TRANSPORT AND LOGISTICS

LAYOUT PLANNING MODELS

1. Introduction to Layout Planning Models

Layout planning models are essential tools in operations management and industrial engineering that help optimize the arrangement of facilities, equipment, and workspaces within a manufacturing or service environment. These models aim to improve efficiency, reduce costs, and enhance overall productivity by strategically organizing physical resources (Tompkins et al., 2010).

2. Common Layout Planning Models

a. Block Layout Models

i. Explanation of Block Layout Models

Block layout models represent facilities or departments as blocks or rectangles, focusing on the relative positioning of these units to optimize material flow, communication, or other relevant factors (Heragu, 2018). These models provide a high-level view of the facility layout without delving into detailed internal arrangements.

ii. Advantages and Disadvantages of Block Layout Models

Advantages

i. Simplicity and ease of understanding

ii. Quick to develop and modify

iii. Useful for initial planning stages

iv. Facilitates communication between stakeholders

Disadvantages

i. Lack of detail for specific equipment placement

ii. May oversimplify complex relationships between areas

iii. Limited ability to account for non-rectangular spaces

iii. Product Characteristics Suitable for Block Layout Models

Block layout models are particularly suitable for

i. Facilities with distinct functional areas or departments

ii. Products requiring sequential processing through multiple departments

iii. Environments where interdepartmental relationships are crucial

iv. Types of Block Layout Models

1. **Systematic Layout Planning (SLP)**

SLP is a structured approach to facility layout planning developed by Richard Muther (1973). It involves a series of steps to analyze relationships between activities and develop an optimal layout.

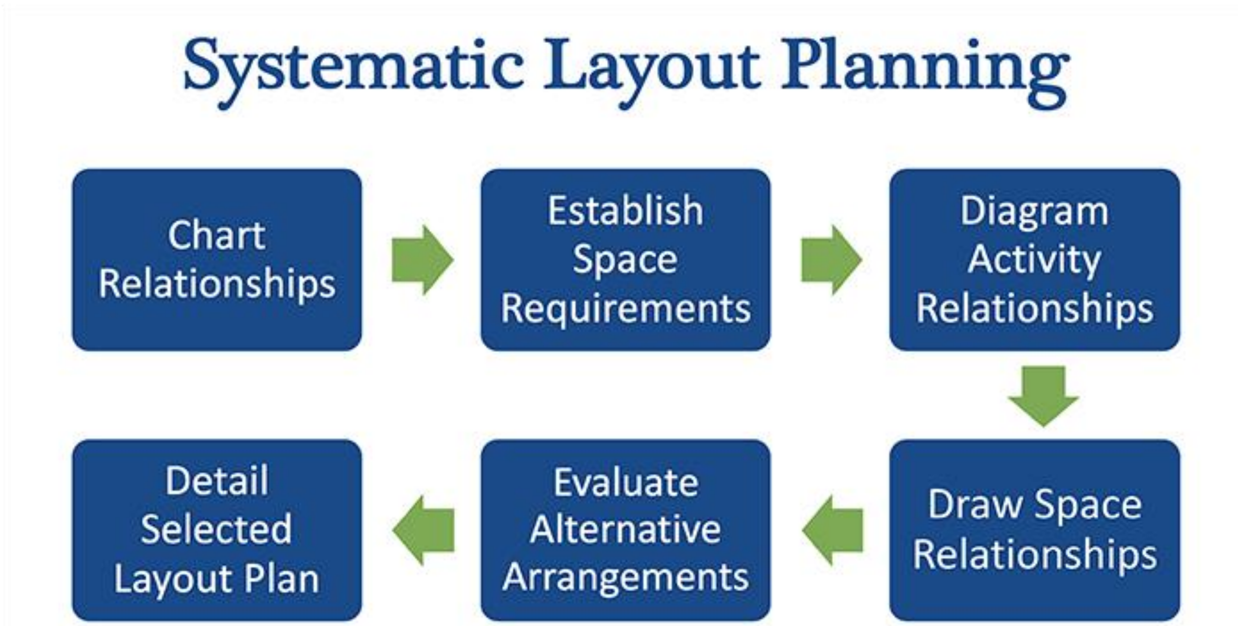

Figure 1: Systematic Layout Planning[1]

The diagram illustrates the systematic layout planning (SLP) process, a structured approach used to optimize facility layouts. The process begins with "Chart Relationships," where the connections between activities or departments are mapped. Next, "Establish Space Requirements" assesses the space needed for each activity. In "Diagram Activity Relationships," these relationships are visualized using charts to depict how closely activities should be placed. The next step, "Draw Space Relationships," translates these connections into a preliminary layout. "Evaluate Alternative Arrangements" explores different layout options to ensure the most efficient use of space. Finally, "Detail Selected Layout Plan" refines the chosen

[1] https://www.bastiansolutions.com/blog/distribution-center-layout-and-design---part-2-systematic-layout-planning/

layout into a finalized, practical design. This flow ensures that spatial design is aligned with operational requirements, enhancing productivity and workflow efficiency.

