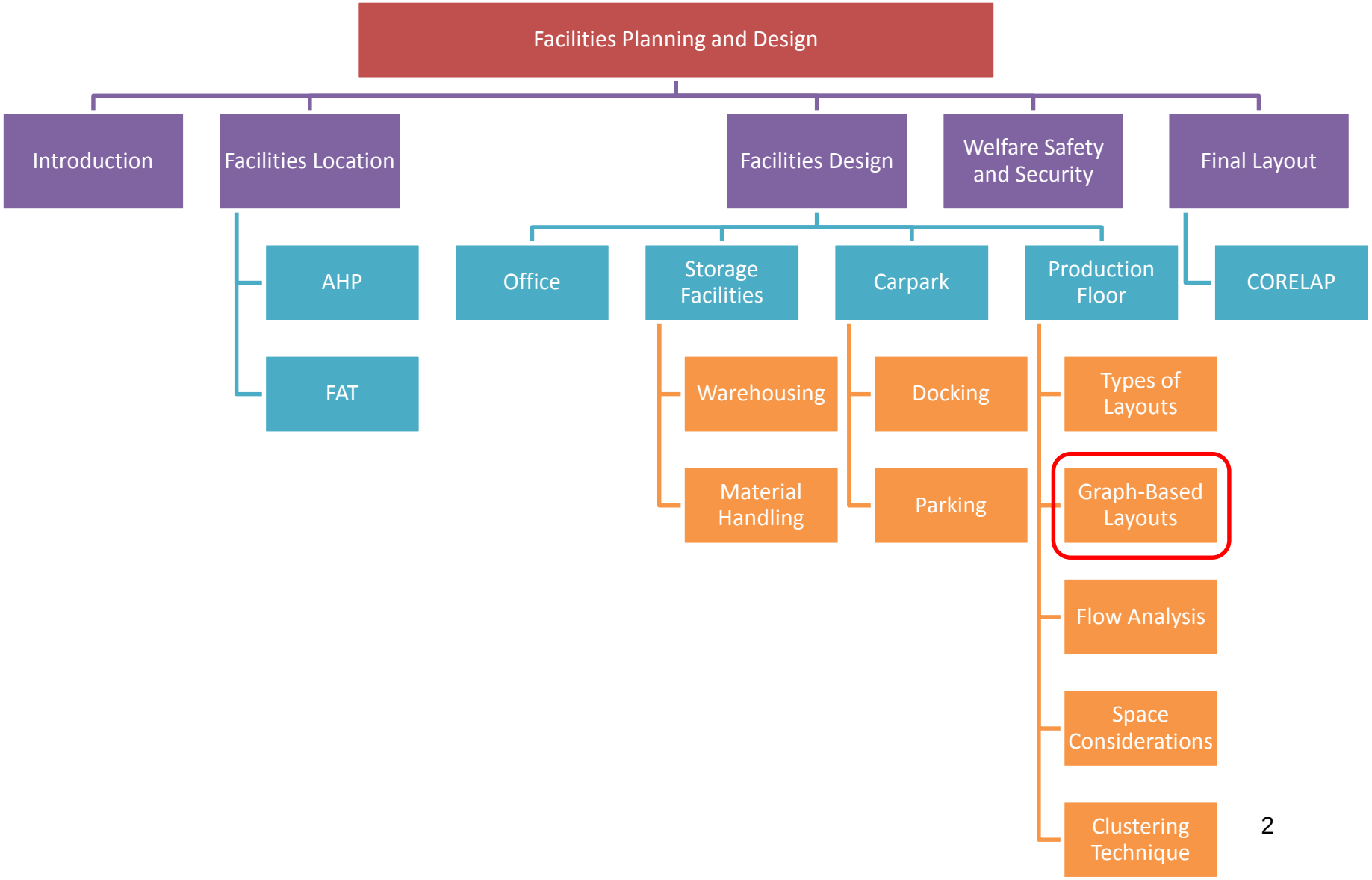
Problem 05
Graph and Layout

E212 – Facilities Planning and Design

SCHOOL OF ENGINEERING

E212 Facilities Planning & Design - Topic Tree



Learning Objectives

- Derive a Relationship (REL) Chart and create a TCR Table for a facility.

- Construct a planar graph of the REL chart by using Graph-Based approach.

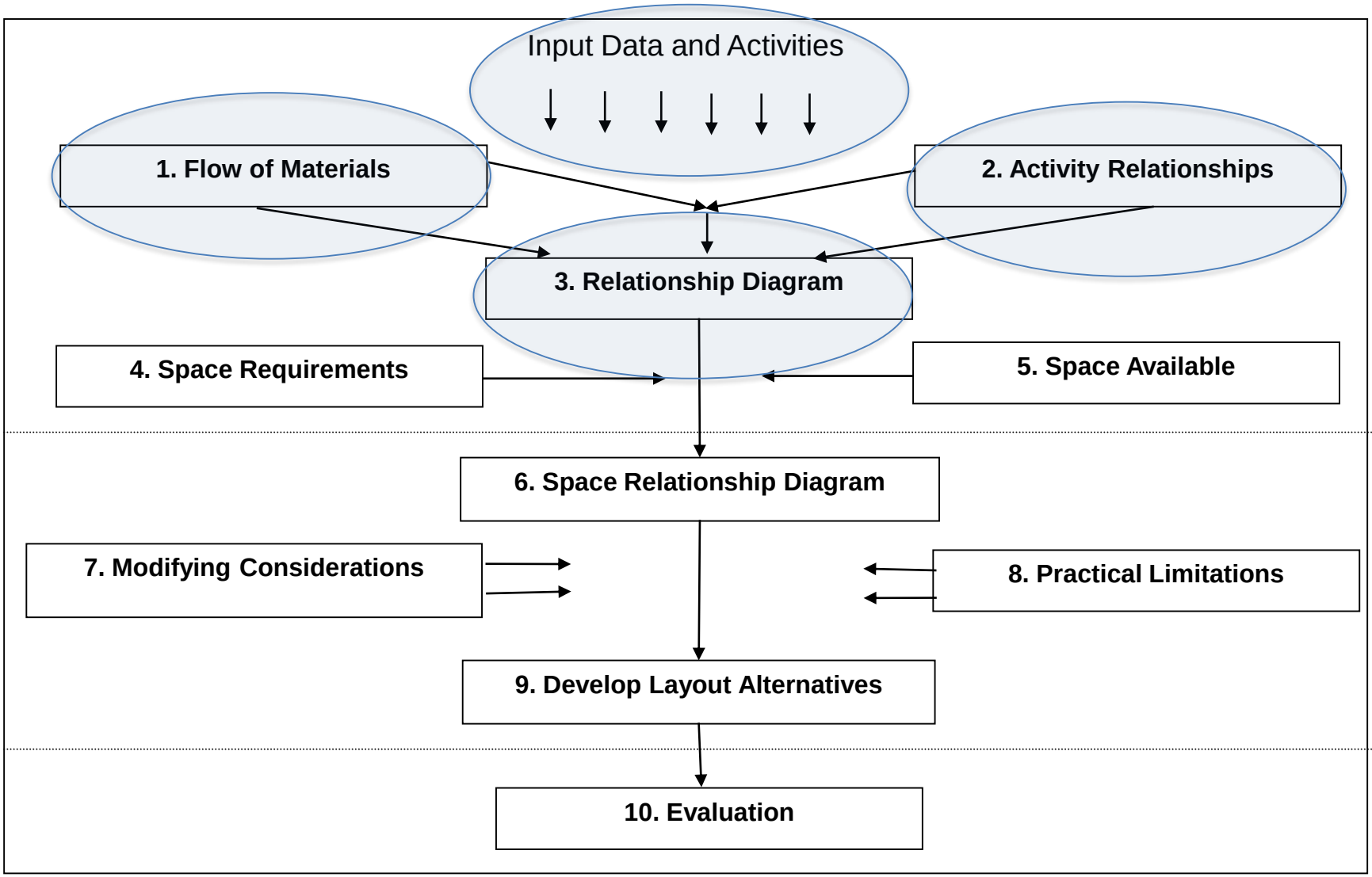
- Draft out a facility layout using AutoCAD.

Layout Decisions (Recall)

- The need for layout decisions:
  - Support new product or service introduction
  - Support change in the design of products or services
  - Remove inefficient operations, e.g. high-cost process
  - Remove safety hazards

- A good layout design is able to:
  - Support changes in volume of output or mix of products
  - Support changes in equipment or work methods
  - Address environmental, legal and other statutory requirements

Systematic Layout Planning (Muther's)

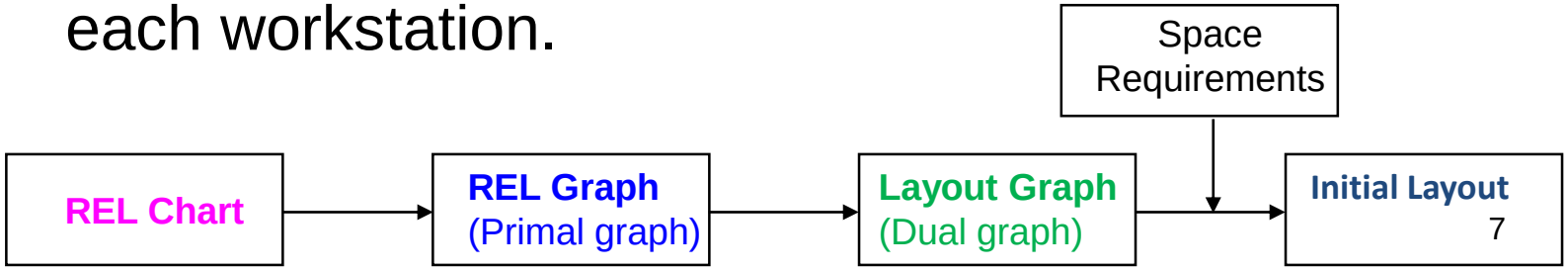


Introduction to Graph Based Method

- Fairly Simple in concept and can be carried out by hand
- Qualitative Relationship (REL) chart is used as opposed to quantitative traffic flow data
- Final solution is dependent on REL chart
- No improvement process is allowed as the procedures focus on construction
- Department can be exchanged to reduce transportation works in Graph-Based Method
- Graph-Based Method does not have to be restricted to a unit square shape placement

Graph-Based Layout Construction

- General Procedures:
  1. Construct a REL chart, relating all departments involved.
  2. With the REL chart, use the Heuristic procedure to construct the REL graph (Primal Graph).
  3. Construct the Layout Graph (Dual Graph) by taking the dual of the REL graph, letting the facility exterior node of the REL graph be in the exterior face of the layout graph.
  4. Convert the layout graph into an initial layout, taking into consideration the space requirement of each workstation.

