for material handling. The left-right, and front-back dimensions are 0.80

meters by 1.00 meters, 1.20 meters by 1.50 meters, and 1.10 meters by 2.90 meters respectively.

For this department, also, no operating equipment is needed, only the operators working area. The material set-down area consists of 2 types, for the pre-process materials and for the post-process materials, which both are put on the standard pallet with the dimension of 1 meter by 1 meter.

The number of machines required consists of 15 finishing machines with 20-cm width, 1 finishing machine with 60-cm width, and 2 1-Ton-forklift. The allowance area for the aisles is 45%. The TAR for the finishing department is 139.43 square meters, as shown in the Table 4.11.

(4) Machinery and equipment area requirement calculation in mold shop department

In the mold shop department, there are only 2 types of machinery and equipment. The milling machine and lathe machine. The left-right, and front-back dimensions are 2.00 meters by 2.30 meters and 1.60 meters by 2.80 meters respectively.

For this department, no operating equipment is needed, only the operators working area. The material set-down area consists of 2 types, for the pre-process materials and for the post-process materials, with the dimension of not more than 50 centimeters by 50 centimeters.

The number of machines required consists of 4 milling and 8 lathe. The allowance area for the aisles is 45%. The TAR for the mold shop department is 141.69 square meters, as shown in the Table 4.12.

(5) Machinery and equipment area requirement calculation in auxiliary department

In the auxiliary department, there are 4 types of machinery and equipment. The cooling tower for cooling the water to the room temperature. This water is used for mold temperature control The chiller for reducing the water to 18 Degree Celsius, the air compressor for the generating air pressure used in the production process, and the main distribution branch for distributing the electrical supply to the distribution branches. The left-right, and front-back dimensions are 3.45 meters by 1.95 meters, 2.95 meters by 3.95 meters, 1.76 meters by 70 centimeters, and 4.30 meters by 1.00 meters respectively.

For this department, also, no operating equipment, operator working area, and material set-down area are needed. But the formula for calculating the maintenance area is slightly different. Each machine needs a spacing of 1 meter away from the other machines and the wall.

The normal formula is:

MA = ((L + 0.80) * 0.50) + (W * 0.40 * 2)

The modify formula is:

MA = ((L + 1.00) * 0.50*2) + (W * 0.50 * 2)

The number of machines required consists of 2 cooling towers, 2 chillers, 4 air compressors, and 2 main distribution branches. The allowance area for the aisles is 45%. The TAR for the auxiliary department is 152.73 square meters, as shown in the Table 4.13.

Table 4.9. Machinery and Equipment Area Sheet in Production Department.

Identification Data		Space (meters)			FP	MA	OWA	MSA			TNA
Machine Identification Number	Name or Description	Left-Right	Front-Back	Height	Area(Sq.m) for Machinery or Equipment	Maintenance Area Required	Operator(s) Work Area	Material Set-Down Area	Total Area of Machinery or Equipment	Number of Machine(s) or Equipment(s)	Total Net Area (Sq.m)
B1.5	Blow Machine 1.5L	2.1	2.90	2.35	6.09	3.77	1.60	3.00	14.46	7.00	101.22
B5	Blow Machine 5L	2.70	3.75	2.70	10.13	4.75	1.60	3.00	19.48	15.00	292.13
B30	Blow Machine 30L	2.70	4.60	3.00	12.42	5.43	1.60	3.00	22.45	12.00	269.40
B120	Blow Machine 120L	4.50	6.20	5.80	27.90	7.61	1.92	3.00	40.43	2.00	80.86
DB1	Electrical Controller	2.30	0.70	2.00	1.61	2.11	-	-	3.72	6.00	22.32
								Total			765.93
								Aisles ASL (45%)			344.67
								Total Area Required TAR(Sq.m)			1,110.59

Table 4.10. Machinery and Equipment Area Sheet in Raw Material Process Department.

Identification Data		Space (meters)			FP	MA	OWA	MSA			TNA
Machine Identification Number	Name or Description	Left-Right	Front-Back	Height	Area(Sq.m) for Machinery or Equipment	Maintenance Area Required	Operator(s) Work Area	Material Set-Down Area	Total Area of Machinery or Equipment	Number of Machine(s) or Equipment(s)	Total Net Area (Sq.m)
G1	Granulator 1/2 Ton	2.50	3.00	2.00	7.50	4.05	0.64	2.00	14.19	4.00	56.76
M2	Mixer 2 Ton	3.00	3.00	2.10	9.00	4.30	0.64	2.00	15.94	6.00	95.64
FL2	Forklift 2 Ton	1.10	2.90	2.10	3.19	3.27	-	-	6.46	1.00	6.46
								Total			158.86
								Aisles ASL (45%)			71.49
								Total Area Required TAR(Sq.m)			230.35

Table 4.11. Machinery and Equipment Area Sheet in Finishing Department.

Identification Data		Space (meters)			FP	MA	OWA	MSA			TNA
Machine Identification Number	Name or Description	Left-Right	Front-Back	Height	Area(Sq.m) for Machinery or Equipment	Maintenance Area Required	Operator(s) Work Area	Material Set-Down Area	Total Area of Machinery or Equipment	Number of Machine(s) or Equipment(s)	Total Net Area (Sq.m)
F20	Finishing - 20 cm	0.80	1.00	1.20	0.80	1.60	0.64	2.00	5.04	15.00	75.60
F60	Finishing - 60 cm	1.20	1.50	1.50	1.80	2.20	0.64	3.00	7.64	1.00	7.64
FL1	Forklift 1 Ton	1.10	2.90	2.10	3.19	3.27	-	-	6.46	2.00	12.92
								Total			96.16
								Aisles ASL (45%)			43.27
								Total Area Required TAR(Sq.m)			139.43

Table 4.12. Machinery and Equipment Area Sheet in Mold Shop.

Identification Data		Space (meters)			FP	MA	OWA	MSA			TNA
Machine Identification Number	Name or Description	Left-Right	Front-Back	Height	Area(Sq.m) for Machinery or Equipment	Maintenance Area Required	Operator(s) Work Area	Material Set-Down Area	Total Area of Machinery or Equipment	Number of Machine(s) or Equipment(s)	Total Net Area (Sq.m)
MI1	Milling	2.00	2.30	2.30	4.60	3.24		0.25	8.09	4.00	32.36
LA1	Lathe	1.60	2.80	1.50	4.48	3.44		0.25	8.17	8.00	65.36
								Total			97.72
								Aisles ASL (45%)			43.97
								Total Area Required TAR(Sq.m)			141.69

Table 4.13. Machinery and Equipment Area Sheet in Auxiliary Department.