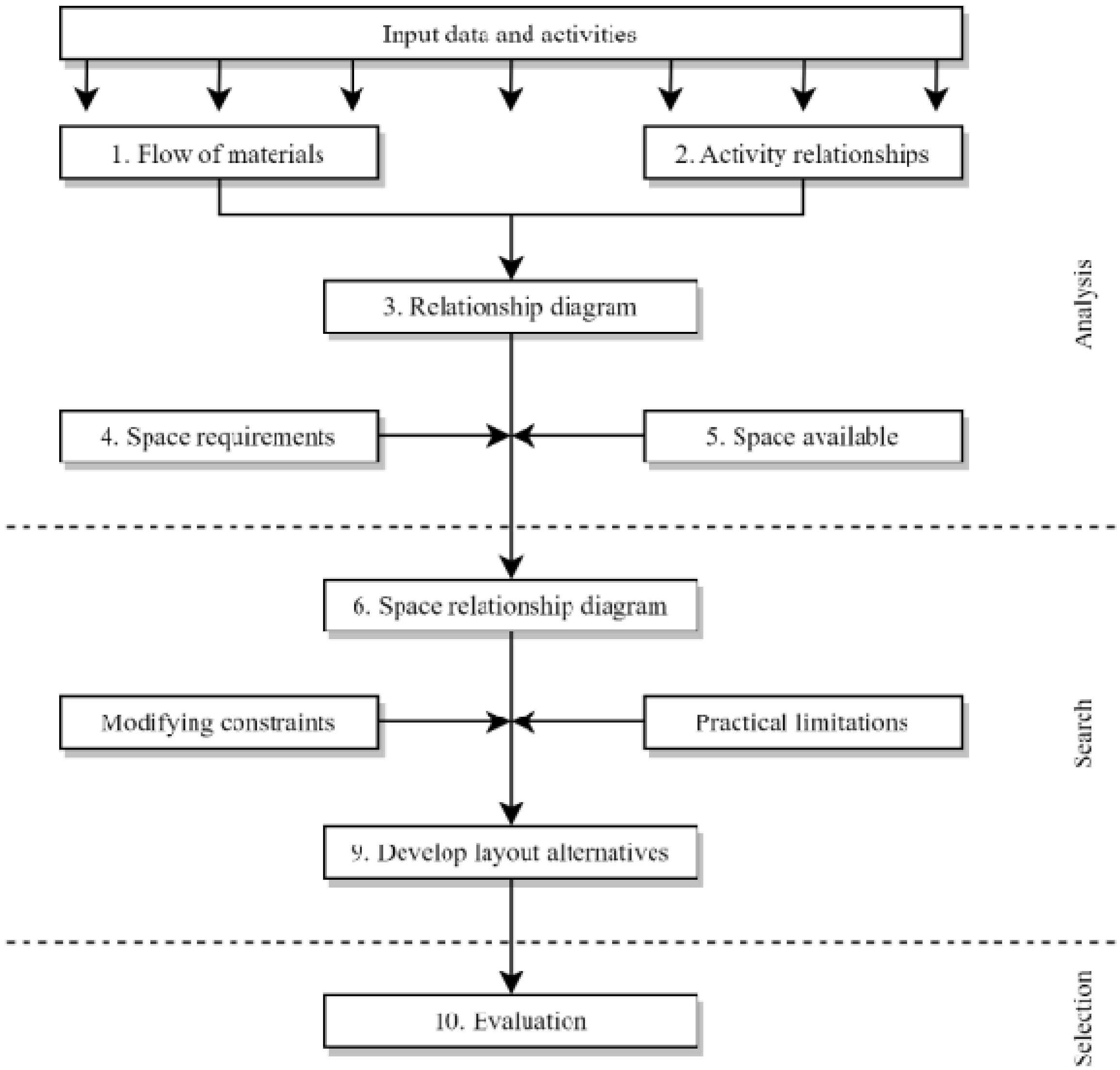

Figure 2: detailed figure steps of Systematic Layout Planning (SLP)

The detailed figure 2 show the first step in Systematic Layout Planning (SLP) is creating the Activity Relationship Chart (ARC). This chart assigns codes to indicate the degree of importance between various layout parameters. The relationships are ranked using a 5-4-3-2-1 scale, corresponding to the codes A-E-I-O-U-X in the Activity Relationship Diagram (ARD). These codes are connected by lines representing the strength of the relationships between activities, making it easier to visualize which elements are most important to place near each other. After constructing the ARD, the next step is to develop the Area Allocation Diagram (AAD), which translates the relationships into a practical floor plan. The AAD represents the spatial arrangement of the layout, ensuring that the relationships identified in the ARD are reflected in the physical space.

