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Flow and Activity Analysis

- Primary activity relationships
  - Organizational relationships
    - » Span of control and reporting hierarchy
  - Flow relationships
    - » Flow of materials, people, equipment, information, and money
  - Control relationships
    - » Material and inventory control, shop floor control, level of automation
  - Environmental relationships
    - » Safety considerations, temperature, noise, fumes, humidity, and dust
  - Process relationships
    - » Floor loadings, water treatment, chemical processing, and special services.

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Flow and Activity Analysis

- Flow Analysis
  - Quantitative measure of movement between departments or activities.
- Activity Analysis
  - Nonquantitative factors that influence the location of departments or activities.
- Analyze the flow of *materials*, *information*, equipment, and personnel

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Flow Pattern Factors

- External transportation facilities
- Number of parts in the product
- Number of operations on each part
- Sequence of operations on each part
- Number of subassemblies
- Number of units to be produced
- Necessary flow between work areas
- Amount and shape of space available
- Influence of processes
- Types of flow patterns
- Product versus process type of layout
- Location of service areas
- Production department locations
- Special requirements of departments
- Material storage
- Desired flexibility
- The building

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Types of Flow Patterns

- Horizontal
  - Straight-line flow
  - L-shaped flow
  - U-shaped flow
  - Circular flow
  - Serpentine flow
- Vertical
  - Ground-level ingress and egress
    - On same side or on different sides
  - Decentralized elevation
  - Centralized elevation
  - Inclined flow
    - Bucket or belt conveyor
    - Escalator

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Flow Pattern Design

- Maximize directed flow paths
  - An uninterrupted path that does not intersect other paths
  - A flow path with no backtracking
- Minimize flow
  - Work simplification approach to material handling
    - » Eliminate flow by delivering to the point of use and eliminating intermediate steps
    - » Minimize multiple flows by moving material directly between two points in one step, i.e., avoid double handling
    - » Combine flows and operations whenever possible
- Minimize the costs of flow
  - Minimize manual handling
  - Eliminate manual handling by mechanizing or automating to allow operators to concentrate on processing

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Flow Analysis

- Analog models for describing flow
  - Flow process charts
    - » Uses circles, squares, arrows, triangles, and D for operations, inspections, transportations, storages, and delays, respectively
  - Multiproduct process charts
    - » Combines the operation process charts for several products
  - Flow diagrams
    - » Depicts the probable movement of materials superimposed on a floor plan
    - » Quite useful for evaluating existing layouts
  - From-to charts
    - » Provides information concerning the number of material handling trips made between two centers of activity and the total material handling distance

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Activity Relationship Analysis

- Assessment of qualitative factors
- Primary tool is the Activity Relationship Chart
  - – Replaces the from-to chart with a qualitative closeness rating
  - – All pairs of relationship are evaluated and assigned a closeness rating representing an ordered preference
    - » A = Absolutely Necessary
    - » E = Especially Important
    - » I = Important
    - » O = Ordinary Closeness O.K.
    - » U = Unimportant
    - » X = Undesirable
      - A and X > E > I > O > U
  - – All ratings but U are explained with a numeric code

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Activity Relationship Analysis

- Relationship Chart Construction Procedure
  - – List all departments or activities to be included.
  - – Obtain closeness ratings by interviewing or surveying persons involved in performing functions within each activity, as well as those responsible for managing one or more activities.
  - – Determine reasons used for closeness ratings and record on the relationship chart.
  - – Assign a closeness rating to each pairwise combination of activities and record the code for the reason behind the rating.
  - – Review the relationship chart with those providing input to the ratings and make appropriate adjustments in the ratings.

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Activity Relationship Analysis

- Activity relationships are often translated into proximity requirements
  - Activities with strong, positive relationships are located close together
  - Activities with strong, negative relationships are separated
- Proximity relationships can sometimes be satisfied without physical separation
  - Activities with high information exchange can be linked with communication systems
  - Negative relationships can be satisfied by enclosing noisy areas, venting fumes, etc., as opposed to physical separation

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Activity Relationship Analysis

- Activity relationship chart construction process is complicated by the multiple types of relationships that exist and influence the layout.
- It may be necessary to determine the major types of relationships and create a separate relationship chart for each one.
  - For example, a relationship chart might be created for material flow, personnel flow, and equipment flow.

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Relationship Diagram

- Activity Relationship Diagram
  - Spatially depicts the relationships between the activities.
  - Based on satisfying relationships with geographic proximity.
    - » However, this may not be the only way to satisfy "closeness" ratings.
  - Process often requires compromises if all closeness ratings cannot be satisfied.
    - » Furthermore, if a 25-ft separation satisfies a closeness requirement, does a 50-ft separation also satisfy the closeness rating?

Relationship Diagram

- Traditional Process
  - Manual "cut and try" method using equal-sized squares to represent activities.
  - Squares are moved until the designer judges that the closeness ratings have been adequately satisfied.
  - Avoid placing squares such that relationships "cross".
  - Additional constraints can be handled implicitly or explicitly
    - » For example, departments that should be located on the outside of the facility.

