Systems Modelling and Simulation (8)

Manual Assembly lines Basics of Plant Layout Design

Further Essential Reading:

1. M. P. Groover (2001); Automation, Production Systems, and Computer Integrated Manufacturing; Second Edition; International Edition; Prentice Hall International, Inc.
2. R. G. Askin and C. R. Standridge (1993), Modelling and Analysis of Manufacturing Systems, John Wiley & Sons, Inc

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Today's discussions

- Introduction to Line Balancing
  - **Manual Assembly lines**
  - **Single model Assembly Lines**
  - **Line balancing algorithms**
  - **Mixed Model Assembly Lines**
- Basics of Plant Layout Design
  - **Introduction**
  - **System Layout Planning**

Manual Assembly Lines

- Due to nature of some manufacturing systems manual assembly is an important component
- Workstations in manual assembly lines are physical areas with the production line
- Workstations represent part of a task conducted on the product
- Each workstation can be assigned with 1 or more operators (refer to manning levels lecture 6)
- Concept of *Line Pacing:*
  - **Definition of work for each operator**
  - **Time that an operator completes a task**
  - **The station cycle time (how long a part spends in a specific workstation) with respect to production rate**

Challenges of Line Balancing

- Each workstation and operator is given equal amount of work
- Prevent bottlenecks
- Divide the total content into minimum rational work elements
- Sequence of work needs to be satisfied

Work Content Time

$$T_{wc} = \sum_{k=1}^{n_e} T_{ek}$$

Where T_{ek} time for each work element e.g. mounting wheel on wheel hub engaging bolts and tightening bolts with pneumatic tool

$$T_{si} = \sum_{k \in i} T_{ek}$$

Where T_{si} is the total time available to station i

And

$$T_{wc} = \sum_{i=1}^{n} T_{si}$$

n is the total number of stations

Example [Groover 2001]

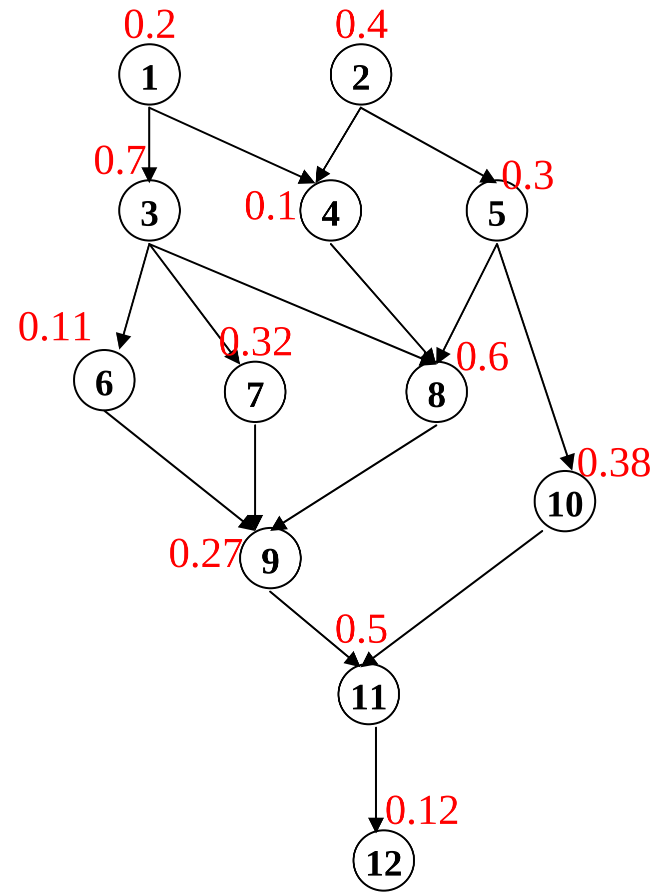
- A small manufacturing line for electronic appliance is a single model assembly line
- The work content and the sequence of each task is shown in the table 1 and diagram 1
- The line needs to be balanced for annual order of 100,000 units
- 50 weeks per year, 5 shift week and each shift 7.5 hrs.
- Manning level is 1 operator per station
- The uptime of line is 95%
- Repositioning time i.e. time lost per cycle 0.07 min.
- *Find: Total work content time T_{wc}? Required hourly production rate R_p to meet the demand? Cycle time T_c? Theoretical minimum number of **workers for the line**? **Service Time** for the balanced line?*

Example cont.