Identification Data		Space (meters)			FP	MA	OWA	MSA			TNA
Machine Identification Number	Name or Description	Left-Right	Front-Back	Height	Area(Sq.m) for Machinery or Equipment	Maintenance Area Required	Operator(s) Work Area	Material Set-Down Area	Total Area of Machinery or Equipment	Number of Machine(s) or Equipment(s)	Total Net Area (Sq.m)
CO1	Cooling Tower 100 Ton	3.45	1.95	2.60	6.73	6.40	-	-	13.13	2.00	26.26
CH1	Chiller 100 HP	2.95	3.95	1.90	11.65	7.90	-	-	19.55	2.00	39.11
AP1	Air Compressor 60 HP	1.76	0.70	0.99	1.23	3.46	-	-	4.69	4.00	18.77
MDB1	Main Electrical Controller	4.30	1.00	2.20	4.30	6.30	-	-	10.60	2.00	21.20
								Total			105.33
								Aisles ASL (45%)			47.40
								Total Area Required TAR(Sq.m)			152.73

4.5.5 Area Requirement Calculation in Administration Department

In office and administration area, it will consist of regular equipment and other equipment. The regular equipment will consist of the working tables and chairs, while the other equipment are the shelf, bookcase, storage cabinet and others.

For the sitting area, from the ergonomic data of National Safety Council, normal people have the upper-leg length about 25 centimeters of space. Therefore the distance of a comfortable sitting area should occupy at least 40 centimeters. In the calculation, we will be using the distance of sitting area of 50 centimeters.

In the calculation of the area of table and sit, the formula is:

TSA = Area for table and sit, L = Left-Right, W = Front-Back

$$TSA = L * (W + 0.50)$$

For example, the TSA of the factory manager, with the table size of L = 1.80 and W = 0.80, is 2.34 square meters.

There will also be the allowance area for the aisles, the calculation is very similar to the allowance area of the machinery and equipment.

The total area of the regular equipment and the other equipment are added up, and the aisle area requirement is calculate by the percentage of the total net area.

ASL = Aisles required area, RE = Total area of regular equipment, OE = Total area of other equipment, TNA = Total net area, and AA= Allowance Area. The formula of calculating the ASL is:

$$TNA_A = (RE + OE)$$

$$ASL_A = TNA_A * AA$$

TAR_A = Total area requirement. Which the formula is:

$$TAR_A = TNA_A + ASL_A$$

(1) Administration area requirement calculation in office department

There are 2 different sizes of table, the management table size and the department table size. The management table size is 1.80 meters by 0.80 meter and the department table size is 1.20 meters by 0.80 meters. The sitting area allowance is 50 centimeters.

There are 3 managers in the office, the factory manager, the production manager, and the logistic manager.

There are 4 assistants, 1 industrial engineer, 2 planning and control personals, and 1 finishing department head.

There are 6 vacancies in the office for future expansion in personnel.

The other equipment consists of document shelf with the size of 1.50 meters by 0.80 meter and document storage rooms with the area of 3.50 meters by 2.00 meters. Allowance area for the aisles is 45%. The TAR for the office department is 61.80 square meters, as shown in the Table 4.14.

(2) Administration area requirement calculation in quality control department

There are 10 personnel in this department, 1 quality control head, 3 quality control staff, 3 production heads, and 3 planned staff for future expansion.

The other equipment consists of document shelf with the size of 1.50 meters by 0.80 meter and test area for quality test area of 5.00 meters by 5.00 meters. Allowance area for the aisles is 45%. The TAR for the quality control department is 67.57 square meters, as shown in the Table 4.15.

(3) Administration area requirement calculation in meeting department

The meeting rooms will consist of 3 rooms, one 20-sit meeting room and two 10-sit meeting rooms.

The other equipment consists of document shelf with the size of 1.00 meters by 0.50 meter. Allowance area for the aisles is 45%. The TAR for the meeting room is 40.60 square meters, as shown in the Table 4.16.

(4) Administration area requirement calculation in maintenance department

There are 7 personnel in this department, 1 engineer head and 6 engineers.

The other equipment consists of document shelf with the size of 1.50 meters by 0.80 meter. Allowance area for the aisles is 45%. The TAR for the maintenance department is 24.53 square meters, as shown in the Table 4.17.

Table 4.14. Office Layout Working Requirement Area.

Identification Data		Regular Equipment RE						Other Equipment OE					
Department	Job Title or Description	Left-Right	Front-Back	Height	Sitting Area Required	Number per Position	Area for Table and Sit	Description	Left-Right	Front-Back	Height	Number of Equipment	Total Required Area
Management	Factory Manager	1.80	0.80	0.75	0.90	1.00	2.34	Shelf1	1.00	0.50	2.00	-	-
	Production Manager	1.80	0.80	0.75	0.90	1.00	2.34	Shelf2	1.50	0.80	2.00	5.00	6.00
	Logistic Manager	1.80	0.80	0.75	0.90	1.00	2.34	Document Area	3.50	2.00	2.00	2.00	14.00
Production	Industrial Engineer	1.20	0.80	0.75	0.60	1.00	1.56						
	Planning and Control	1.20	0.80	0.75	0.60	2.00	3.12						
	Finishing Head	1.20	0.80	0.75	0.60	1.00	1.56						
Planned Staff	Planned Staff	1.20	0.80	0.75	0.60	6.00	9.36						
			Total Area				22.62			Total Area			20.00

Area Required by Regular Equipment RE	22.62
Area Required by Other Equipment OE	20.00
Total Net Area TNA	42.62
Aisles(45%) ASL	19.18
Net Total Area Required TAR (Sq.m)	61.80

Table 4.15. Quality Control Room Layout Working Requirement Area.

Identification Data		Regular Equipment RE						Other Equipment OE					
Department	Job Title or Description	Left-Right	Front-Back	Height	Sitting Area Required	Number per Position	Area for Table and Sit	Description	Left-Right	Front-Back	Height	Number of Equipment	Total Required Area
Quality Control	Quality Control Head	1.20	0.80	0.75	0.60	1.00	1.56	Shelf1	1.00	0.50	2.00	-	-
	Quality Control Staff	1.20	0.80	0.75	0.60	6.00	9.36	Shelf2	1.50	0.80	2.00	5.00	6.00
	Production Head	1.20	0.80	0.75	0.60	3.00	4.68	Test Area	5.00	5.00	-	1.00	25.00
			Total Area				15.60			Total Area			31.00

Area Required by Regular Equipment RE	15.60
Area Required by Other Equipment OE	31.00
Total Net Area TNA	46.60
Aisles(45%) ASL	20.97
Net Total Area Required TAR (Sq.m)	**67.57**

Table 4.16. Meeting Room Layout Working Requirement Area.