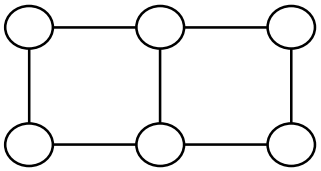


Requirement: Planar Graph

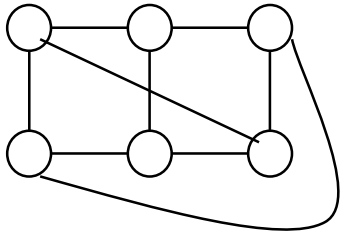
- A requirement for a layout to satisfy the workstation relationships depicted in the graph: the graph has to be planar.

- A graph is planar if
  - its vertices are points in the space
  - each edge does not intersect other edges or vertices.

  e.g.



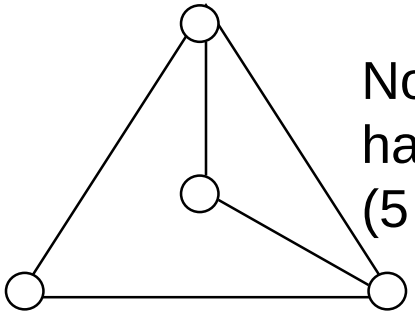
Planar



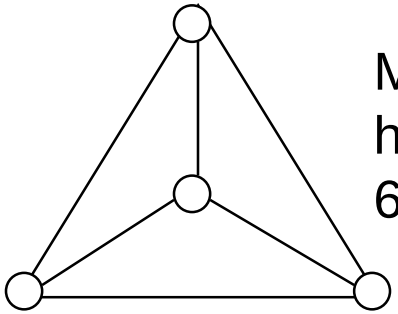
Nonplanar

Maximally Planar Graph (MPG)

- Given an M number of activities, a planar graph with exactly 3M-6 arcs is called **Maximally Planar Graph (MPG).**
- E.g. if given 4 activities, M=4:

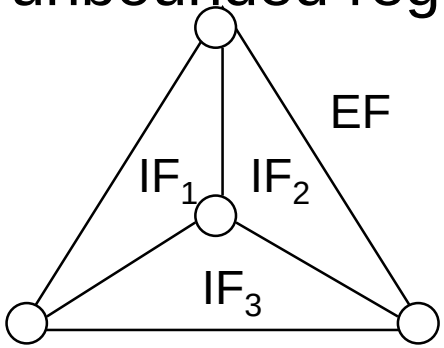


Not MPG since has only 5 arcs ($5 < 6 = 3M-6$)



MPG since has 6 arcs ($3M-6 = 3(4)-6$)

- The interior faces of a graph are the bounded regions formed by its arcs, and its exterior face is the unbounded region formed by its outside arcs.



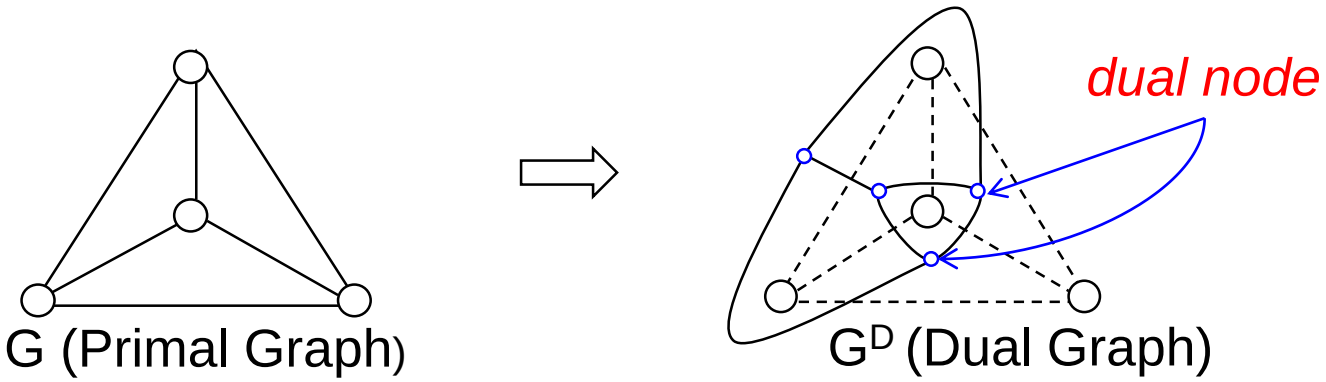
The tetrahedron has 3 interior faces (IF_1, IF_2 and IF_3) and 1 exterior face (EF)

Maximally Planar Weighted Graph (MPWG)

- An MPG whose sum of arc weights is as large as any other possible MPG is called a Maximally Planar Weighted Graph (MPWG).
- Using the $V(r_{ij})$'s as arc weights, a REL graph that is a MPWG has the maximum possible Layout Score (LS^a), close to Layout Score Upper Bound (LS^a_{UB}) which is the sum of 3M-6 highest $V(r_{ij})$.
- A Heuristic (non-optimal) procedure will be used to construct a REL graph that is an MPG, but may not be an MPWG (although its LS^a will be close to LS^a_{UB}).
- If $LS^a_{UB}=LS^a$, the final REL Graph is an MPWG - it is optimal.
- If $LS^a_{UB}>LS^a$, the final REL Graph may not be an MPWG -it may not be optimal.

Dual Graph

- An additional aspect of a graph is its dual.
- To construct the dual of a planar graph, place a dual node in each face of the primal graph.
- Whenever two faces are adjacent in primal, connect the corresponding dual nodes by an edge such that it crosses the edge that divides the primal faces, e.g.:

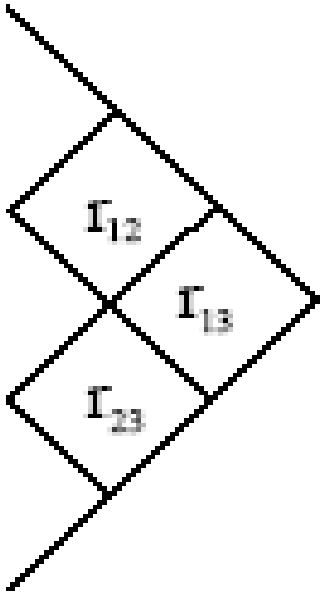


- If the REL Graph (also known as Primal Graph) is a planar graph, its Layout Graph (also known as Dual Graph) will also be planar.

Relationship (REL) Chart

- A number of factors other than material handling flow (cost) might be of primary concern in layout.
- A Relationship (REL) Chart represents M(M-1)/2 symmetric qualitative relationships, i.e.

  (M = number of departments)



$r_{ij} \in \{A, E, I, O, U, X\}$: Closeness Value (CV) between activities i and j; r_{ij} is an ordinal value

Assignment of Importance – Closeness Ratings

Assign the relationship with the ratings shown.

The percentage is a guideline to how much of each rating should be assigned with respect to the total number of relationships in the REL chart, in order for the REL chart to be appropriate.

A = absolutely necessary ≤ 5 %
E = especially important ≤ 10 %
I = important ≤ 15 %
O = ordinary closeness ≤ 20 %
U = unimportant ≥ 50 %
X = undesirable ≤ 5 %

In some cases, due to real-life circumstances (i.e.: safety considerations), it may not be possible to follow the guideline strictly. However, if the REL chart is just slightly inappropriate, most likely it will still be usable.