Table 1

Task No.	Work element Time(min.)	Must be Proceeded
1	0.2	
2	0.4	
3	0.7	1
4	0.1	1,2
5	0.3	2
6	0.11	3
7	0.32	3
8	0.6	3,4
9	0.27	6,7,8
10	0.38	5,8
11	0.5	9,10
12	0.12	11

Diagram 1



Solution

$$T_{wc} = \sum T_{ek} = 0.2+0.4+0.7+0.1+0.3+0.11+0.32+0.6+0.27+0.38+0.5+0.12 = 4.0$$

$$R_p = \frac{100000}{50\times 5\times 7.5} = 53.33 \textbf{ units/hr}$$

$$T_c = \frac{60(E)}{R_p} \Rightarrow T_c = \frac{60(0.95)}{53.33} = 1.07 \textbf{ min}$$

$$w = \left(\textbf{min } Int \geq \frac{T_{wc}}{T_c} \right) = \frac{4}{1.07} = 3.74 \textbf{ or 4 operators}$$

$$T_s = 1.07 - 0.07 = 1.0 \textbf{ min available service time for each station}$$

Conclusions: A line with 4 stations, 1 operator at each, available Time for each station 1 min with respect to task sequence and production rate.

Line Balancing Algorithms

The objective of line balancing is to:

$$\textbf{Minimise}\ (wT_S - T_{wc})\ \textbf{or Minimise}\ (\sum_{i=1}^{w} T_s - T_{si})$$

subject to :

$$\sum_{k \in i} T_{ek} \leq T_{wc}$$

- Largest Candidate Rule
- Kilbridge and Wester Method
- Ranked Positional Weights Method

Largest Candidate Rule (LCR)

1. Sort work elements (tasks) in descending order of their T_{ek}
2. Assign the tasks to the first work station according to precedence (sequence of tasks) ensure that Total T_{ek} is not greater than T_s
3. Start back from the top once a task is assigned
4. Proceed to next station
5. Repeat steps 1 & 2 until all tasks are assigned to the stations.

Solution

Task No.	Work element Time(min.)	Must be Proceeded
3	0.7	1
8	0.6	3,4
11	0.5	9,10
2	0.4	
10	0.38	5,8
7	0.32	3
5	0.3	2
9	0.27	6,7,8
1	0.2	
12	0.12	11
6	0.11	3
4	0.1	1,2

Solution cont.

Station	Task No.	Work element Time(min.)	Must be Proceeded	Station Time
1	2	0.4		
	5	0.3	2	
	1	0.2		
	4	0.1	1,2	1
2	3	0.7	1	
	6	0.11	3	0.81
3	8	0.6	3,4	
	10	0.38	5,8	0.98
4	7	0.32	3	
	9	0.27	6,7,8	0.59
5	11	0.5	9,10	
	12	0.12	11	0.62

Station 1	***Station 2***	***Station 3***	***Station 4***	***Station 5***
2,5,1,4	***3,6***	***8,10***	***7,9***	***11,12***

$$\textbf{Balance Efficiency} = \frac{\textbf{Total Work Content Time}}{\textbf{No. Stations} \times \textbf{max. service available time}} \frac{T_{wc}}{wT_s} = \frac{4}{5(1.0)}$$

System Layout Planning

The main objectives of facility layout planning is to:

- Improve the flow of material
- Reduce material handling time
- Health and safety
- Increase productivity by reducing operator motion and fatigue

The goal is to produce block plans showing the positioning of various departments.

The underpinning criteria for evaluating Plant layout alternatives

The main criteria for evaluating plant layout alternatives is **Material Handling Costs** consisting of:

- Depreciation of material handling equipment
- Variable operating costs of equipment
- Labour expenses for material handlers
- Material handling is considered to be an *increasing function of frequency and length of product move.*

Plant Layout Design [Askin et al 1993]