2. **Activity Relationship Diagram**

The Activity Relationship Diagram is a tool used within SLP to visually represent the relationships between different activities or departments. It uses a standardized format to show the importance of proximity between areas (Tompkins et al., 2010).

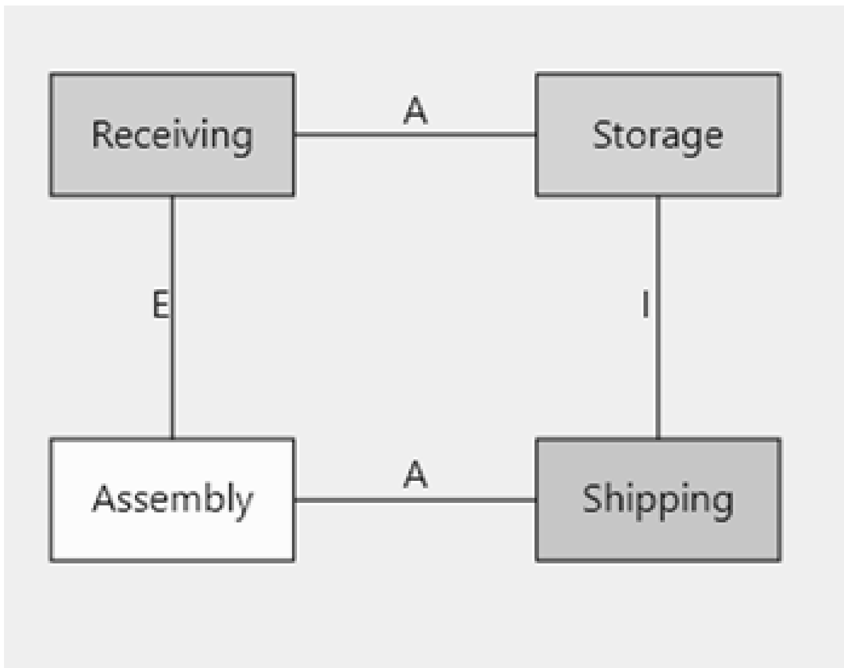

Figure 3: Activity Relationship Diagram

This diagram shows a simplified Activity Relationship Diagram with four departments, Receiving, Storage, Assembly, and Shipping. The lines connecting the departments indicate the importance of their relationships, with 'A' representing an absolutely necessary closeness, 'E' representing especially important, and 'I' representing important.