Identification Data		Regular Equipment RE						Other Equipment OE					
Department	Room or Description	Left-Right	Front-Back	Height	Sitting Area Required	Number per Position	Area for Table and Sit	Description	Left-Right	Front-Back	Height	Number of Equipment	Total Required Area
Meeting	Plant	6.00	2.00	0.75	8.00	1.00	18.00	Shelf1	1.00	0.50	2.00	8.00	4.00
	Departmental	3.00	1.00	0.75	1.50	2.00	6.00	Shelf2	1.50	0.80	2.00	-	-
			Total Area				24.00			Total Area			4.00

Area Required by Regular Equipment RE	24.00
Area Required by Other Equipment OE	4.00
Total Net Area TNA	28.00
Aisles(45%) ASL	12.60
Net Total Area Required TAR (Sq.m)	**40.60**

Table 4.17. Maintenance Store Layout Working Requirement Area.

Identification Data		Regular Equipment RE						Other Equipment OE					
Department	Job Title or Description	Left-Right	Front-Back	Height	Sitting Area Required	Number per Position	Area for Table and Sit	Description	Left-Right	Front-Back	Height	Number of Equipment	Total Required Area
Maintenance	Engineer Head	1.20	0.80	0.75	0.60	1.00	1.56	Shelf1	1.00	0.50	2.00	-	-
	Engineers	1.20	0.80	0.75	0.60	6.00	9.36	Shelf2	1.50	0.80	2.00	5.00	6.00
			Total Area				10.92			Total Area			6.00

Area Required by Regular Equipment RE	10.92
Area Required by Other Equipment OE	6.00
Total Net Area TNA	16.92
Aisles(45%) ASL	7.61
Net Total Area Required TAR (Sq.m)	**24.53**

4.5.6 Area Requirement Calculation for Storage

In the storage area, it will consist of the units to be stored, the probable method of stacking, and the area required per unit stored.

The main difference for area calculation in the storage and the other department is the allowance area for the aisle calculation. The AA for the storage space that uses forklift will increase from the normal 45% to 200%.

For the calculation, Q = the quantity to be stored, U = the amount stored in one unit, S = the number of stacking storey, A = the area required per unit stored, ASL = Aisles required area, TNA = Total net area, and AA= Allowance Area. The formula is:

$TNA_S = (Q / U / S) * A$

The formula of calculating the ASL is:

$ASL_S = TNA_S * AA$

TAR_S = Total area requirement. Which the formula is:

$TAR_A = TNA_A + ASL_A$

(1) Area requirement calculation for raw material storage

In the raw material storage area, there are 2 types of raw materials stored here, the plastic resin and the pigment. The plastic resin will be packed in a 25-kilograms pack. One unit consisting of 40 packs of the plastic resin will be arranged in one pallet. The total load of one unit is 1,000 kilograms and occupies 1 square meter. The policy of the management required that the storage can at least store up to 10 days of raw material stocks. From the data, you will see that the required amount of raw material used per day is approximately 29,000 kilograms. Therefore, the quantity of the raw material that is to be kept as safety stock is about 290,000 kilograms. The method of stacking will be 2 storey-high.

For the pigment, half of the products are produced in color, therefore only 145,000 kilograms of raw material needs the pigment. The formula for adding the pigment has the average of 2% of the raw material. Therefore there will be 2,900 kilograms of pigment to be stored. The pigment is also packed in a 25-kilograms pack. One unit will consist of 1 pack and occupies 0.20 square meter. The method of stacking is 8 storey-high.

From the data, and with the allowance area for the aisles of 200%, the TAR for the raw material process department is 443.70 square meters, as shown in the Table 4.18.

(2) Area requirement calculation for finished goods storage

In the finished goods storage area, all the finished goods will be arranged in the pallet. The 1-liter container will be packed in a 90 containers pack, 5-liter container in a 50-container pack, 30-liter in a 12-container pack, and 120-liter in 7-container pack. Each pallet can hold 20 packs, 14 packs, 10 packs, and 8 packs respectively. And everyday, the workers have to make approximately 7 trips, 33 trips, 49 trips, and 20 trips respectively from the production department to finishing department, and from finishing department to the finished product store. Each pallet occupies 1 square meter. The policy of the management required that the storage can at least store up to 10 days of finished goods stocks. From the data, you will see that the required amount of pallet load per day is approximately 109 pallet-load. Therefore, the volume of the finished goods that is to be kept as safety stock is about 1,090 pallet-load. The method of stacking will be 3 storey-high.

From the data, and with the allowance area for the aisles of 200%, the TAR for the finished goods department is 1,090 square meters, as shown in the Table 4.19.

(3) Area requirement calculation for mold storage

There are 4 groups of mold. The 1.5-liter mold, 5-liter mold, 30-liter mold, and 120-liter mold. Each has the dimension of 30 centimeters by 30 centimeters, 40 centimeters by 40 centimeters, 60 centimeters by 60 centimeters, and 80 centimeters by 80 centimeters. There will be around twenty 1.5-liter molds, forty-two 5-liter molds, thirty-six 30-liter molds, and six 120-liter molds. The method of stacking will be 1 storey-high.

From the data, and with the allowance area for the aisles of 45%, the TAR for the mold storage is 50.64 square meters, as shown in the Table 4.20.

(4) Area requirement calculation for sample storage

There are 4 groups of sample. The 1.5-liter sample, 5-liter sample, 30-liter sample, and 120-liter sample. Each has the dimension of 10 centimeters by 20 centimeters, 20 centimeters by 30 centimeters, 40 centimeters by 40 centimeters, and 60 centimeters by 60 centimeters. For 1 mold, changes can be differentiate by color, and weight. From the data, for 1 mold, there is an average of 4 different color and 2 different weight. We need to keep at least 2 samples for each product. There will be around three hundred and twenty 1.5-liter samples, six hundred and seventy-two 5-liter samples, five hundred and seventy-six 30-liter samples, and ninety-six 120-liter samples for the store room. The method of stacking will be 15 storey-high, 10 storey-high, 5 storey-high, and 3 storey-high, respectively.

From the data, and with the allowance area for the aisles of 45%, the TAR for the sample storage is 49.90 square meters, as shown in the Table 4.21.

(5) Area requirement calculation for maintenance and equipment storage

There are 2 groups of material to be stored in the maintenance department, the spare parts of the machines and the tools. The average dimension of the spare parts is approximately 40 centimeters by 50 centimeters, and the average dimension of the tools is 15 centimeters by 10 centimeters. From the data, there is an average of 40 different common spare parts and 150 different tools. For the calculation, we will prepare the storage space of 5 units for each type of spare parts and tools. There will be around 200 units of spare parts and 750 units of tools. The method of stacking will be 3 storey-high for the spare parts and 8 storey-high for the tools.