Closeness Values

- $V(r_{ij})$ = arbitrary closeness value assigned to r_{ij},

  For example,

  V(A) = 125

  V(E) = 25

  V(I) = 5

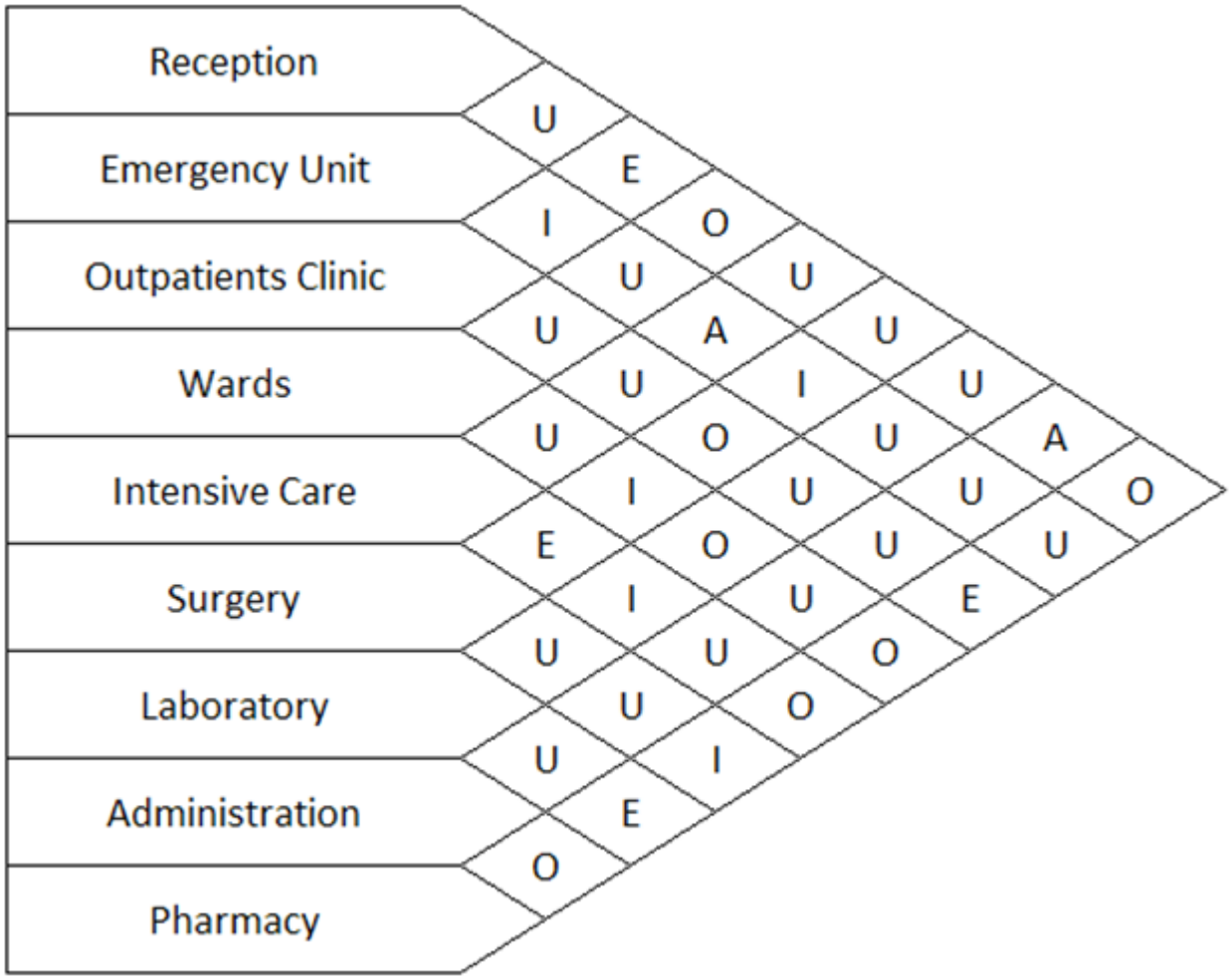
  V(O) = 1

  V(U) = 0

  V(X) = -125

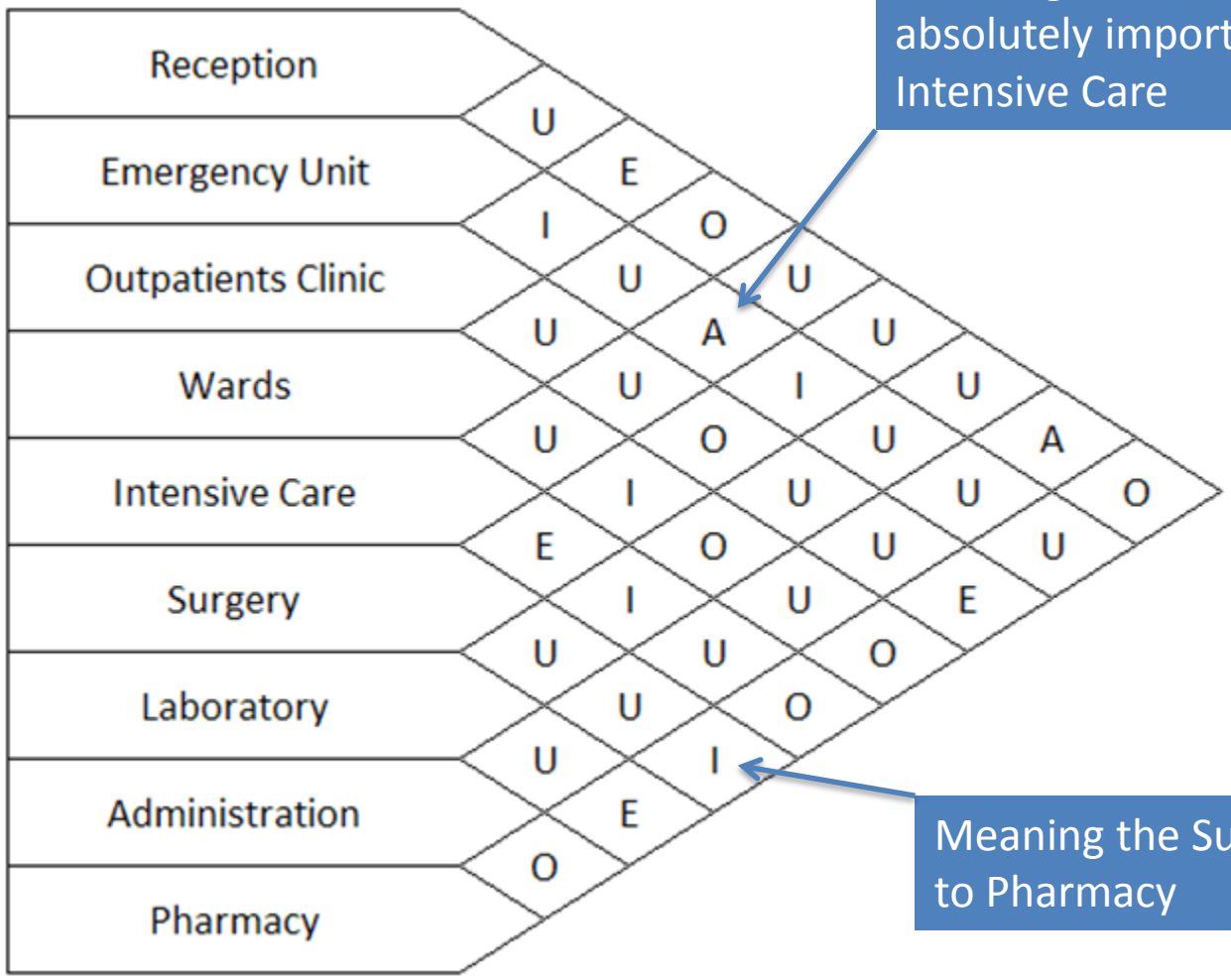
- The closeness values chosen are purely **arbitrary**, however it is recommended that the assigned closeness values have sufficiently large differences between different ratings

Example of REL Chart



V(A) = 125
V(E) = 25
V(I) = 5
V(O) = 1
V(U) = 0
V(X) = -125

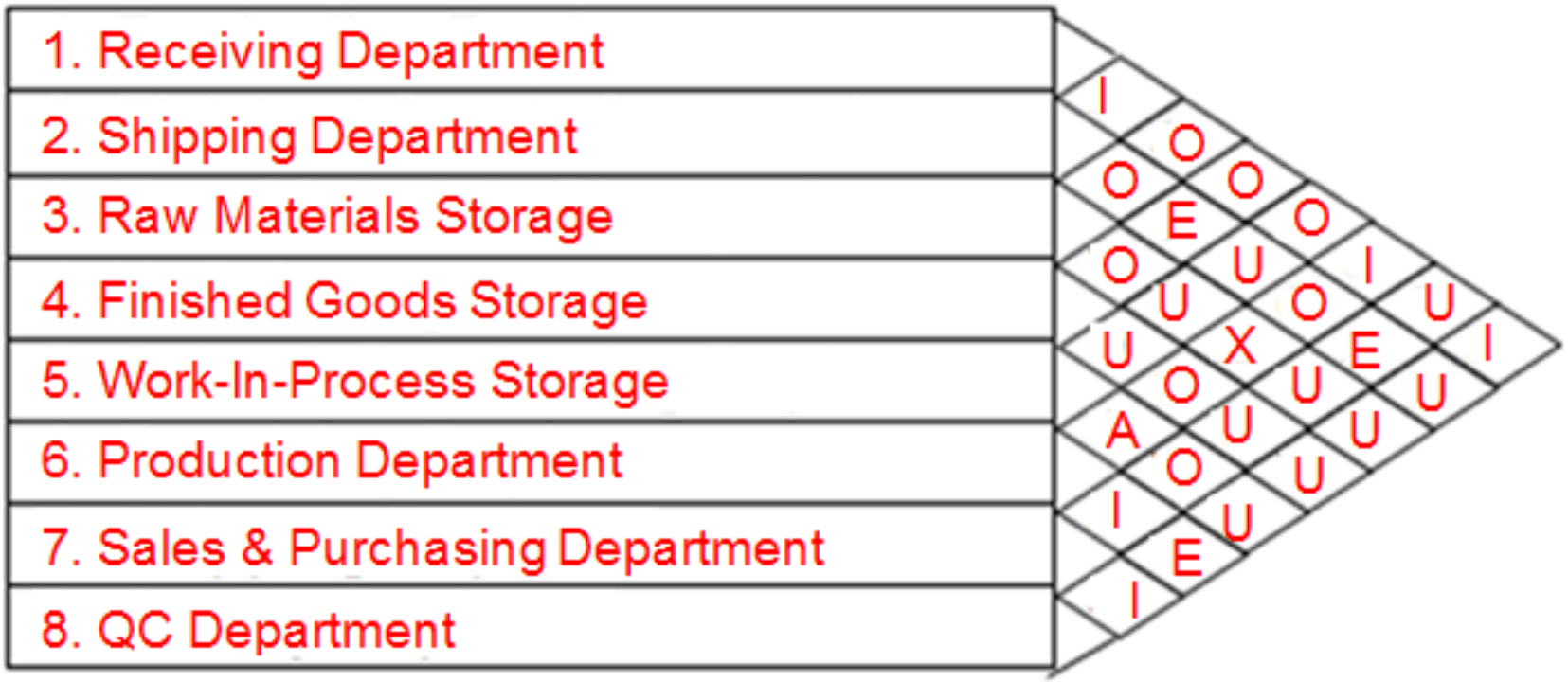
Example of REL Chart for a Hospital



Meaning the Emergency Unit is absolutely important to be closed to Intensive Care

Meaning the Surgery Unit is important to Pharmacy

Another example…Relationship Chart



What is the relationship between Shipping department and QC department ?