Let’s look on another bigger example for better understanding

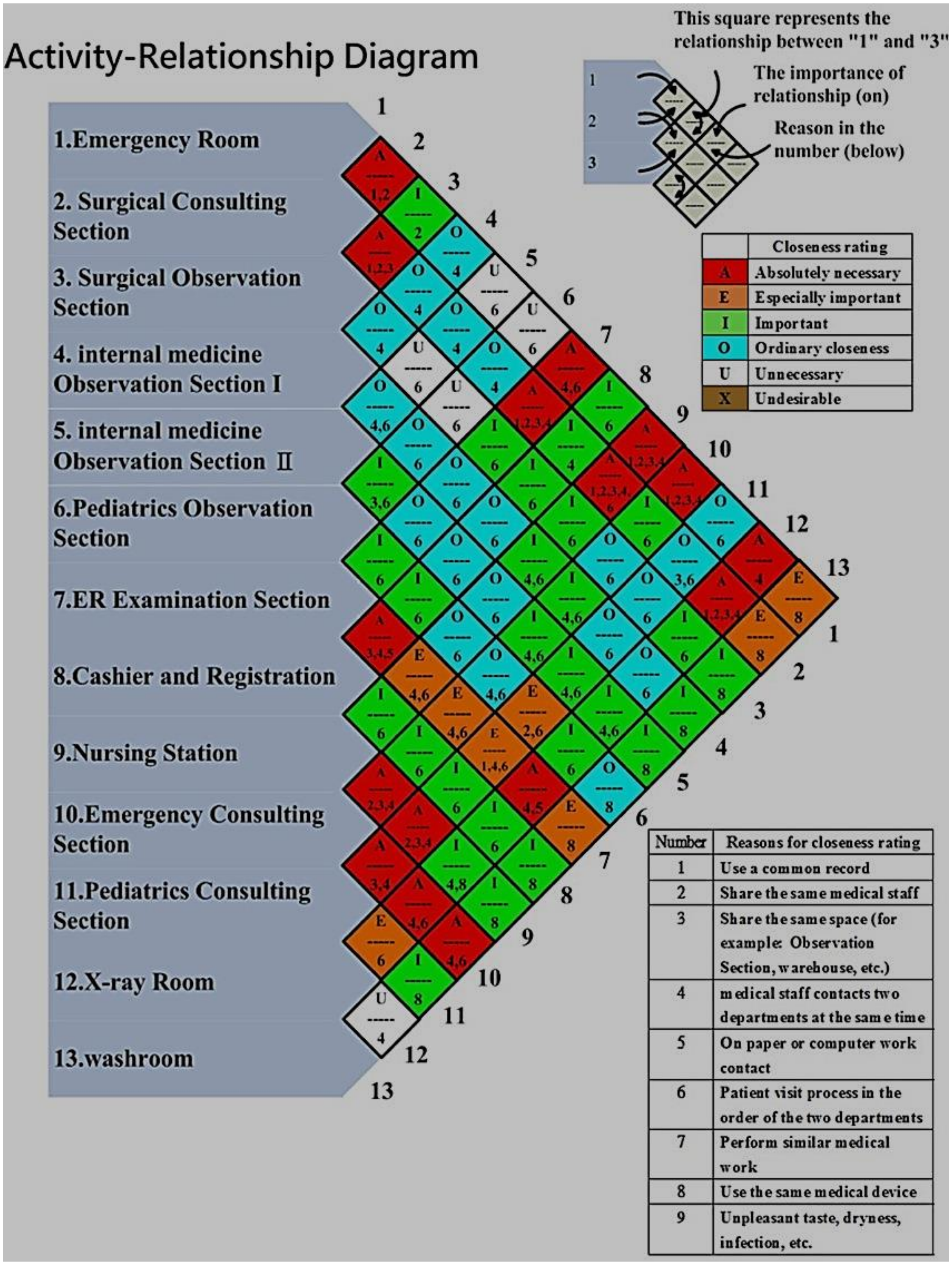

Figure 4: ARD for various healthcare facility departments[2]

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2 https://www.researchgate.net/publication/337268716_Improving_the_Efficiency_of_an_Emergency_Department_Based_on_Activity-Relationship_Diagram_and_Radio_Frequency_Identification_Technology

In this particular ARD, various healthcare facility departments are analyzed to determine how closely they should be positioned based on specific criteria. The closeness ratings are denoted by the letters A, E, I, O, U, and X, representing the importance of proximity: "A" for absolutely necessary, "E" for especially important, "I" for important, "O" for ordinary closeness, "U" for unnecessary, and "X" for undesirable.

Each square on the diagram connects two departments, with codes and numbers indicating the strength of their relationship. For example, the relationship between the Emergency Room (1) and the Surgical Observation Section (3) is rated "A" (absolutely necessary) due to reasons like shared staff, common medical records, and the need for immediate patient transitions between departments (reasons 1, 2, and 3 as per the key). The color-coding further enhances visual clarity, with red indicating a high-priority relationship and white or black representing minimal or no necessity for closeness.

This diagram simplifies the complexity of hospital layouts by visually mapping out how different sections should be spatially arranged to optimize efficiency, patient flow, and staff coordination. By following this structure, designers can develop layouts that minimize patient transport time, enhance coordination between related sections, and improve overall healthcare delivery. This process also ensures that undesirable pairings (marked with "X")—such as those between incompatible departments—are avoided, ensuring better workflow and safety.

b. Flow Models

i. Explanation of Flow Models

Flow models focus on optimizing the movement of materials, information, or people through a system. These models are particularly useful in manufacturing and logistics settings where efficient material handling is crucial (Heragu, 2018).

ii. Advantages and Disadvantages of Flow Models

Advantages

i. Direct focus on material or information flow

ii. Quantitative approach to layout optimization

iii. Ability to handle complex flow patterns

Disadvantages

A. May oversimplify non-flow-related factors

B. Can be computationally intensive for large problems

C. Requires detailed flow data, which may be challenging to obtain

iii. Product Characteristics Suitable for Flow Models

Flow models are particularly suitable for

a) High-volume production environments

b) Products with well-defined process sequences

c) Facilities where material handling costs are significant

iv. Types of Flow Models

1. **Linear Programming**

Linear programming is a mathematical optimization technique used to find the best outcome in a mathematical model whose requirements are represented by linear relationships (Dantzig, 1963). Flow models seek to optimize the flow of materials, information, or people. The goal is to achieve the most efficient path, minimizing costs or maximizing output. Consider a system with two variables x and y representing two types of resources or processes. The objective is to maximize the function $x + y$, subject to a series of constraints.

Objective Function

Maximize

$$Z = x + y$$

Where

a. x and y are the decision variables representing, for example, the quantity of materials or goods flowing through a system.

b. Z is the value of the objective function that we want to maximize (the total flow or efficiency).