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Relationship Diagram

- Graph Based Process
  - Attempts to apply results from graph-theory to aid in creating relationship diagrams and block layouts.
  - "Close" is interpreted to mean *adjacent*.
  - Activities are represented by a *circle, node,* or *vertex*.
  - Activities that must be adjacent are denoted by connecting the nodes with *lines, links,* or *edges*.
  - This process yields an activity relationship diagram or graph.
    - » Also, referred to as an adjacency graph.

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Relationship Diagram

- Graph Based Process (cont.)
  - A requirement for the existence of a layout satisfying the activity relationships in the graph is that the graph be planar.
    - » A graph is planar if it can be drawn so that each edge intersects no other edge.
  - Regions defined by a graph are referred to as faces.
    - » The unbounded outside region is the exterior face.
  - Dual graph
    - » Place a node in each face
    - » Whenever two faces share an arc as a common boundary, join the nodes of the two faces by an edge crossing that arc
  - If the primal graph is planar, the dual graph will be planar also.

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Relationship Diagram

- Graph Based Process (cont.)
  - The faces of the dual graph correspond to the space assigned to the activities in the primal graph
  - Therefore, the dual graph can be used to develop a block layout
    - » Theoretically, if a dual graph is planar, a block plan exists that will satisfy all the adjacency requirements
  - However, it is not straightforward to convert the dual graph into a block plan
    - » Faces may not enclose enough space
    - » Some departments may have undesirable shapes in order to satisfy all of the adjacencies

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Relationship Diagram

- Graph Based Approach
  - May be difficult to determine planarity
    - » With N activities, at most $3N - 6$ can be adjacent.
  - Has shortcomings
    - » Nesting, close = adjacent, planarity, peculiar shapes, and no well-defined construction algorithm.
  - However, it is an aid to the layout designer in constructing more effective and efficient layouts.

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Relationship Diagram

- Relationship Diagramming Process
  - Algorithmic development of the activity relationship diagram and the unit block plan.
- Layout Algorithms
  - Construction
    - » Add departments to the layout one at a time until all departments have been placed.
  - Improvement
    - » Begin with an initial layout and search for improved solutions.
- Algorithms must address two issues:
  - The *order of placement* of departments in the relationship diagram (or unit block plan)
  - The *relative locations* of the departments

Relationship Diagramming

- Algorithm 1
  - Use equal sized square block templates to represent each department
    - » Templates record the department and its relationships with other departments
  - Select the template with the greatest number of "A" relationships
    - » Tie-breaking hierarchy: greatest number of "E" relationships, greatest number of "I" relationships, the fewest number of "X" relationships, random selection
  - Place the selected template in the center of the unit block layout
  - Select template with an "A" relationship with the already placed template and the greatest number of other "A" relationships -- Place it next to the first template

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Relationship Diagramming

- Algorithm 1 (cont.)
  - Third template should have the highest combined relationships with the two templates already selected -- It is placed as close as possible to the templates with which it has the closest relationship
  - Procedure continues in this manner until all templates are included in the unit block layout
- Because of the subjective nature in which unit block templates are located, several unit block layouts should be developed and evaluated.

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Relationship Diagramming

- Algorithm 1 Example

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Relationship Diagramming

- Algorithm 2 -- Placement Sequence
  - Assign numerical values to the closeness ratings
    - » A=10,000 ; E=1,000 ; I=100 ; O=10 ; U=0 ; X=-10,000
  - The sum of the values for the relationships of a particular department is referred to as the total closeness rating (TCR)
  - Select the initial department as the one with the greatest TCR value
    - » If ties exist, choose the one with the greatest number of "A" relationships. If ties still exist, randomly choose
  - If a department has an "X" relationship with the department just placed, it will be placed in the layout last
  - The second department placed will have an "A" relationship with the first department and have the greatest TCR value

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Relationship Diagramming

- Algorithm 2 -- Placement Sequence (cont.)
  - The third department placed is the one with the greatest TCR among those having an "A" (if none, an "E" and so forth) relationship with one of the placed departments
  - The process continues until all of the departments have been selected for placement in the layout
  - We now have a sequence of placements to be made in the layout -- the next step is to determine the relative locations

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Relationship Diagramming

- Algorithm 2 -- Relative Locations
  - Determined by weighted placement value
    - » The sum of the numerical values for all pairs of adjacent departments
  - Place "new" activities by beginning at the "western edge" of the partial layout and evaluates all possible location in counterclockwise order
  - Assign new activity to the location with the greatest weighted placement value
    - » Break ties by choosing the first encountered location with the greatest weighted placement value
  - Locations can be either "fully adjacent" or "partially adjacent", in which case they only receive half the weight for adjacency

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Relationship Diagramming

- Algorithm 2 Example

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Deltahedron Heuristic

- Adjacency based approach
- Build the graph to guarantee planarity
- Achieve the maximal weight (largest adjacency score) possible
- Algorithm
  1. Select department pair with largest weight
  2. Select next department with largest total weight with existing two departments
  3. Assign a department to a face such that the value added is maximized
  4. If unassigned departments remain, goto step 3.