From the data, and with the allowance area for the aisles of 45%. The TAR for the maintenance department is 21.37 square meters, as shown in the Table 4.22.

Table 4.18. Storage Space Requirement for Raw Material.

Type of Material Store	Container Stored in	Unit(Kgs)	(Q)Quantity(kgs) to be Stored in This Area	(S) Probable Method of Stacking	(A) Area(Sq.m) Required per Unit Stored	(TNA) Total Net Area (Sq.m)
Resin	Pallet	1,000.00	290,000.00	2.00	1.00	145.00
Pigment	Box	25.00	2,900.00	8.00	0.20	2.9000
			Total			147.90
			Aisles ASL (200%)			295.80
			TAR Total Area Required (Sq.m)			443.70

Table 4.19. Storage Space Requirement for Finished Goods.

Type of Material Store	Container Stored in	Unit(Pack)	(Q)Quantity(kgs) to be Stored in This Area	(S) Probable Method of Stacking	(A) Area(Sq.m) Required per Unit Stored	(TNA) Total Net Area (Sq.m)
Finished Goods	Pallet	1.00	1,090.00	3.00	1.00	363.33
			Total			363.33
			Aisles ASL (200%)			726.67
			TAR Total Area Required (Sq.m)			1,090.00

Table 4.20. Storage Space Requirement for Mold.

Type of Material Store	Left-Right	Front-Back	Height	(A)Area(Sq.m) Required per Unit Stored	Number of Machine(s) or Equipment(s)	(TNA) Total Net Area (Sq.m)
Mold 1.5L	0.30	0.30	0.40	0.09	20.00	1.80
Mold 5L	0.40	0.40	0.45	0.16	42.00	6.72
Mold 30L	0.60	0.60	0.70	0.36	36.00	12.96
Mold 120L	0.80	0.80	1.20	0.64	6.00	3.84
			Total			25.32
			Aisles ASL (45%)			11.39
			TAR Total Area Required (Sq.m)			36.71

Table 4.21. Storage Space Requirement for Sample.

Type of Material Store	Container Stored in	Unit(Drums)	(Q)Quantity(kgs) to be Stored in This Area	(S) Probable Method of Stacking	(A) Area(Sq.m) Required per Unit Stored	(TNA) Total Net Area (Sq.m)
Sample 1L	Unit	1.00	320.00	15.00	0.020	0.43
Sample 5L	Unit	1.00	672.00	10.00	0.060	4.03
Sample 30L	Unit	1.00	576.00	5.00	0.160	18.43
Sample 120L	Unit	1.00	96.00	3.00	0.360	11.52
			Total			34.41
			Aisles ASL (45%)			15.48
			TAR Total Area Required (Sq.m)			49.90

Tablel 4.22. Storage Space Requirement for Maintenance and Equipment.

Type of Material Store	Container Stored in	(U)	(Q)Quantity(kgs) to be Stored in This Area	(S) Probable Method of Stacking	(A) Area(Sq.m) Required per Unit Stored	(TNA) Total Net Area (Sq.m)
Spare Parts	Unit	1.00	200.00	3.00	0.200	13.33
Tools	Unit	1.00	750.00	8.00	0.015	1.41
			Total			14.74
			Aisles ASL (45%)			6.63
			TAR Total Area Required (Sq.m)			21.37

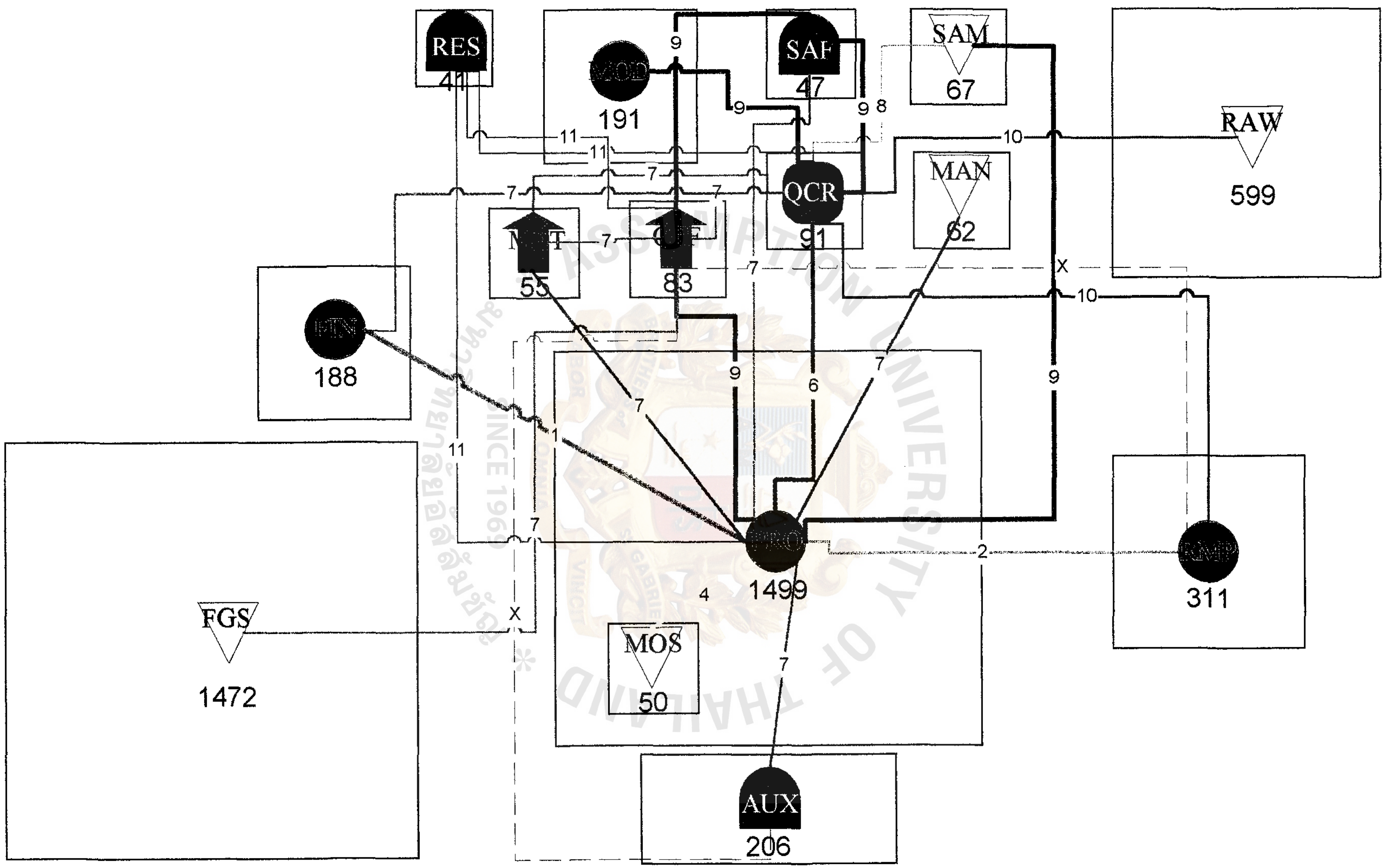


Figure 4.11. Space Relationship Diagram.