Constraints

The system has some constraints, represented as inequalities. These constraints limit the resources or define the capacity of processes. Let’s assume the following constraints

$$2x + y \leq 20 \quad \text{(Constraint based on material availability or process capacity)}$$

$$x + 2y \leq 20 \quad \text{(Another process capacity constraint)}$$

$$x \geq 0 \quad (\text{Non} - \text{negativity constraint for } x)$$

$$y \geq 0 \quad (\text{Non} - \text{negativity constraint for } y)$$

System of Constraints

The complete system of constraints is

$$2x + y \leq 20$$

$$x + 2y \leq 20$$

$$x \geq 0$$

$$y \geq 0$$

Solving the Linear Programming Problem

To solve this, we graph the system of inequalities to find the feasible region, which is the set of values for x and y that satisfy all the constraints. The optimal solution will occur at one of the vertices of this feasible region.

First Constraint

For the first constraint

$$2x + y = 20 \quad \text{(rearranged to find intercepts)}$$

At $x = 0$, $y = 20$, and at $y = 0$, $x = 10$.

Second Constraint

For the second constraint

$$x + 2y = 20$$

At $x = 0$, $y = 10$, and at $y = 0$, $x = 20$.

Intersection Points

The feasible region is bounded by these constraints, and the vertices of the region include points like $(0,10)$, $(10,0)$, and the intersection of the two lines.

Solving Using Simplex Method

We evaluate the objective function at the vertices of the feasible region. For each vertex, we calculate $Z = x + y$

$$\text{At } (0,10),\ Z = 0 + 10 = 10$$

$$\text{At } (10,0),\ Z = 10 + 0 = 10$$

At the intersection point of the two lines, solve

$$2x + y = 20 \quad \text{and} \quad x + 2y = 20$$

Solving this system gives the intersection at $(8,6)$. At this point, $Z = 8 + 6 = 14$.

Thus, the optimal solution is $x = 8$, $y = 6$, and the maximum value of Z is 14.

The flow model, when expressed using linear programming, focuses on optimizing resource allocation. By solving the system of constraints, the optimal flow configuration is identified, maximizing efficiency. Linear programming provides a quantitative method to handle complex flow patterns, but it can also become computationally intense for larger problems.

c. Grid Layout Models

i. Explanation of Grid Layout Models

Grid layout models divide the available space into a grid of equal-sized cells. Facilities or departments are then assigned to these cells, allowing for a systematic approach to space allocation (Heragu, 2018).

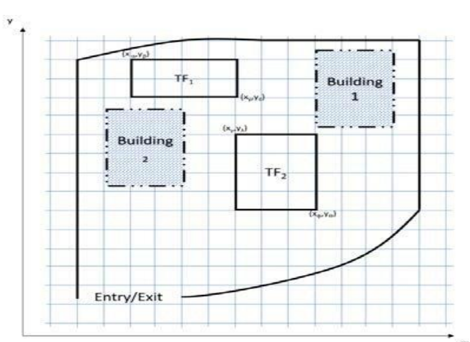

Figure 5: Example of Grid-based SLP problem representation. of a building[3]

[3] https://www.researchgate.net/publication/372188661_Design_based_Constraint_Handling_for_Site_Layout_Planning?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoiX2RpcmVjdCJ9fQ

Figure 5 illustrates a grid layout model, which organizes space into a grid of equal-sized cells. In this model, facilities such as "Building 1" and "Building 2" are systematically placed within specific cells, demonstrating a structured approach to space allocation. The diagram includes an entry/exit point, marked at the bottom, indicating access to the layout. Additionally, coordinates (x,y) are used to denote the positions of buildings and reference points "TF1" and "TF2" within the grid.

ii. Advantages and Disadvantages of Grid Layout Models

Advantages

i. Systematic approach to space allocation

ii. Easy to implement and understand

iii. Facilitates quantitative analysis of layout efficiency

Disadvantages

i. May lead to suboptimal use of space due to fixed cell sizes

ii. Limited flexibility for irregular-shaped areas

iii. Can oversimplify complex spatial relationships

iii. Product Characteristics Suitable for Grid Layout Models

Grid layout models are particularly suitable for

i. Modular manufacturing environments

ii. Warehouses with uniform storage requirements

iii. Retail spaces with standardized display units

d. Fixed Position Layout Models

i. Explanation of Fixed Position Layout Models

In fixed position layouts, the product remains stationary while resources and workers move around it. This approach is typically used for large, immobile products or projects (Slack et al., 2013).