Total Closeness Rating

- For each department, the Total Closeness Rating (TCR) is the sum of the values of the relationships with other departments

- For example:

Department	Department									Summary							
	1	2	3	4	5	6	7	8	9	A	E	I	O	U	X	TCR	Order
1. Reception		U	E	O	U	U	U	A	O	1	1	0	2	4	0	152	2
2. Emergency Unit	U		I	U	A	I	U	U	U	1	0	2	0	5	0	135	3
3. Outpatients Clinic	E	I		U	U	O	U	U	E	0	2	1	1	4	0	56	6
4. Wards	O	U	U		U	I	O	U	O	0	0	1	3	4	0	8	9
5. Intensive Care	U	A	U	U		E	I	U	O	1	1	1	1	4	0	156	1
6. Surgery	U	I	O	I	E		U	U	I	0	1	3	1	3	0	41	7
7. Laboratory	U	U	U	O	I	U		U	E	0	1	1	1	5	0	31	8
8. Administration	A	U	U	U	U	U	U		O	1	0	0	1	6	0	126	4
9. Pharmacy	O	U	E	O	O	I	E	O		0	2	1	4	1	0	59	5

Example: TCR Value Computation

Closeness Values	
V (A)	1000
V (E)	100
V (I)	10
V (O)	1
V (U)	0
V (X)	-1000

Choose the department with highest TCR (Department 5) to start the layout

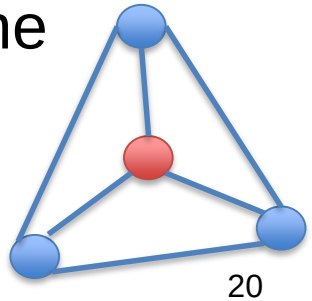
	Departments								Summary						
Departments	1	2	3	4	5	6	7	8	A	E	I	O	U	X	TCR
1. Receiving Department		I	O	O	O	I	U	I	0	0	3	3	1	0	33
2. Shipping Department	I		O	E	U	O	E	U	0	2	1	2	2	0	212
3. Raw Materials Storage	O	O		O	U	X	U	U	0	0	0	3	3	1	-997
4. Finished Goods Storage	O	E	O		U	O	U	U	0	1	0	3	3	0	103
5.Work-In-Process Storage	O	U	U	U		A	O	U	1	0	0	2	4	0	1002
6. Production Department	I	O	X	O	A		I	E	1	1	2	2	0	1	122
7. Sales & Purchasing Department	U	E	U	U	O	I		I	0	1	2	1	3	0	121
8. QC Department	I	U	U	U	U	E	I		0	1	2	0	4	0	120

REL Graph Construction

Step 1: Start by identifying FOUR (4) departments of the highest Total Closeness Rating (TCR).

Each department is represented by a node (or circle, or vertex).

Step 2: These 4 departments are then connected between one another with lines. All departments that must be adjacent are denoted by connecting the respective nodes with lines (or links, or edges). Form a **tetrahedron** with the first 4 departments with the highest TCR - to form an MPG.



REL Graph Construction

Step 3: Then, choose the next entering department with the next highest TCR (i.e. the 5th highest TCR). To place the next node 5 at all internal and external faces to determine the Layout Score (LSa) of node 5.

Step 4: Select the best location for this entering department, which is the face (can be External or Internal faces) with the maximum possible LS^a (to be Maximally Planar Weighted Graph (MPWG)).

Step 5: Continue Step 3-4 until all departments are inside the REL graph.

Layout Graph and Initial Layout

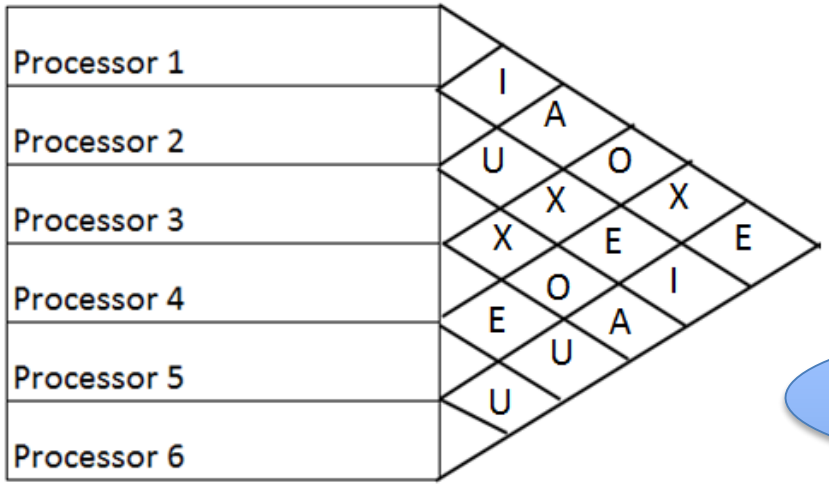
Step 6: Add a final exterior workstation (denoted by "EX") that connects the departments with outside arcs.

Step 7: Construct a Layout Graph, which is the dual of the REL graph.

Step 8: Convert the Layout Graph (Dual Graph) into Block Layout (that represents the initial layout).

Work Example

- Given the following REL Chart & TCR table



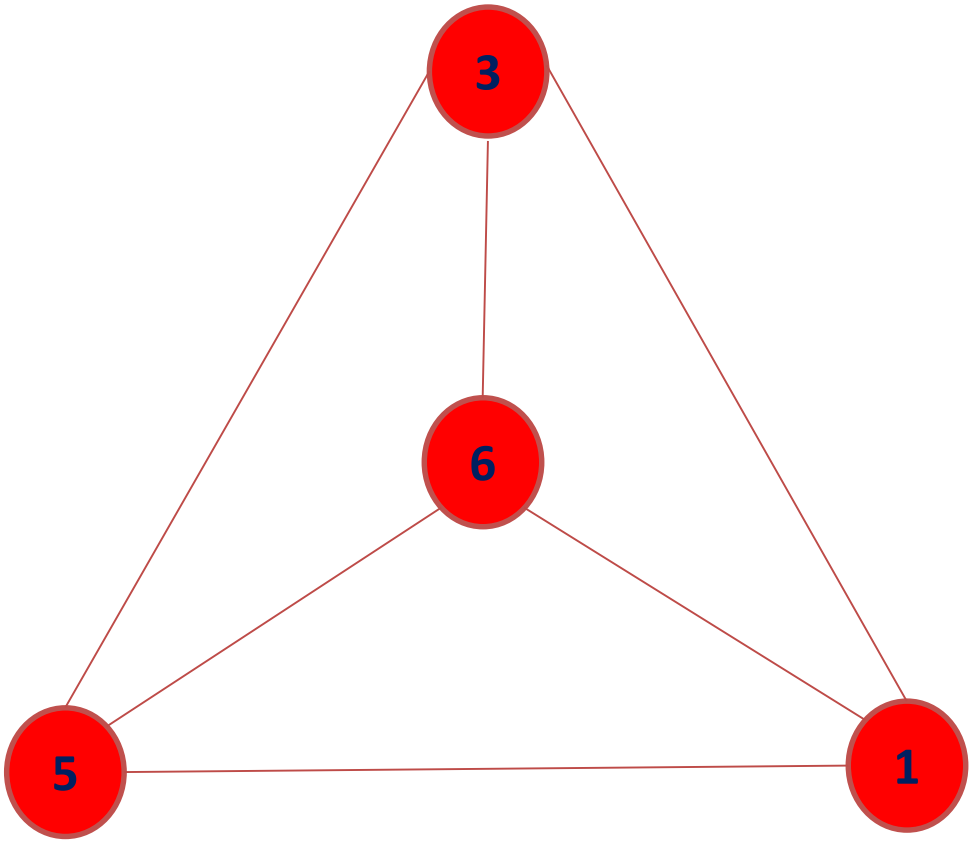
V(A) = 125
V(E) = 25
V(I) = 5
V(O) = 1
V(U) = 0
V(X) = -125

TCR
=1*125+1*25+1*5+1*(-125)
= 31

	Processor Activity						Summary							
Processor Activity	1	2	3	4	5	6	A	E	I	O	U	X	TCR	Rank
Processor 1		I	A	O	X	E	1	1	1	1	0	1	31	3*
Processor 2	I		U	X	E	I	0	1	2	0	1	1	-90	5
Processor 3	A	U		X	O	A	2	0	0	1	1	1	126	2*
Processor 4	O	X	X		E	U	0	1	0	1	1	2	-224	6
Processor 5	X	E	O	E		U	0	2	0	1	1	1	-74	4*
Processor 6	E	I	A	U	U		1	1	1	0	2	0	155	1*