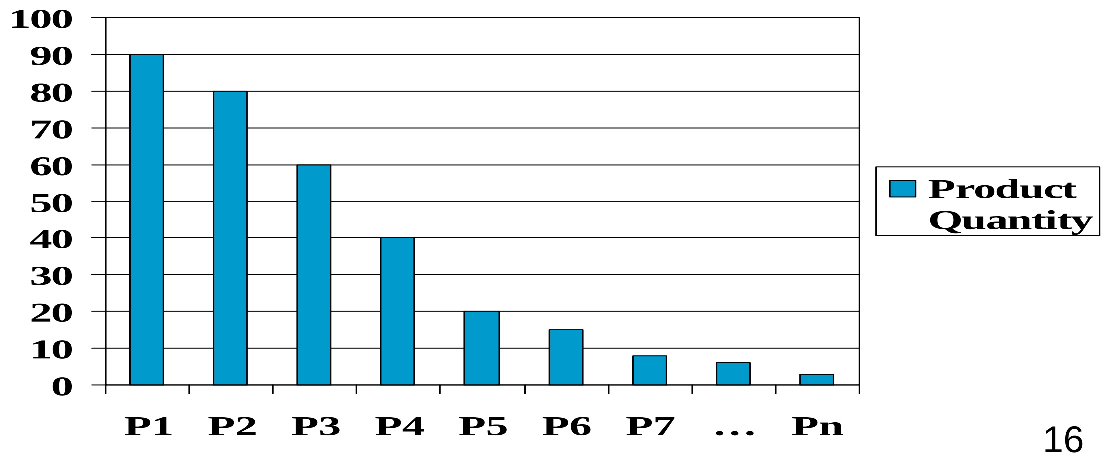
1. Systematic Layout Planning
2. Quadratic Assignment Problem Approach
3. Graph Theoretical Approach

Systematic Layout Planning (SLP)

Step 0. Data Collection: Collect relevant data – some times difficult – collect data on:

- *Product*
- *Quantity*
- *Routing*
- *Support services*
- *Timing and transport*

Product-Quantity Chart



SLP cont.

Step 1. Flow Analysis:

- *Determine the work centres that need to be spatially arranged*
- *Depends on layout type (department definitions based on product, process or cellular)*
- *Flow volumes and patterns*
- *Production Process Flowcharts (PFC) help show pattern of movement and nature of work (e.g. operation, inspection, transport, delay and storage)*
- *Quantitative flow data can be summarised with From-To charts (parts flowing from workstation **i** to department **j***
- *Determine the cost:*

$$c_{ij} = f_{ij} h_{ij} d_{ij}$$

f_{ij} **: product flow volume measured in (trips/time)**

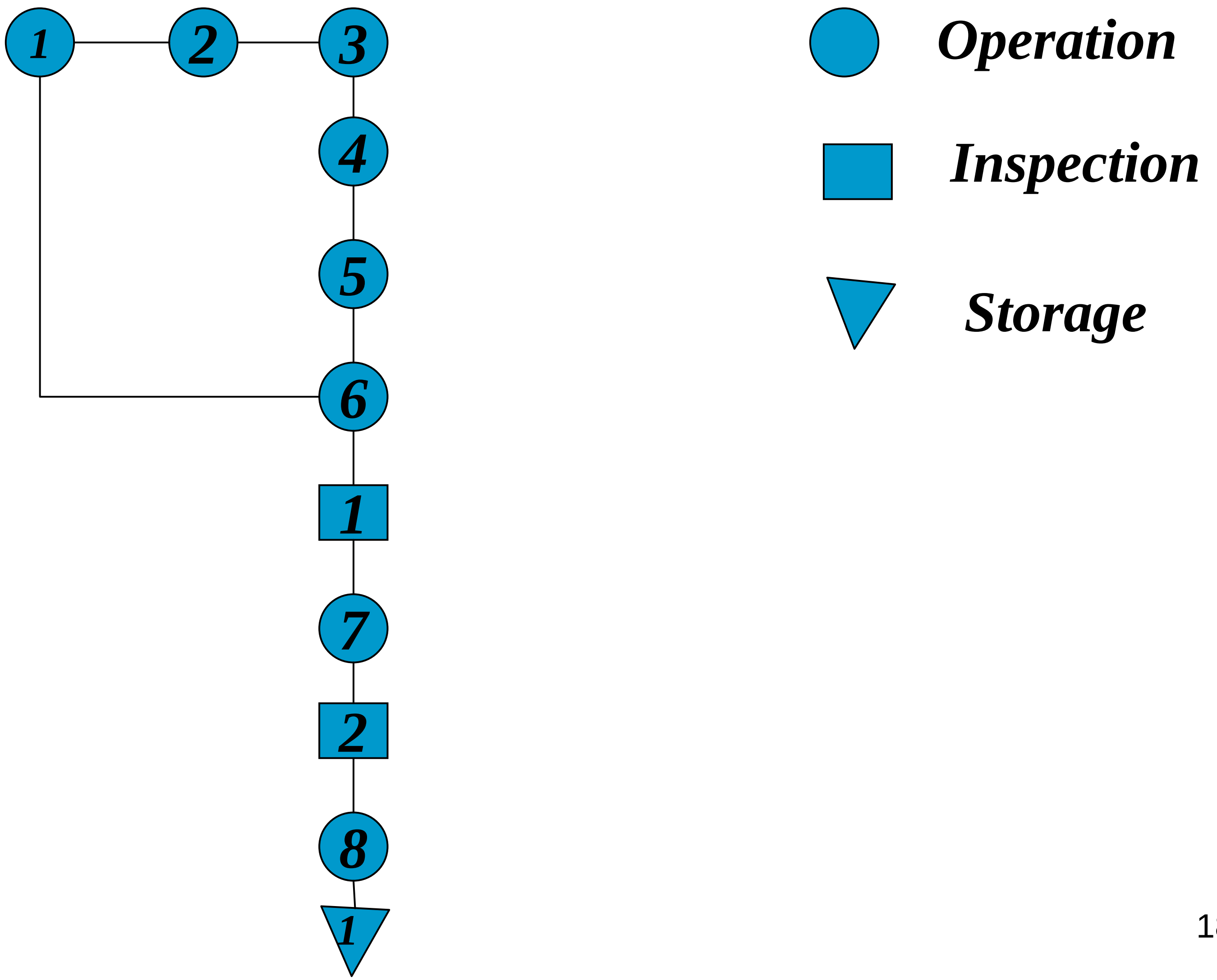
h_{ij} **: material handling system cost factor (cost/unit)**