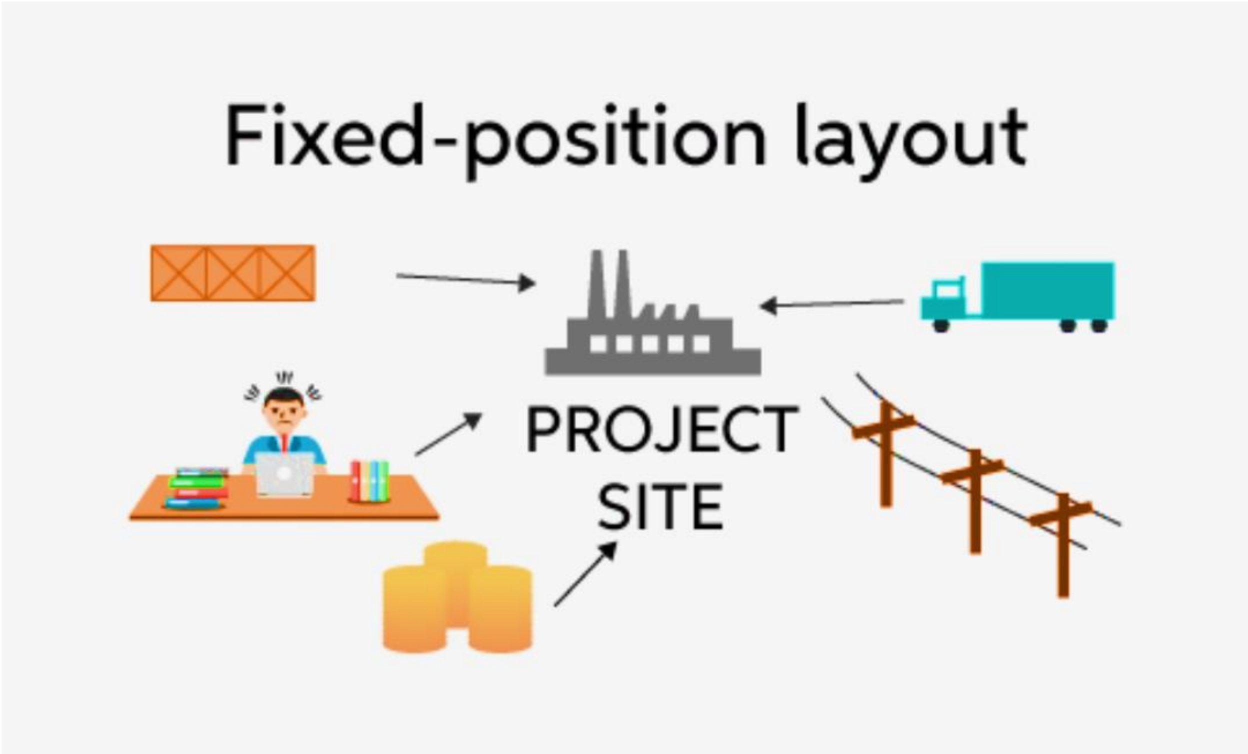

Figure 6: Fixed Position Layout Models

Figure 6 shows a fixed position layout model, In this layout, the product or project remains stationary at the “PROJECT SITE,” while resources and workers move around it. The diagram shows various elements such as an orange crate, an industrial building, and a blue truck, all directed towards the central project site. This setup is typical for large, immobile projects where it is more efficient to bring resources and labor to the site rather than moving the product through different stages. The inclusion of utility poles and a desk with a person working on a computer highlights the coordination and planning involved in managing such a layout.

ii. Advantages and Disadvantages of Fixed Position Layout Models

Advantages

i. Suitable for large, complex products

ii. Allows for high product customization

iii. Reduces material handling of the main product

Disadvantages

i. Can lead to inefficient use of space and resources

ii. May result in longer production times

iii. Requires careful scheduling and coordination of resources

iii. Product Characteristics Suitable for Fixed Position Layout Models

Fixed position layout models are particularly suitable for

i. Large construction projects (e.g., ships, aircraft)

ii. Customized, one-off products

iii. Products that are difficult or impossible to move during production

e. Process Layouts

i. Explanation of Process Layout Models

Process layouts group similar equipment or functions together, regardless of the products being produced. This approach is often used in job shop environments where a variety of products are manufactured (Stevenson, 2018).