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Deltahedron Heuristic Example

Material Flow Matrix

No.	Department	01	02	03	04	05	06	07	08	09
01	Receiving		70							
02	Storage			15	12	20	32		5	
03	Shearing									20
04	Sawing					5	10	5		
05	Screw m/c						5	10		3
06	Lathe					12		22		5
07	Mill									20
08	Press									15
09	Assembly									

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Deltahedron Heuristic Example

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Deltahedron Heuristic

- May exhibit umbrella effect
- Flexibility in node placement
- May be difficult to convert to suitable rectangular block layout

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Structured Adjacency Graph

- Adjacency based approach
- Build the graph to guarantee planarity
- Use a “structured” graph to facilitate creation of a block layout
  - Hexagonal grid of potential node locations
  - Limits each node to at most 6 adjacencies
- Within these constraints, achieve the maximal weight (largest adjacency score) possible

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Structured Graph Example

Material Flow Matrix

No.	Department	01	02	03	04	05	06	07	08	09
01	Receiving		70							
02	Storage			15	12	20	32		5	
03	Shearing									20
04	Sawing					5	10	5		
05	Screw m/c						5	10		3
06	Lathe					12		22		5
07	Mill									20
08	Press									15
09	Assembly									

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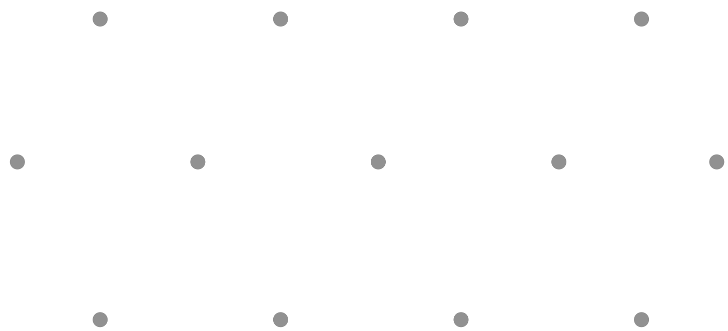
Structured Graph Example



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Structured Adjacency Graph

- Many different alternative graphs can be created
- Each graph can generate multiple layouts
- Other grid shapes are possible, but six seems to work well

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Quadratic Assignment Problem

- Departments are to be assigned to predetermined locations (sites) in the floor plan.
- Each department is treated as a unit square, so that any department can be assigned to any site.
- This is a quadratic assignment problem, since the "cost" of assigning a department to a particular location depends on the locations of the other departments.

Quadratic Assignment Problem

- Mathematical Formulation

$$\text{Min } z = \sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{h=1}^{n}\sum_{l=1}^{n} c_{jkhl} x_{jk} x_{hl}$$

$$\text{st: } \sum_{j=1}^{n} x_{jk} = 1 \text{, for } k = 1,\ldots,n$$

$$\sum_{k=1}^{n} x_{jk} = 1 \text{, for } j = 1,\ldots,n$$

$$x_{jk} = (0,1) \quad \forall j,k$$

QAP Example

- Example Formulation

Quadratic Assignment Problem

- Optimal solution procedures are difficult to solve for realistic size problems. Therefore, two types of heuristic procedures are considered.
  - Construction Procedures
    - » Develop a solution from "scratch"
  - Improvement Procedures
    - » Begin with all facilities located and try to improve the solution by switching facility locations.

QAP Algorithms

- Generic Construction Procedure
  - Assume cost is flow times distance, c = f · d
  - Order flow values from largest to smallest
  - Order distances from smallest to largest
  - Assign pairs of facilities to pairs of sites such that the facilities with the greatest flow are located at the sites having the smallest distance separation
  - Continue until all facilities have been assigned
- Lower Bound
  - Used to check quality of a given solution
  - Multiply ordered flow vector by ordered distance vector, LB = f′ · d′
  - Will not necessarily be feasible, but gives lowest possible solution value

QAP Algorithms

- Example

$$D = \begin{pmatrix} - & 8 & 10 & 2 \\ 8 & - & 4 & 7 \\ 10 & 4 & - & 9 \\ 2 & 7 & 9 & - \end{pmatrix} \quad F = \begin{pmatrix} - & 2 & 8 & 3 \\ & - & 4 & 9 \\ & & - & 5 \\ & & & - \end{pmatrix}$$

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QAP Algorithm

- Generic Improvement Procedure
  - Consider all pairwise interchanges and evaluate the cost of each
  - Perform the one that yields the greatest reduction in total cost
  - Continue until no further improvement is obtained

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