d_{ij} **: distance between department/work centre** i **and** j

Total Cost :

$$C = \sum_i \sum_j c_{ij}$$

SLP cont. (Sample FPC)



SLP cont.

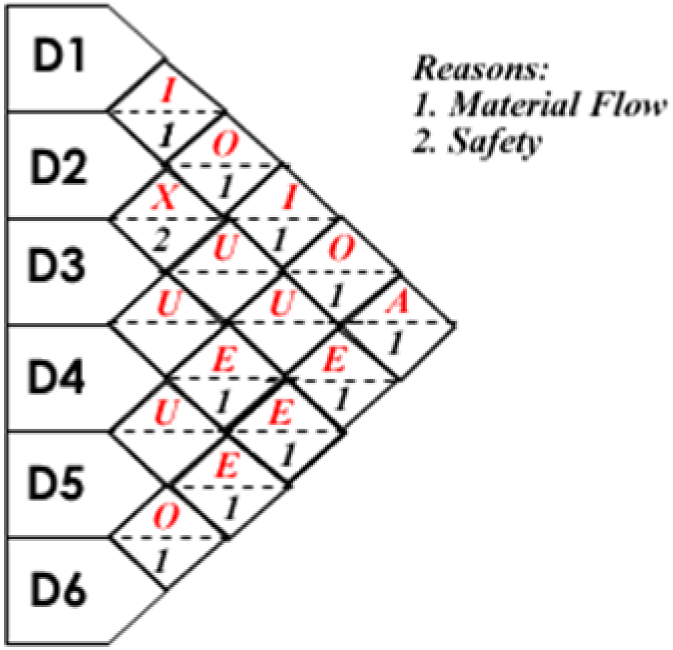
Step 2. Qualitative Considerations: In cases qualitative approach is not sufficient to determine the location of work centres. Factors such as **safety and Material Flow** have a role in plant layout design.

- Relationship Charts (REL) were design for this purpose:
  - **Upper triangular matrix that is displayed as triangle**
  - **Contains a unique diamond for each pair of work centres**
  - **Each diamond is marked with a value of (A,E,I,O,U,X)**
  - **Each mark indicates the level of desirability of two associate departments to be adjacent to one another**
  - **In this range A represents "*<u>Absolutely necessary</u>*" to X as "*Undesirable*" – *This is a quantitative approach***