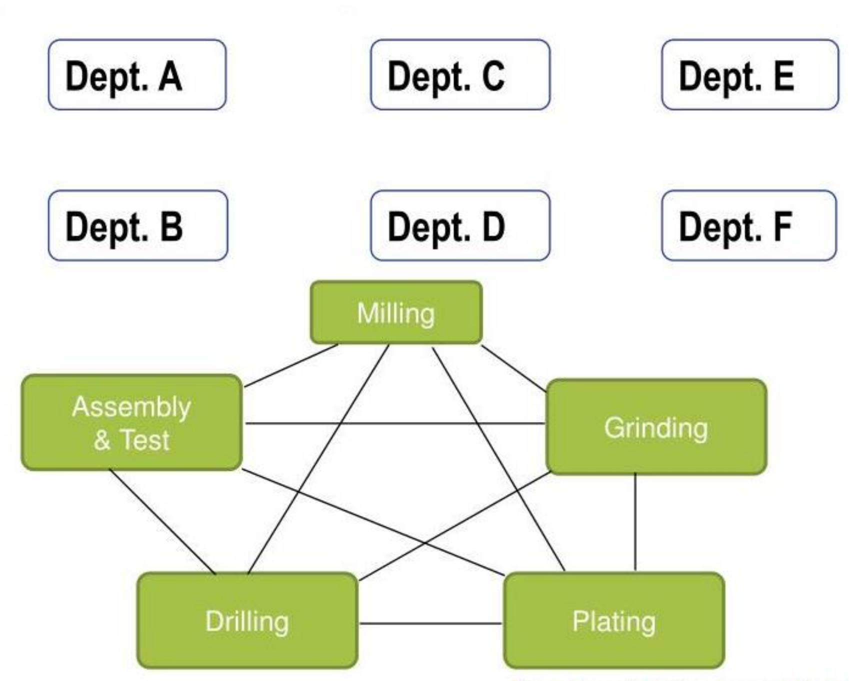

Figure 7: Process Layout -Functional

For example figure 7 illustrates a **Process Layout Model**, where similar functions or equipment are grouped together. In this diagram, various departments such as "Milling," "Grinding," "Drilling," and "Plating" are organized into distinct boxes, each representing a specific function. These departments are interconnected, forming a network that indicates the flow of materials or products between them. This layout is typical in job shop environments where a variety of products are manufactured, as it allows for flexibility in handling different processes. The inclusion of an “Assembly & Test” area further highlights the versatility of this layout, accommodating various stages of production within a single facility.

ii. Advantages and Disadvantages of Process Layout Models

Advantages

i. High flexibility for product mix changes

ii. Efficient use of specialized equipment

iii. Facilitates job enrichment and skill development

Disadvantages

i. Can lead to complex material flow patterns

ii. May result in longer production lead times

iii. Potentially higher work-in-process inventory

iii. Product Characteristics Suitable for Process Layout Models

Process layout models are particularly suitable for

i. Job shop environments with high product variety

ii. Businesses offering a wide range of services

iii. Manufacturing environments with frequently changing product mixes

f. Cellular Layouts

i. Explanation of Cellular Layout Models

Cellular layouts combine elements of both process and product layouts by grouping machines into cells to process families of similar parts or products (Groover, 2015).

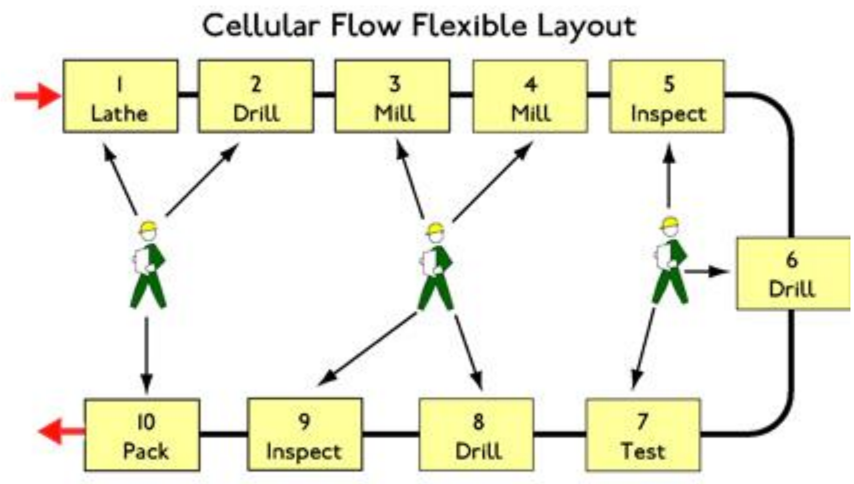

Figure 8: Cellular Layouts model

In this diagram (Figure 8), machines are grouped into cells to process families of similar parts or products. The sequence starts with a lathe, followed by drilling, milling, inspection, and continues through various stages including testing and packing. Each cell is designed to handle specific operations, minimizing movement and handling. This layout enhances efficiency by organizing workflow into manageable units, allowing for flexibility and reduced production time.

ii. Advantages and Disadvantages of Cellular Layout Models

Advantages

i. Reduces material handling and setup times

ii. Improves quality control and teamwork

iii. Combines efficiency of product layouts with flexibility of process layouts

Disadvantages

i. May require duplicating equipment across cells

ii. Can be challenging to balance workload between cells

iii. Requires careful analysis to group parts into families

iii. Product Characteristics Suitable for Cellular Layout Models

Cellular layout models are particularly suitable for

i. Environments with distinct product families

ii. Medium-volume, medium-variety production

iii. Products that benefit from grouped processing of similar parts

g. Dynamic Simulation Models

i. Explanation of Dynamic Simulation Models

Dynamic simulation models use computer software to create virtual representations of layout designs, allowing for the analysis of system behavior over time and under various conditions (Law, 2015).