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4.5.7 Total Area Summary

With the aisle allowance of 35%, each department's total required area are as follows: The production department 1,499 square meters. The raw material process 311 square meters. The finishing department 188 square meters. The mold shop 191 square meters. The auxiliary room 206 square meters. The office 83 square meters. The quality control room 91 square meters. The meeting room 55 square meters. The maintenance room 62 square meters. The raw material store 599 square meters. The finished goods store 1,472 square meters. The mold store 50 square meters. The sample room 67 square meters. The safety room 47 square meters. The rest room 41 square meters.

With the adjustment into one combined building, the adjusted areas for each department are as follow: The production department 1,500 square meters. The raw material process 440 square meters. The finishing department 240 square meters. The mold shop 200 square meters. The auxiliary room 200 square meters. The office 100 square meters. The quality control room 100 square meters. The meeting room 100 square meters. The maintenance room 100 square meters. The raw material store 660 square meters. The finished goods store 1,960 square meters. The mold store 100 square meters. The sample room 100 square meters. The safety room 60 square meters. The rest room 40 square meters.

Table 4.23. Summary of Each Department Space Area Requirement.

Identification Data	Equipment	Storge	Aisles(35%)	Total	Actual	Adjusted
Department	Area (Sq.m)	Area (Sq.m)	Area (Sq.m)	Required Area	Dimension (meters)	Area (Sq.m)
Production	1,110.59		388.71	1,499.30	37.50 by 40	1,500.00
Raw Material Process	230.35		80.62	310.97	22 by 20	440.00
Finishing	139.43		48.80	188.23	12 by 20	240.00
Mold Shop	141.69		49.59	191.29	20 By 10	200.00
Auxiliary	152.73		53.45	206.18	5 by 40	200.00
Office	61.80		21.63	83.43	10 by 10	100.00
Quality Control Room	67.57		23.65	91.22	10 by 10	100.00
Meeting	40.60		14.21	54.81	10 by 10	100.00
Maintenance Room	24.53	21.37	16.07	61.97	10 by 10	100.00
Raw Material Store		443.70	155.30	599.00	33 by 20	660.00
Finished Goods Store		1,090.00	381.50	1,471.50	(55+43) by 20	1,960.00
Mold Store		36.71	12.85	49.56	5 by 20	100.00
Sample Room		49.90	17.46	67.36	10 by 10	100.00
Safety Room		35.00	12.25	47.25	6 by 10	60.00
Rest Room		30.00	10.50	40.50	4 by 10	40.00
	Total Area Required (Sq.m)			4,962.57		5,900.00

4.6 Adjustment

The plant will be divided into 3 separated buildings. Building 1 is the main building, which consists of 11 departments, the production department, auxiliary room, the mold shop, the mold store, the maintenance room, the meeting room, the office, the quality control room, the sample room, the safety room, and the main rest room. Building 2 consists of 2 departments, the finishing department, and the finishing store. Building 3 consists of 2 departments, the raw material process department, and the raw material store.

4.6.1 The Building Layout

The 3 buildings will be arranged into a L-Shape layout. Each of the 3 buildings will be surrounded with a pavement 1.50 meters in width. The road within the buildings will be 4.00 meters in width.

The dimension of the buildings including the pavement are as follows: Building 1, 43.0 meters by 68.0 meters. Building 2, 43.0 meters by 58.0 meters. Building 3, 23.0 meters by 58.0 meters.

With the site dimension of approximately 140.0 meters by 245.0 meters, and the road with the width of 4.00 meters, the duplicate plan or modular units dimension will be 129.0 meters by 76.0 meters. The land will consist of other facilities such as the parking lot, the sport complex, the main dining room, gardens, and others, with approximately 140.0 meters by 30.0 meters of land is reserved for these. Therefore, only 140 meters by 215.0 meters of land is for the plant and future expansion. With the width of the modular unit, 76.0 meters, we can only expand another duplicate plant. These will cover about 140.0 meters by 152.0 meters of the land. The rest of the land will have the dimension of approximately 140.0 meters by 63.0 meters.

From the calculation, the adjustment we need to make is to expand upwards or multi-storey layout. If we can reduce the duplicate plant to the dimension of approximately 140.0 meters by 72.0 meters, we can increase the number of duplicate plant from two to three.

From the dimension of the 3 buildings, only building 1 is 68.0 meters in length, the rest is 58.0 meters in length. With the road width of 4.0 meters on each side, it will sum up to 76.0 meters, which exceeds the ideal width of 72.0 meters. We can reduce the length of building 1 by constructing a 40.0 meters by 10.0 meters second storey, so that the length of the 3 buildings will be equally 58.0 meters. Even the sum of the road of 4.0 meters on each side will sum up to only 66.0 meters, which is less than 72.0 meters that we have planned.