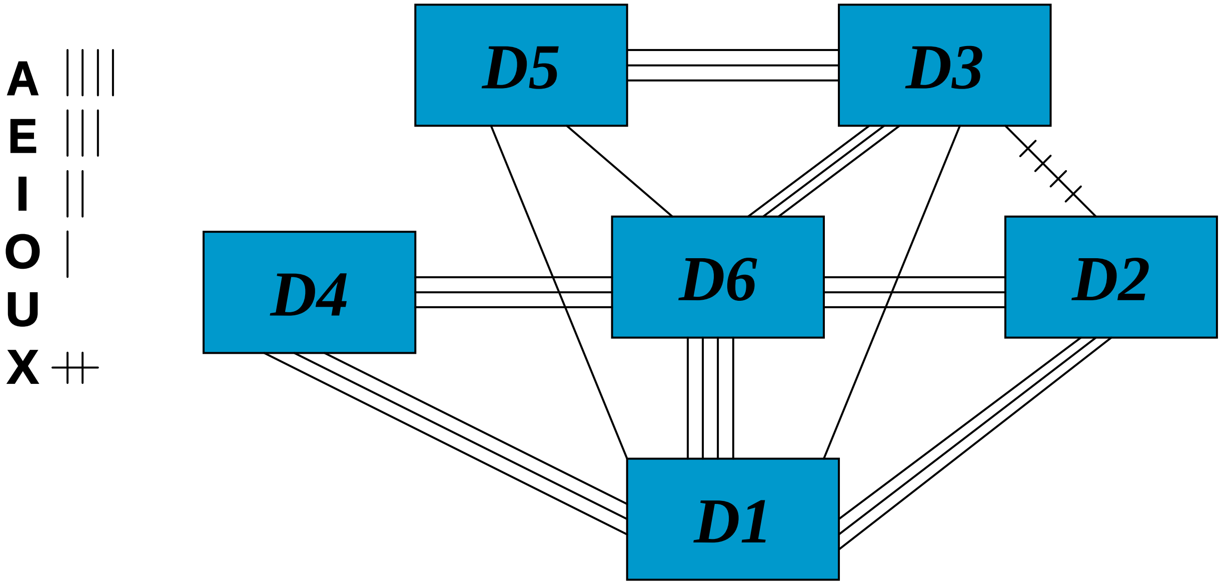
REL Chart

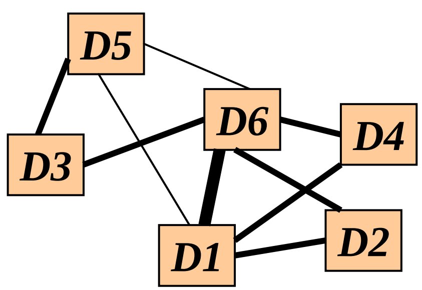
- Represents the importance of adjacency between departments:

A	Absolutely important
E	Especially important
I	Important
O	Ordinary importance
U	Unimportant
X	Undesirable



SLP Relational Diagram





Relational Diagram cont.

- The value of ratings r_{ij} *denoted as* $V(r_{ij})$ would be judged by the analyst. For example:

  V(A) = 81 , V(E) = 27, V(I) = 9, V(O) = 3, V(U) = 1 and V(X) = -243

- Total closeness rating for department " *i* " would be:

$$TCR_i = \sum_{j=1,\, j \neq i}^{M} V(r_{ij})$$

- A large value for TCR_i is an indication that a department is adjacent to many others and should be located in the centre of the plant

Relational Diagram – Maximise Closeness and Minimise Distance

1. Rank the departments in the order of their TCR_i
2. Place the department in accordance to:

$$\max V = \sum_{i=1}^{M-1} \sum_{j=i+1}^{M} \mathbf{a}_{ij} V(r_{ij}) \text{ where } \mathbf{a}_{ij} = 1 \text{ if } i \text{ and } j \text{ are adjacent}$$

$$\text{otherwise } \mathbf{a}_{ij} = 0$$

Minimising Distance

$$\min \; Z = \sum_{i=1}^{M-1} \sum_{j=i+1}^{M} V(r_{ij}) d_{ij} \text{ where } d_{ij} \text{ is the distance between } i \text{ and } j$$

Example

- Build the TCR_i the 6 departments in slide 20.

  $TCR_1 = V(I)+V(O)+V(I)+V(O)+V(A) = 9 + 3 + 9 + 3 + 81 = 105$

  $TCR_2 = V(I)+V(U)+V(U)+V(E) = 9 + 1 + 1 + 27 = 38$ V(X) is ignored? {departments 1 & 6 relationship}