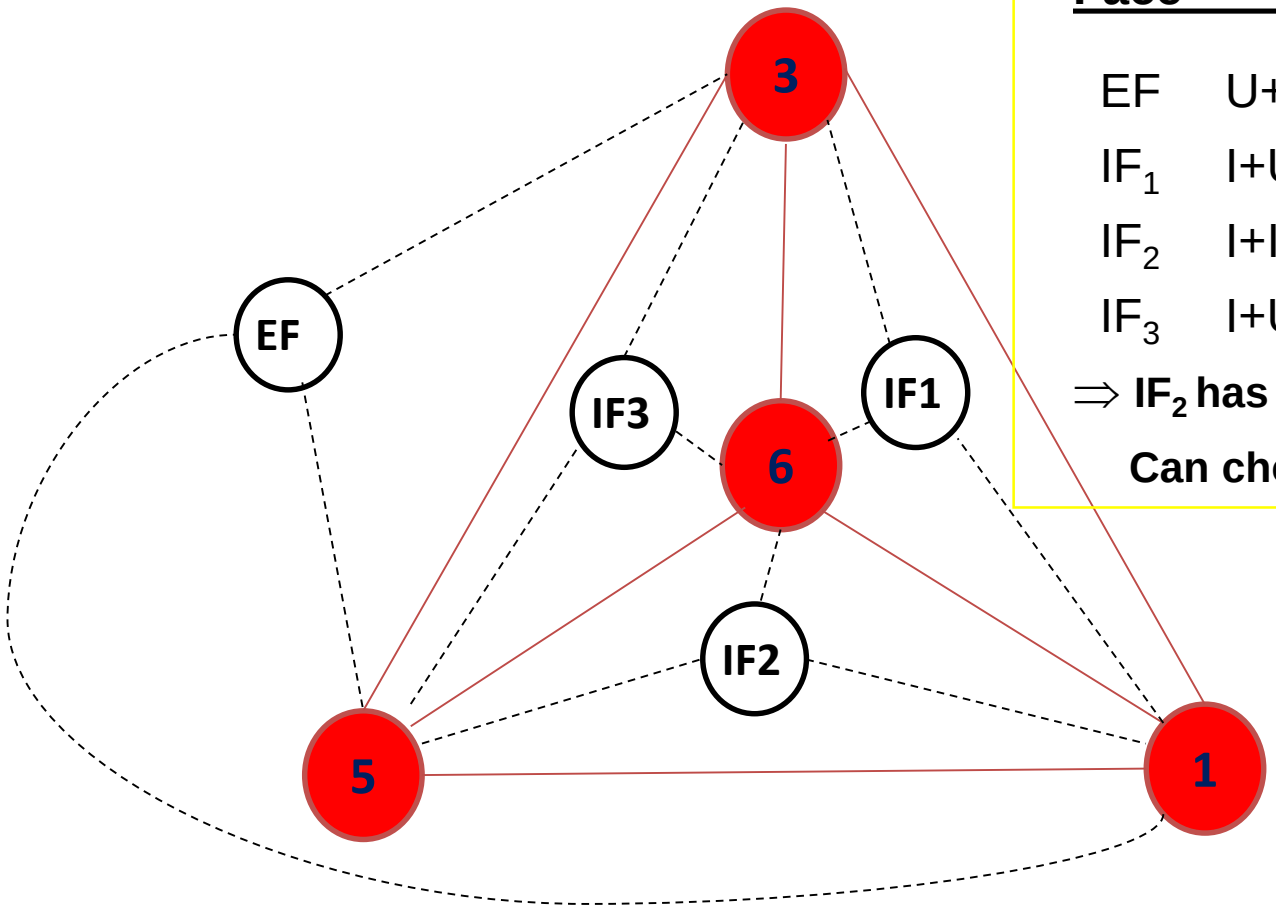
Work Example

- Form a tetrahedron with the first 4 workstation with the highest TCR - to form an MPG.



Work Example

- To place the next workstation 2
- Layout Score (LS^a) of workstation 2 at all internal and external faces (IF1~IF3, EF):



Face	LS^a
EF	U+E+I =0+25+5 = 30
IF_1	I+U+I = 5+0+5 = 10
IF_2	I+I+E= 5+5+25 = 35
IF_3	I+U+E = 5+0+25 = 30

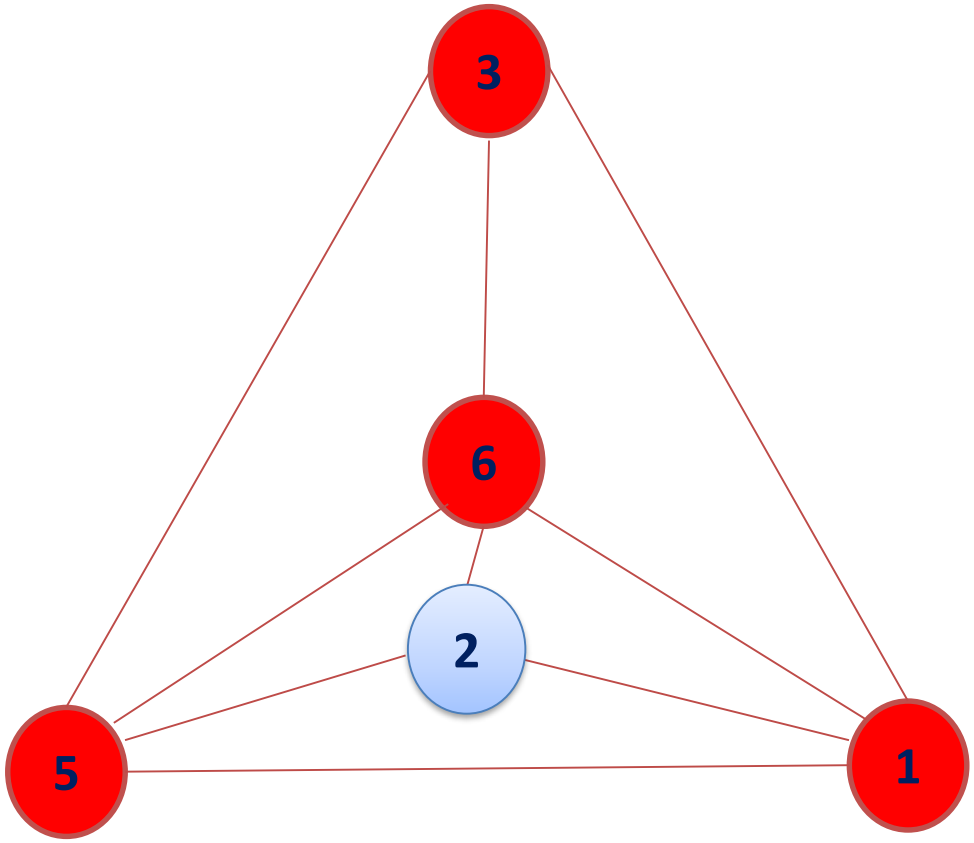
⇒ **IF_2 has the highest Ls^a;**

Can choose IF2

Closeness Values	
V (A)	125
V (E)	25
V (I)	5
V (O)	1
V (U)	0
V (X)	-125

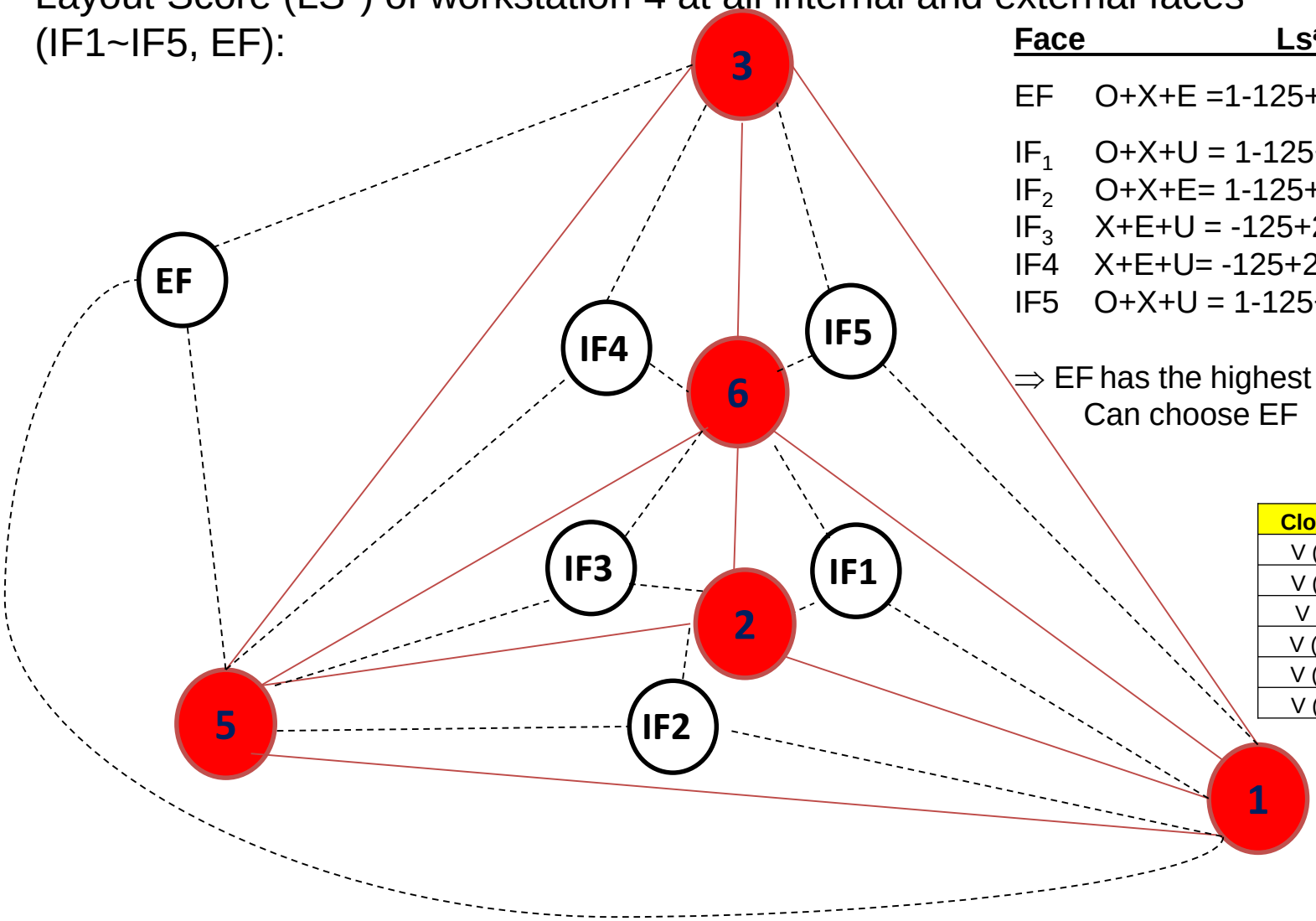
Work Example

Added workstation 2



Work Example

To place the next workstation 4
Layout Score (LS^a) of workstation 4 at all internal and external faces (IF1~IF5, EF):