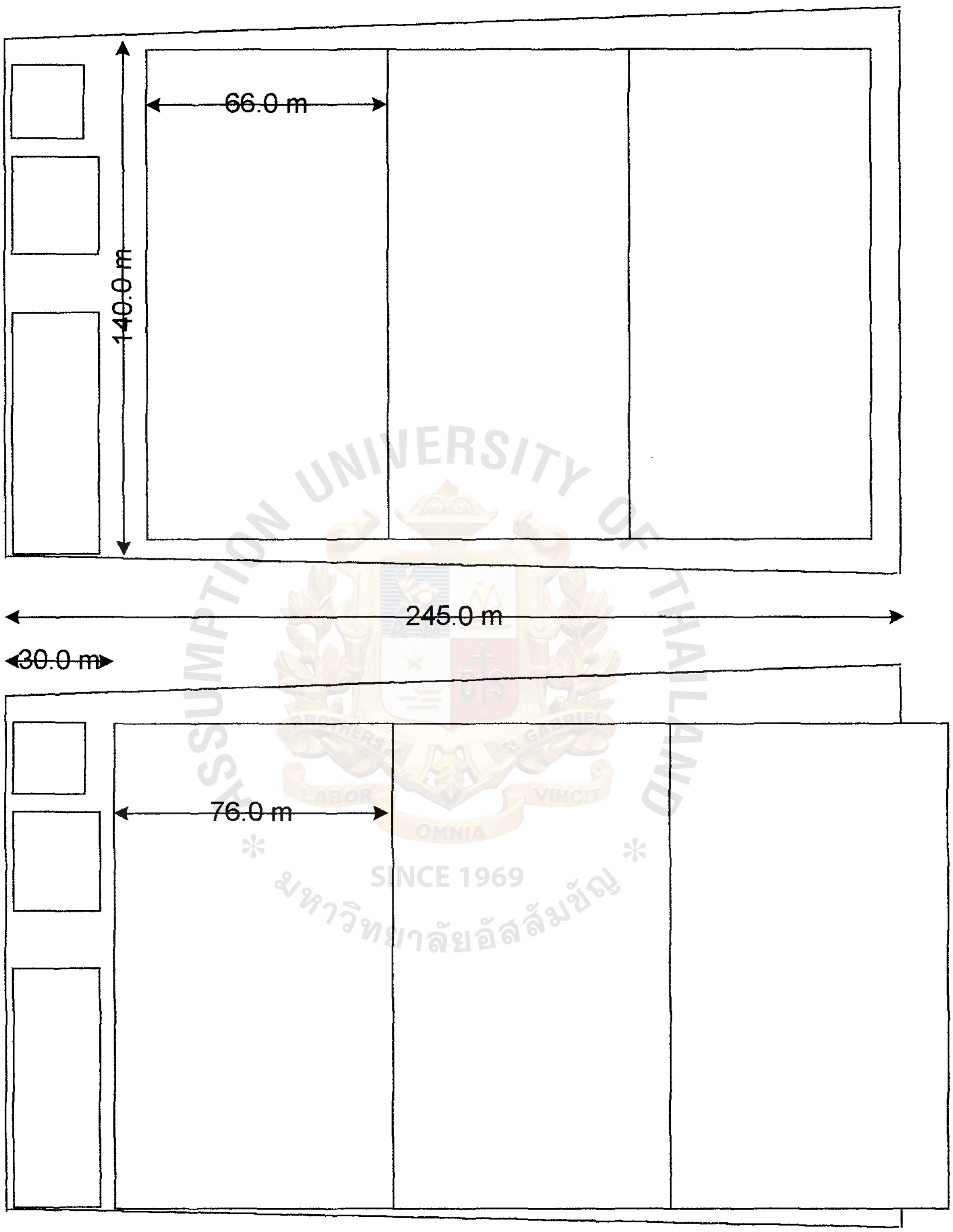

Figure 4.12. Duplicate Plant Comparison.

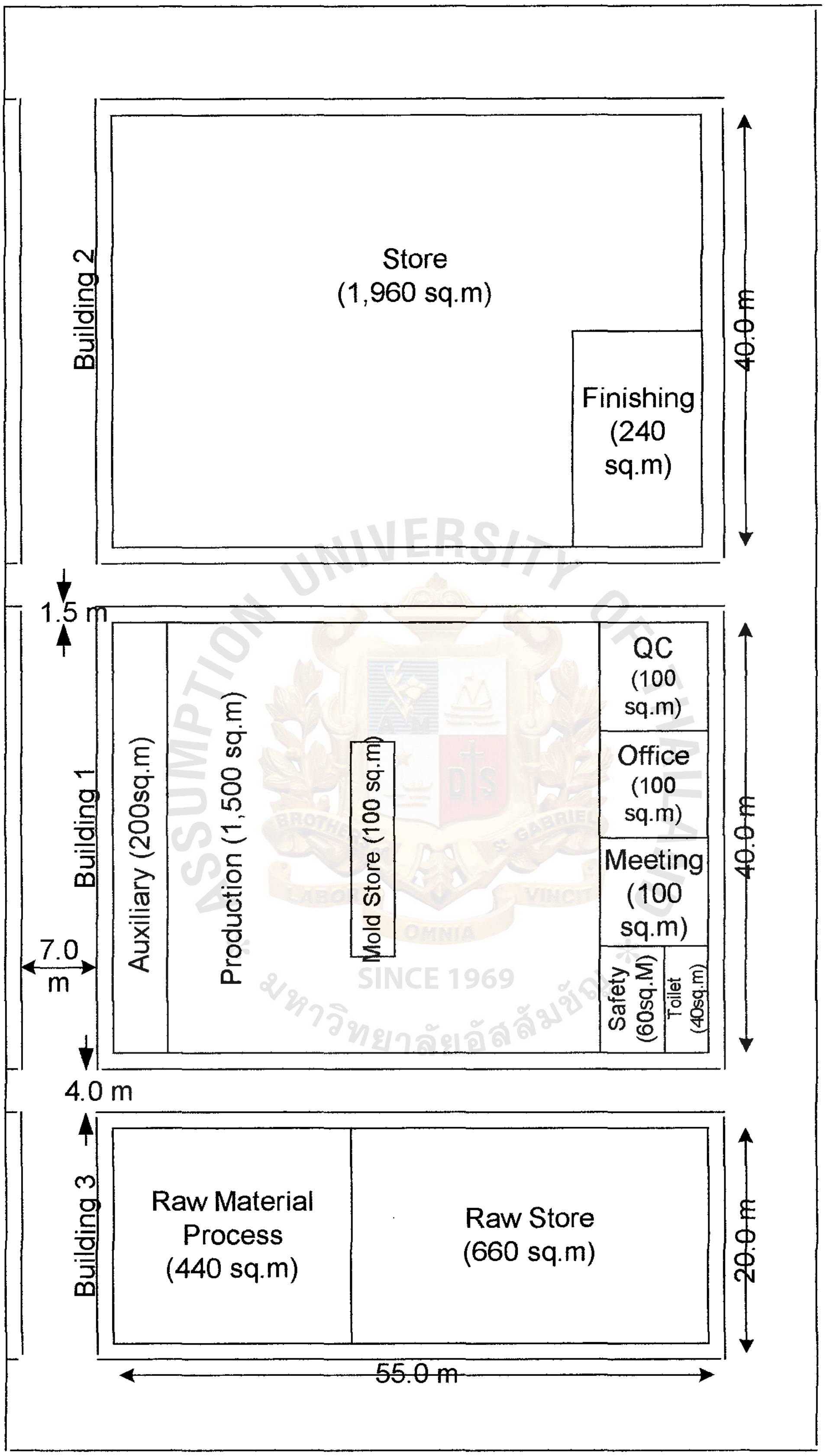

Figure 4.13. Adjusted Overall Layout-Ground Floor.