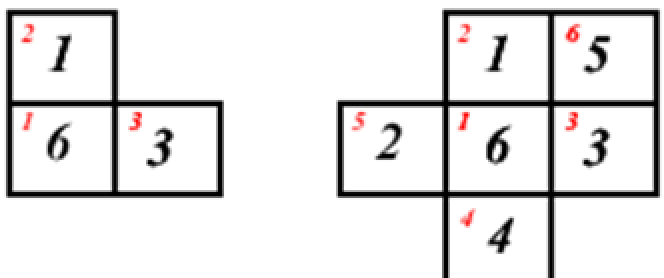
  $TCR_3 = V(O)+V(U)+V(E)+V(E) = 58$

  $TCR_4 = V(U)+V(U)+V(I)+V(U)+V(E) = 39$

  $TCR_5 = V(O)+V(U)+V(E)+V(U)+V(O) = 35$

  $TCR_6 = V(O)+V(E)+V(E)+V(E)+V(A) = 164$

Rank	Dept.
1	6
2	1
3	3
4	4
5	2
6	5

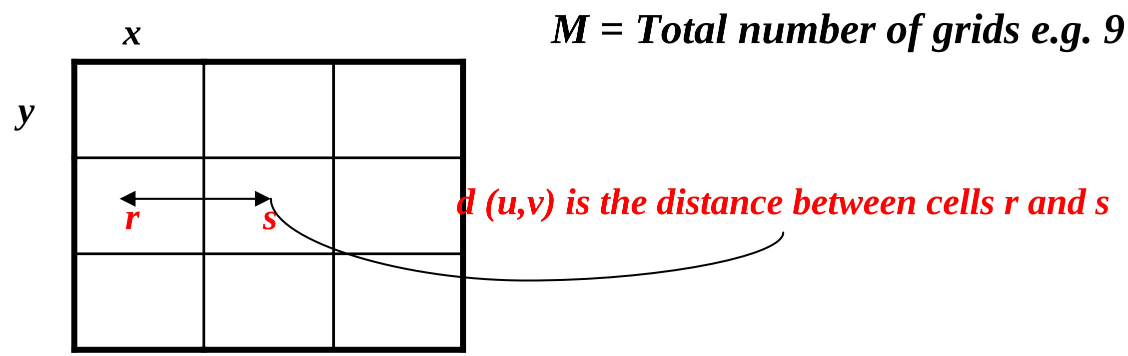


(a) (b)

Example cont.

- Further improvement to the layout can be sought by switching departments locations
- Improvements can be made with either ***distance*** or ***adjacency*** measurement
- To simplify the calculations we do as follows:
  - ***Assume that $f_{ij} = f_{ji}$ is the flow of material in both directions***
  - ***Prospective departments constitute a grid with specified dimensions***

M = Total number of grids e.g. 9



Example cont.

- A feasible solution to layout problem is a vector:

$$\alpha = (\alpha_1, \alpha_2, ..., \alpha_M) \text{ where } \alpha_i \text{ is the grid assigned to department } i$$

- So that:

$$\textbf{Total flow cost}: C(\alpha) = \sum_{i=1}^{M-1} \sum_{j>i} f_{ij} d(\alpha_i, \alpha_j)$$

- Suppose we exchange departments *u* and *v* and α is the original assignment and α' is the modified layout then:

$$\Delta C_{uv}(\alpha) = C(\alpha) - C(\alpha') = \sum_{i=1}^{M-1} \sum_{j>i} f_{ij} d(\alpha'_i, \alpha'_j) \quad \textbf{or}$$

$$\Delta C_{uv}(\alpha) = \sum_{i=1}^{M} (f_{iu} - f_{iv})[d(\alpha_i, \alpha_u) - d(\alpha_i, \alpha_v)] - 2 f_{uv} d(\alpha_u, \alpha_v)$$

Example cont.

- **And for adjacency measurement:**

$$\Delta V_{uv}(\alpha) = \sum_i [V(r_{ui}) - V(r_{vi})][\mathbf{a}_{ui}(\alpha) - \mathbf{a}_{vi}(\alpha)] - 2\mathbf{a}_{uv}(\alpha)V(r_{uv})$$

Where r_{ij} is the relationship between two adjacent departments

- **Exercise:**

  Assume we want to switch the places for department 6 and 5 – Using Adjacency measurement assess if it is a good idea to do so.

$$\Delta V_{6,5}(\alpha) = [(81-3)(1-1)]_{i=1} + [(27-1)(1-0)]_{i=2} + [(27-27)(1-1)]_{i=3} + [(27-1)(1-0)]_{i=4} + [(3-0)(0-1)]_{i=5} + [(0-3)(1-0)]_{i=6} - 2(0)3 = 26$$

A positive $\triangle V$ represents decrease in adjacency score and it is not desirable.

SLP cont.

- There are a few more steps such as:
  - **Space requirements (how much space each department needs)**
  - **Space availability**
  - **Space relationship (due to the shape and land availability it is important to account for space relationship – awkward shapes may lead to loss of space**
  - **Other limitations that may influence decisions**
  - **Continuous evaluation with changes occurring to the processes**

Further reading Askin et al (1993)

Finally