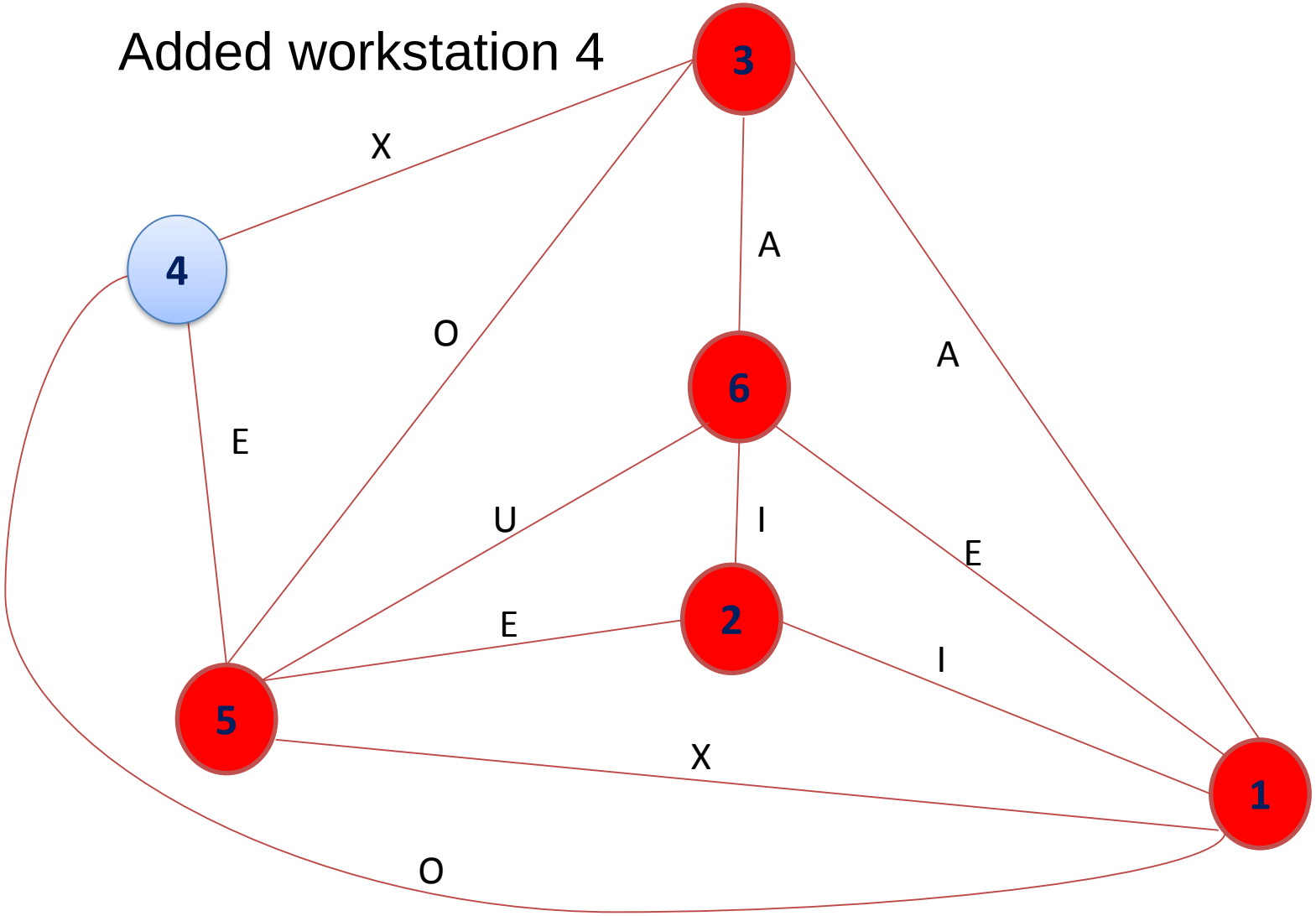
Face	Ls^a
EF	O+X+E =1-125+25 = -99
IF_1	O+X+U = 1-125+0 = -124
IF_2	O+X+E= 1-125+25 = -101
IF_3	X+E+U = -125+25+0 = -100
IF4	X+E+U= -125+25+0 = -100
IF5	O+X+U = 1-125+0=-124

⇒ EF has the highest Ls^a;
Can choose EF

Closeness Values	
V (A)	125
V (E)	25
V (I)	5
V (O)	1
V (U)	0
V (X)	-125

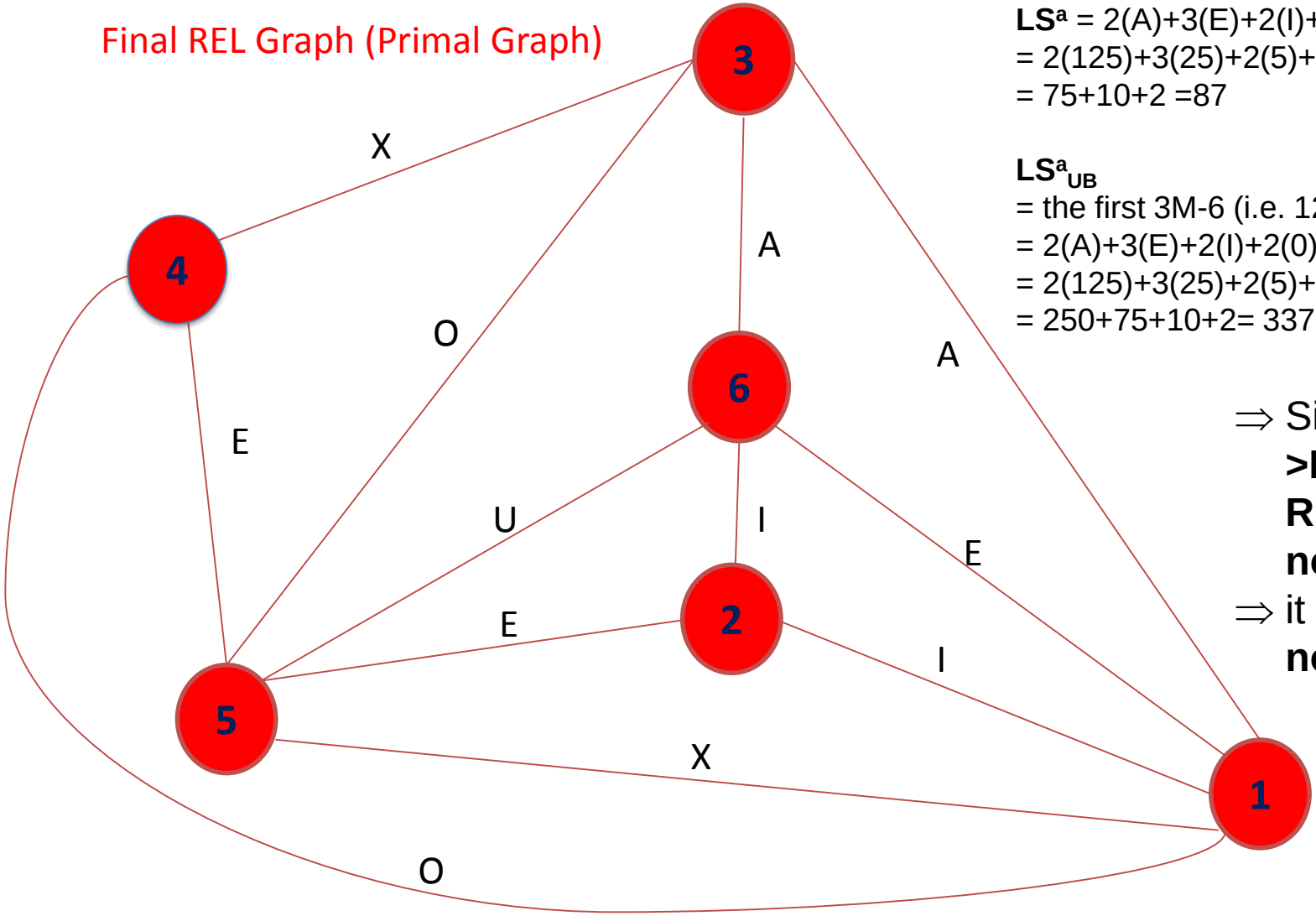
Work Example

Added workstation 4



Work Example

Final REL Graph (Primal Graph)



LS^a = 2(A)+3(E)+2(I)+2(O)+1(U)+2(X)
= 2(125)+3(25)+2(5)+2(1)+1(0)+2(-125)
= 75+10+2 =87

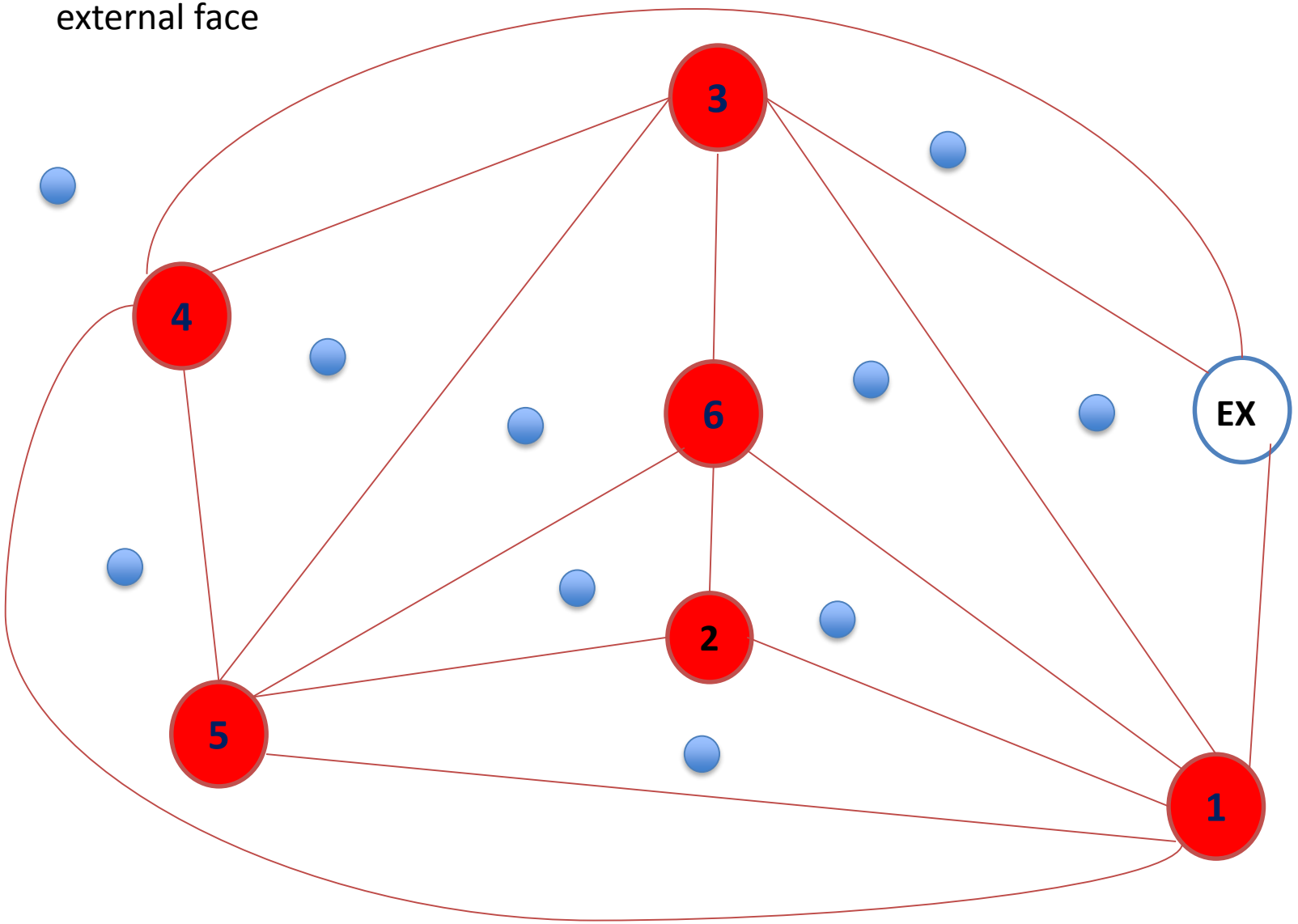
LS^a_{UB}
= the first 3M-6 (i.e. 12) highest V(rij)s
= 2(A)+3(E)+2(I)+2(0)+3(U)
= 2(125)+3(25)+2(5)+2(1)+3(0)
= 250+75+10+2= 337