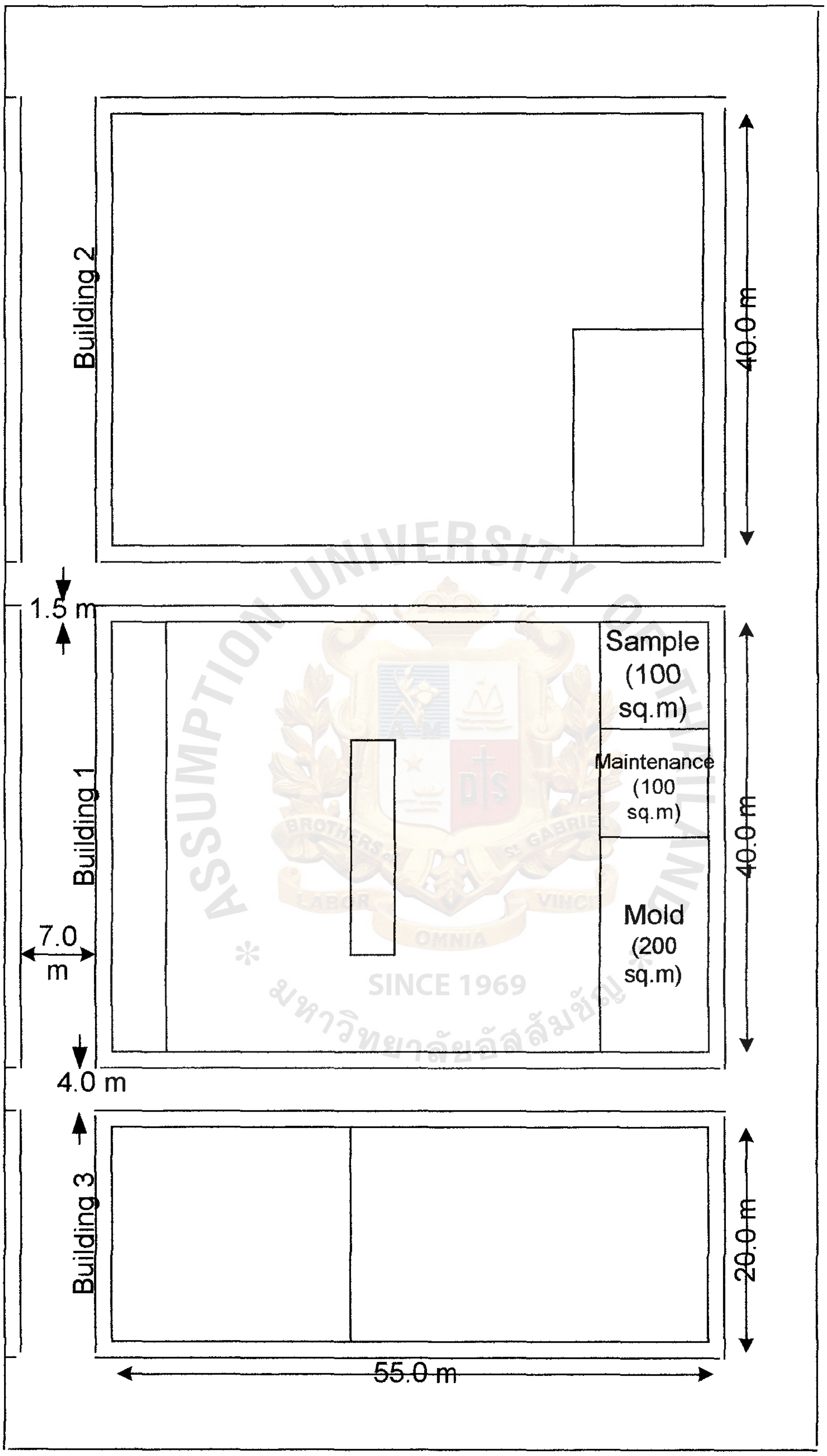

Figure 4.14. Adjusted Overall Layout-Second Floor.

4.6.2 Multi-Storey Layout

With the site layout planning, we find out that if the plant has the additional space of 400 square meters, we can increase the duplication of the plant expansion from 2 modular units into 3 modular units. Therefore we concluded that within the layout, the additional 400 square meters will be constructed on the multi-storey basic. This is because of the space limitations of the total site area.

4.6.3 Calculation

We come out with 3 different alternatives. The first alternative, by moving the office department, quality control room, meeting room, and sample room on the second floor. Each occupies 85 square meters, 95 square meters, 55 square meters, and 70 square meters respectively. The total is 305 square meters, which is suitable. There are 4 departments, which relationships are broken. The office from the production department, the safety room, the rest room, and the finished goods store. The quality control room from the raw material store, the raw material process department, the production department, the mold shop, the safety room, the rest room, and the finishing department. The meeting room from the raw material store, raw material process department, the production department, the mold shop, the safety room, the rest room, the finishing department, and finishing store. The sample room from the production department, and the rest room. The relationships that are broken sum up to 57 points.

The second alternative, by moving the mold shop, quality control room, and sample room on the second floor. Each occupies 195 square meters, 95 square meters, and 70 square meters respectively. The total is 360 square meters, which is suitable. There are 3 departments, which relationships are broken. The mold shop from the mold store, the meeting rooms the safety room, and the rest room. The quality control room from the raw material store, the raw material process department, the production department, the meeting room, the office, the safety room, the rest room, and the finishing department. The sample room from the production department, the meeting room, and the rest room. The relationship that is broken sums up to 46 points.

The last alternative, by moving the mold shops, maintenance room, and sample room up. With the area of 195 square meters, 65 square meters, and 70 square meters respectively. The total is 330 square meters, which is suitable. There are 3 departments, which relationships are broken. The mold shop from the mold store, the quality control room, the meeting rooms the safety room, and the rest room. The maintenance room from the raw material process department, the production department, the mold store, the safety room, the rest room, and the finishing department. The sample room from the production department, the quality control room, the meeting room, and the rest room. The relationship that is broken sums up to 39 points. From the results, we can conclude that the last alternative is the optimum solution.

Table 4.24. Multi-storey Layout Calculation.