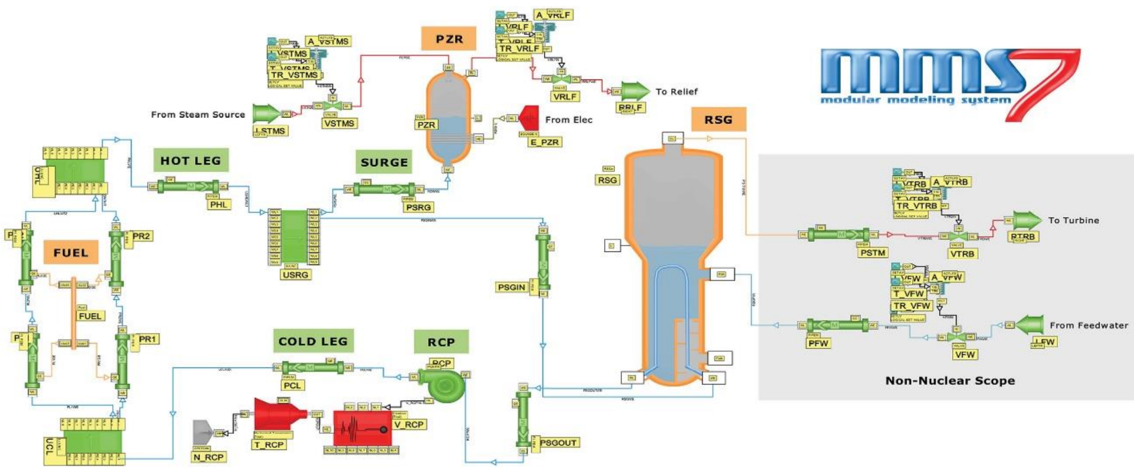

Figure 9: Dynamic Simulation Models[4]

Figure 9 shows the example of a detailed representation of a **Dynamic Simulation Model**. This model appears to simulate a complex system, such as a nuclear power plant, using computer software. The diagram includes various interconnected components like pumps, valves, tanks, and heat exchangers, each labeled with abbreviations such as ‘PZR’ for pressurizer and ‘RCP’ for reactor coolant pump. The layout is color-coded to differentiate between different parts of the system: green for flow paths, red for heat exchange elements, yellow for control systems, and blue for the reactor itself.

Explanation of Dynamic Simulation Models:

I. **Virtual Representation**

The model creates a virtual representation of the system, allowing for detailed analysis without physical trials.

[4] https://nhancetech.com/products/dynamic-simulation/

II. **System Behavior Analysis**

By simulating the system, engineers can observe how it behaves over time and under various conditions, identifying potential issues and optimizing performance.

III. **Complex Interconnections**

The interconnected components illustrate the complexity of the system and how different parts interact with each other.

IV. **Color Coding**

The use of colors helps in distinguishing different elements, making it easier to understand the flow and control mechanisms within the system.

ii. Advantages and Disadvantages of Dynamic Simulation Models

Advantages

i. Allows for testing of multiple scenarios without physical implementation

ii. Can account for complex system interactions and variability

iii. Provides visual representation of layout performance

Disadvantages

i. Requires specialized software and expertise

ii. Can be time-consuming to develop and validate

iii. Accuracy depends on the quality of input data and model assumptions

iii. Product Characteristics Suitable for Dynamic Simulation Models

Dynamic simulation models are particularly suitable for

i. Complex manufacturing systems with many variables

ii. Environments with high variability in demand or processing times

iii. Facilities requiring optimization of multiple performance metrics

Conclusion

Layout planning models play a crucial role in optimizing facility designs across various industries. Each model offers unique advantages and is suited to different types of products and production environments. The choice of layout model depends on factors such as product characteristics, production volume, variety, and specific business objectives. As manufacturing and service environments continue to evolve, the integration of these models with advanced technologies like artificial intelligence and the Internet of Things presents exciting opportunities for further optimization and efficiency gains in facility layout planning.

For example, standardized products produced in high volumes may benefit from the systematic efficiency of grid layouts, while highly customized, large products require the flexibility of fixed position layouts. As manufacturing and service environments evolve, advanced technologies like artificial intelligence (AI) and the Internet of Things (IoT) are increasingly integrated into these models, opening up new opportunities for real-time optimization and efficiency gains. AI and machine learning can analyze data from production schedules, worker movements, and equipment utilization to make data-driven decisions, enhancing layout flexibility and responsiveness to changing conditions.

IoT, by connecting machinery and devices within a facility, provides real-time insights into operational bottlenecks and resource allocation, further refining layout efficiency. As these technologies continue to advance, layout models can evolve to increase operational flexibility, support sustainability goals, and offer better scalability for businesses. In this way, layout planning remains a crucial aspect of facility design, driving continuous improvements in productivity and space utilization.

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