⇒ Since LS^a_{UB} **>LS^a**, the **final REL Graph is not MPWG**.

⇒ it **mean that it is not optimal**.

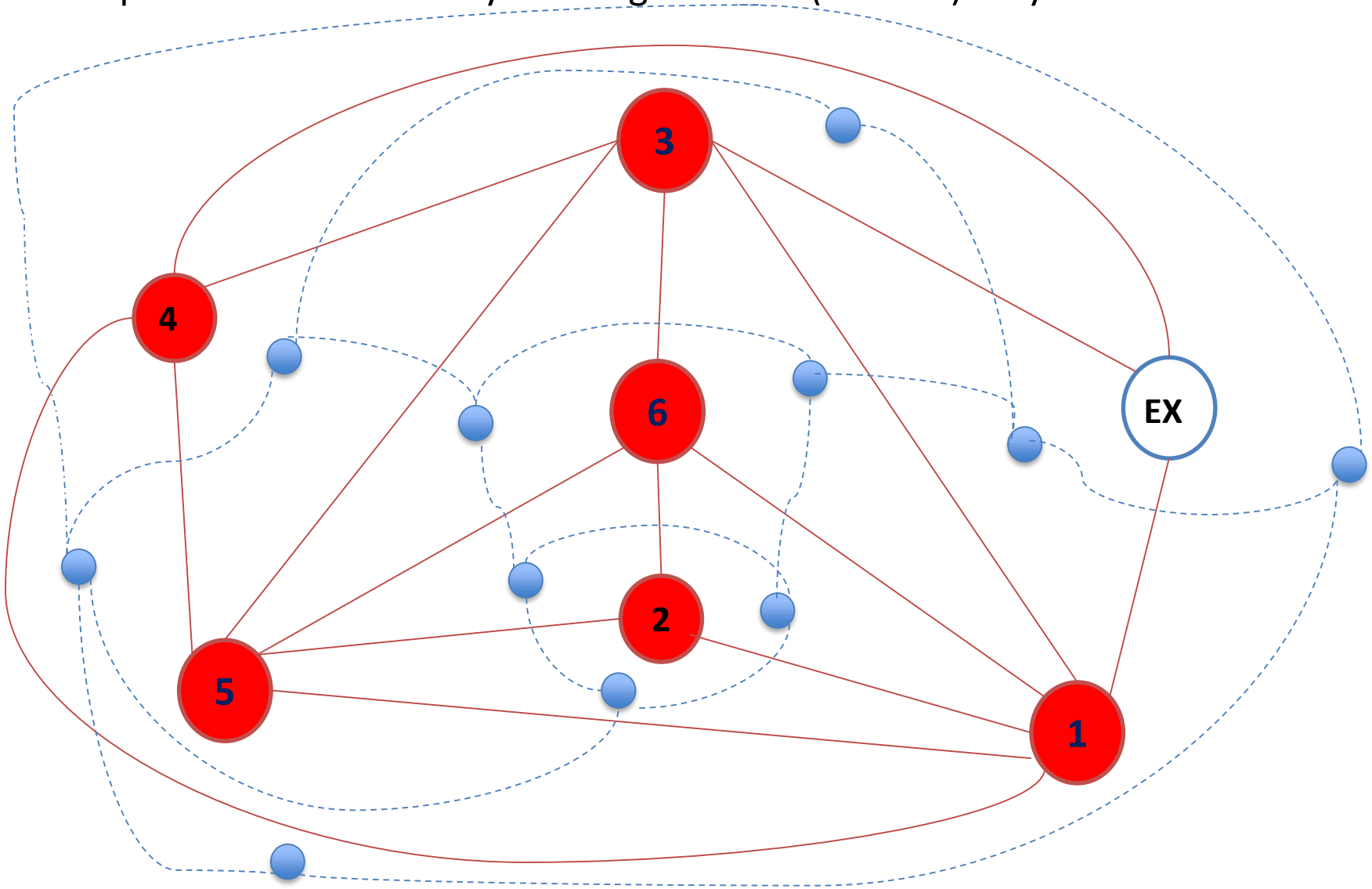
Work Example Constructing the Layout Graph (Dual Graph)

Add one dual node in each of the internal faces. Also, add one dual node in the external face



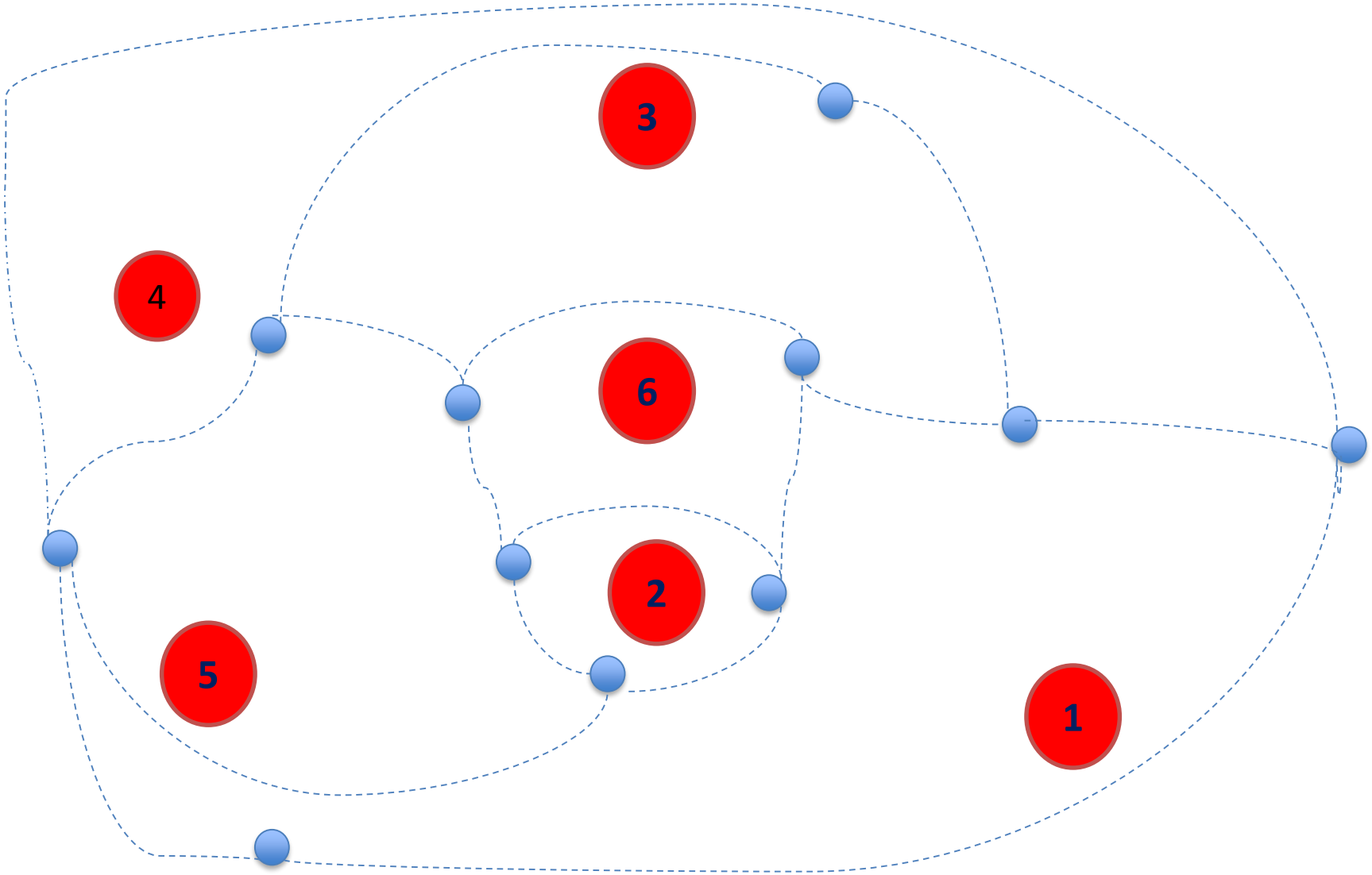
Work Example Constructing the Layout Graph (Dual Graph)

Join up all the dual nodes by crossing each arc (red line) only once.