Activity-Area (Sq.m)		Alt No. 1 (Sq.m)		Alt No. 2 (Sq.m)		Alt No. 3 (Sq.m)	
Department	Area	Ground	Upper	Ground	Upper	Ground	Upper
Production	1,500.00	1,500.00		1,500.00		1,500.00	
Raw Material Process	315.00	315.00		315.00		315.00	
Finishing	190.00	190.00		190.00		190.00	
Mold Shop	195.00	195.00			195.00		195.00
Auxiliary	210.00	210.00		210.00		210.00	
Office	85.00		85.00	85.00		85.00	
Quality Control Room	95.00		95.00		95.00	95.00	
Meeting	55.00		55.00	55.00		55.00	
Maintenance Room	65.00	65.00		65.00			65.00
Raw Material Store	600.00	600.00		600.00		600.00	
Finished Goods Store	1,475.00	1,475.00		1,475.00		1,475.00	
Mold Store	50.00	50.00		50.00		50.00	
Sample Room	70.00		70.00		70.00		70.00
Safety Room	50.00	50.00		50.00		50.00	
Rest Room	40.00	40.00		40.00		40.00	
	4,995.00	4,690.00	305.00	4,635.00	360.00	4,665.00	330.00

			No. of	Points	No. of	Points	No. of	Points
Relationships Broken	A	11		0		0		0
	A-	10		0		0		0
	E+	9		0		0		0
	E	8		0		0		0
	E-	7		0		0		0
	I+	6	1	6	2	12	1	6
	I	5	4	20	3	15	1	5
	I-	4		0		0	1	4
	O+	3	5	15	3	9	4	12
	O	2	5	10	3	6	4	8
	O-	1	6	6	4	4	4	4
	Total			57		46		39

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Overall Review

Abba Plastic as a process layout plastic manufacturing facility, after facing the problem of space limitation and decided to move to a new factory in Saraburi, understand the importance of layout planning and decided to apply the Systematic Layout Planning (SLP) theory in designing their new plant layout.

From the study, we realized that the key for planning a good process layout is to concentrate in the input data of the five element, P—Product, Q—Quantity, R—Routing, S—Supporting Service, and T—Timing.

Every layout rests on the three fundamentals:

(1) Relationships—the relative degree of closeness desired or required among things

(2) Space—the amount, kind, and shape or configuration of the things being laid out

(3) Adjustment—the arrangement of things into a realistic best fit

These three are always the heart of any layout planning project, regardless of products, processes, or size of project. It is therefore logical and to be expected that the pattern of layout planning procedures is based directly on these fundamentals.

After gathering the needed data, we combined the flow of materials and the activity relationships to form the relationship diagram.

Next, we calculate the space requirements for all the machinery, equipment, working area, storage area, supporting services, and others. Then summarize and compare the space available to find the most suitable layout for the plant with the help of the space relationship diagram.

For the adjustment, practical limitations in implementing according to the plan are needed for considerations. Some parts of the plan might need modification during the implementation part.

All these procedures are linked together; a change in information might effect the whole layout plan. Therefore the importance of gathering the most accurate data for SLP is very essential. Each step in the SLP is overlapping. For example, before completing overall layout, some information and calculation, which are in the detailed layouts phases, are needed in the overall planning process.

From the planning, we come to the conclusion that, our products, are grouped into 4 groups. The 1.5-liter container, 5-liter container, 30-liter container, and 120-liter container have the production demand in the next 8 years will be approximately 382,000 containers, 684,000 containers, 178,000 containers, and 17,000 containers respectively. The total number of 1.500-liter machine, 5-liter machine, 30-liter machine, and 120-liter machine needed for the next 8 years are 7 machines, 15 machines, 12 machines, and 2 machines respectively.

The most important department that must be at the center of the plant is the production department. It is linked closely to the raw material process department and the finishing department.

As the finished products and the finished goods in process are very bulky, they sometimes occupy space as big as 8 times the raw materials, therefore the flow of materials is very important.

From the traditional degree of closeness, which uses A, E, I, O, U, and X for representing the degree of closeness, we found that we need more degrees in classifying the closeness of each department. Therefore some modification of the degree is used in this project. We increased the intensity of the traditionally 5 level of different degrees into 12 level of different degree. They are A, A-, E+, E, E-, I+, I, I-, O+, O, O-, U, and X.

In the planning, we also emphasized on providing a standard working environment and condition for the aspect of safety and health of the employees. Safety information, such as minimum area required for a safe logistic of a forklift and the spacing of each machine for the safety and maintenance aspects. Most of the plant layout do not emphasize on this area. But as for Abba Plastic, the management policy is to produce quality product by safe and healthy employees.

After calculation and some modifications, we come to the conclusion that the area of land development occupies approximately 6.5 rais of the available land. There will be 3 main buildings, 2 buildings with the dimension of 40 meters by 55 meters, and the other building with the dimension of 20 meters by 55 meters. Each building has a 1.5 meters pavement around it. The main road is 7 meters wide and the between each building the road is 4 meters wide. There are areas within the plant that is designed especially for the aspect of safety and health of the employees, which occupies more than 100 square meters. There are, for example, a safety room, that the main idea is for the first-aid room, is also used for recreation.

The multi-storey layout planning is very useful. With the limitations of space and a good strategic or site layout planning, we can make use of the available space efficiently. Each stage of the layout planning must be well synchronized. From the stage of site layout planning, overall layout planning, to the detail layout planning. Dr. Richard Muther found the systematic layout planning for almost 40 years and still it is the most practical theory used widely throughout the world.

5.2 Recommendations

For the recommendation for the layout planner, it is very important for you to gather the data from the beginning of the project, from the stage of site layout planning, overall layout planning, to the detail layout planning. Each data is very important. Try to look for the most accurate data source. If the data you obtain is not accurate, what will follow is that your layout plan will not be accurate. The planner must base his work on projected input figures. This means that input data, to which the layout will be designed, must be projected for conditions which will exist beyond—or at least at the time—the layout is installed.

The extent of the projections varies with the nature of the project. On a total, new facility involving several buildings, it is entirely practical to attempt projections extending over 25 or even 50 years, although precise forecasts can seldom be made so far into the future. When projecting many years ahead, the planner usually can use only policy statements regarding the company's basic direction.

Changes in the inherent characteristics of products and materials must also be anticipated by the planner. Changes in product design can defeat the best layout planning. One layout, for example voted the finest in its industry, became obsolete within 10 years and was completely abandoned, primarily because of a change in size of the product. It is well worthwhile, therefore, to check past trends in nature or characteristics of the products or materials involved in a layout plan.

One warning should be made—the tendency to get too specific. Layout planners must have data to plan their layouts; this has been emphasized. However, even though a company's management or product-planning group has set such figures down in writing, they cannot be considered as either unchangeable or precise. In fact, if any projection figures come out exactly as set down, it is a coincidence—except perhaps where contractual customers are involved.

Usually, the set of plan-for input data must include some kind of cushion, or safety factor, or it must be recognized that overtime or a second or third shift will be used to pick up peak conditions. This should be understood by everyone before a specific plan—for figures are agreed upon.

Similarly, once the figures are agreed upon, the layout planner must recognize that these figures are, at best, estimates and that some condition may occur which will change completely the nature of his design criteria—his projected input data. Changes to meet competitor's product design, to take advantage of a new process, to conform to new sanitation or labor-union provisions are bound to occur. The rapidity of such changes is becoming more important each year. If the layout planner relies too literally on the plan—for figures, his layout will be too inflexible or too costly to adapt to the inevitable minor changes.

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