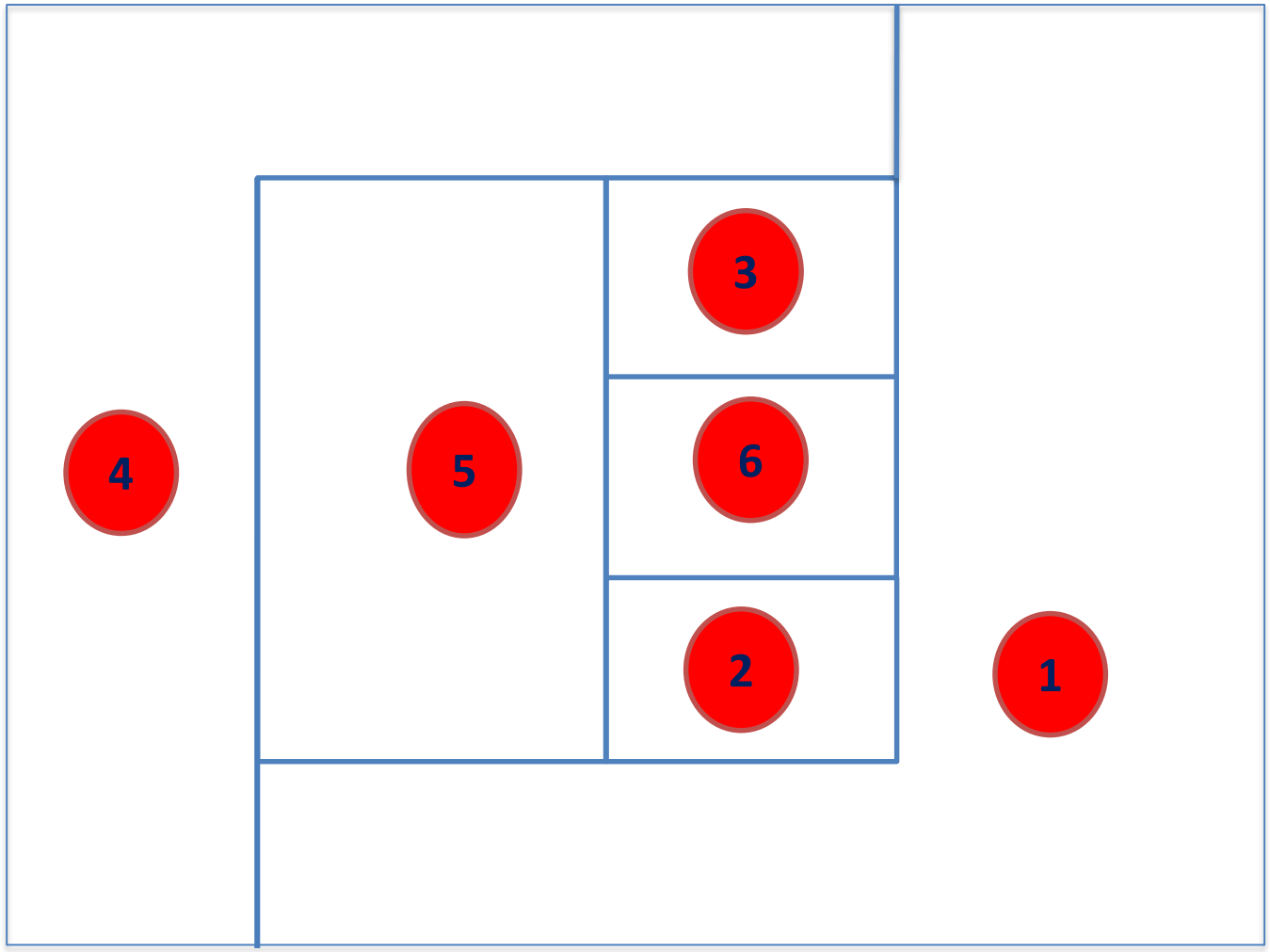
Work Example Constructing the Layout Graph (Dual Graph)

Remove all the arc (red lines), leaving behind the layout graph (dual graph).

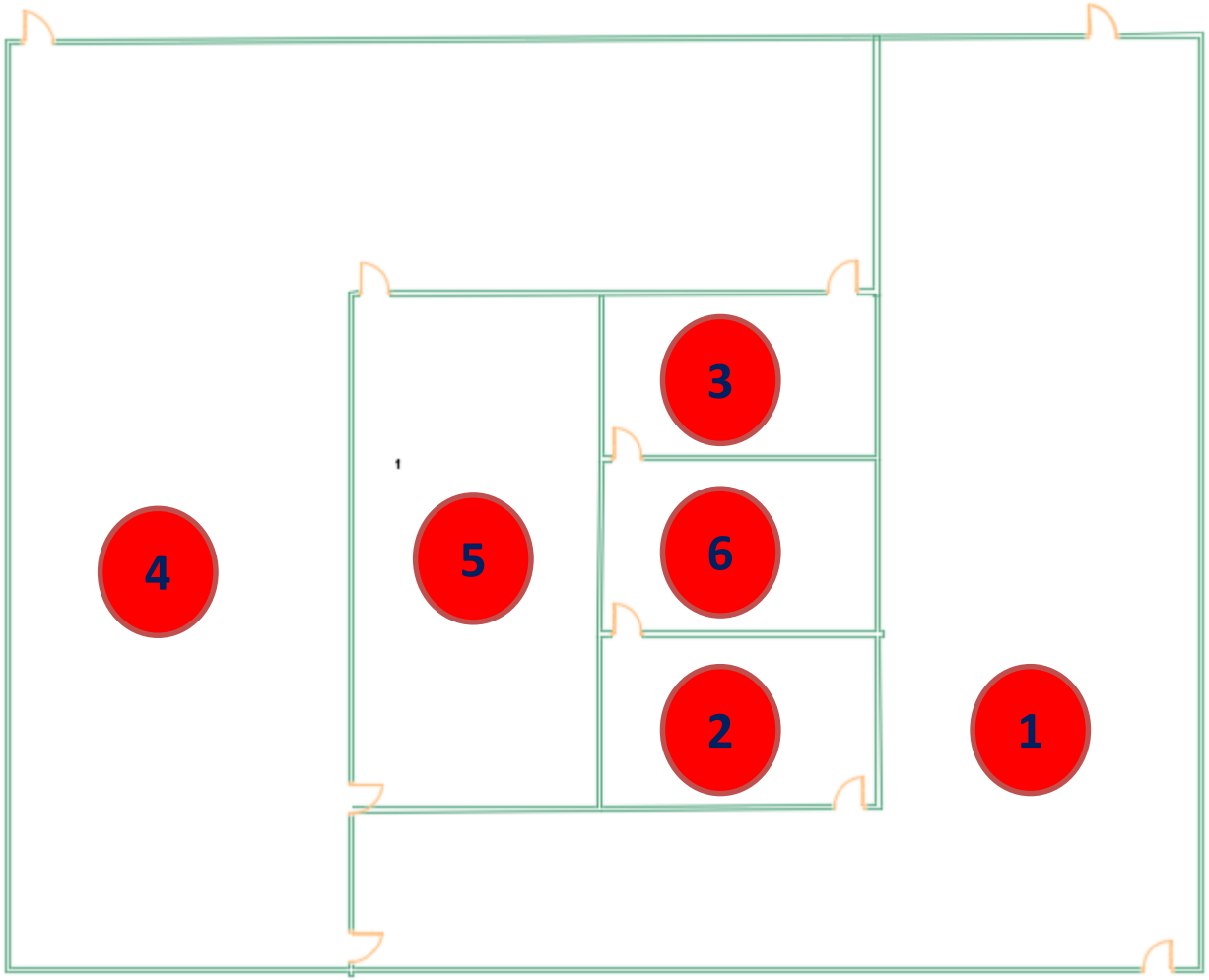


Work Example

Finally, adjust the layout graph into an initial block diagram.



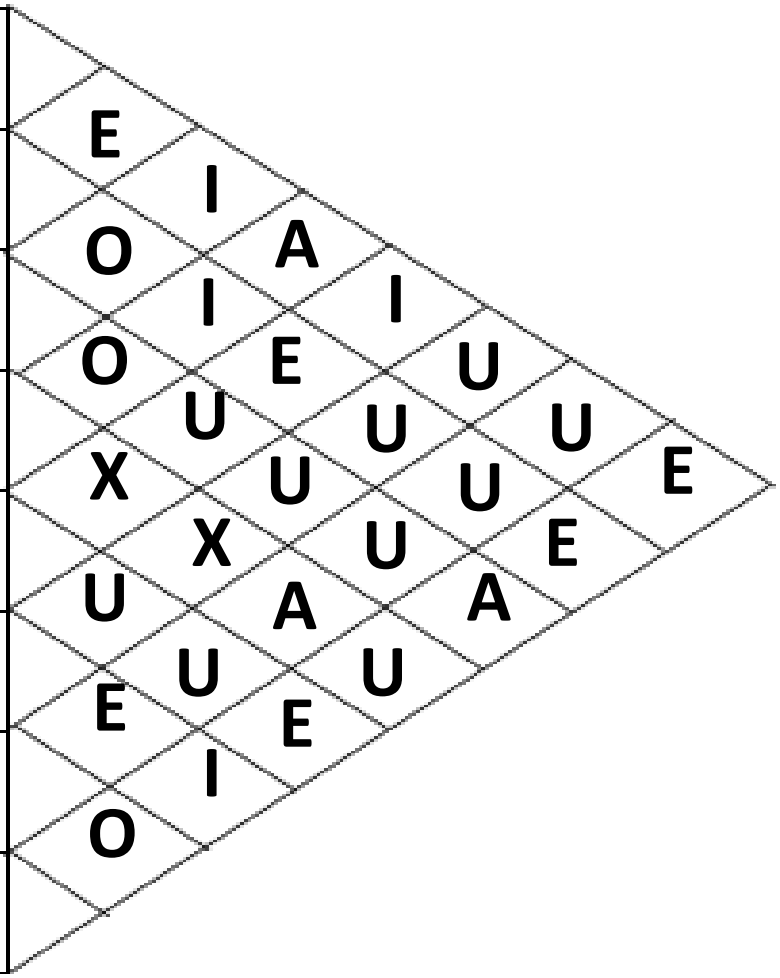
AUTOCAD DRAWING



Problem 05
Suggested Solution

REL Chart for the Proposed Production Floor

1	Drilling
2	Bending
3	Plastic Molding
4	Painting #
5	Cutting & Welding #
6	Motor & Electronics #
7	Final Assembly & Testing
8	Scarp Area



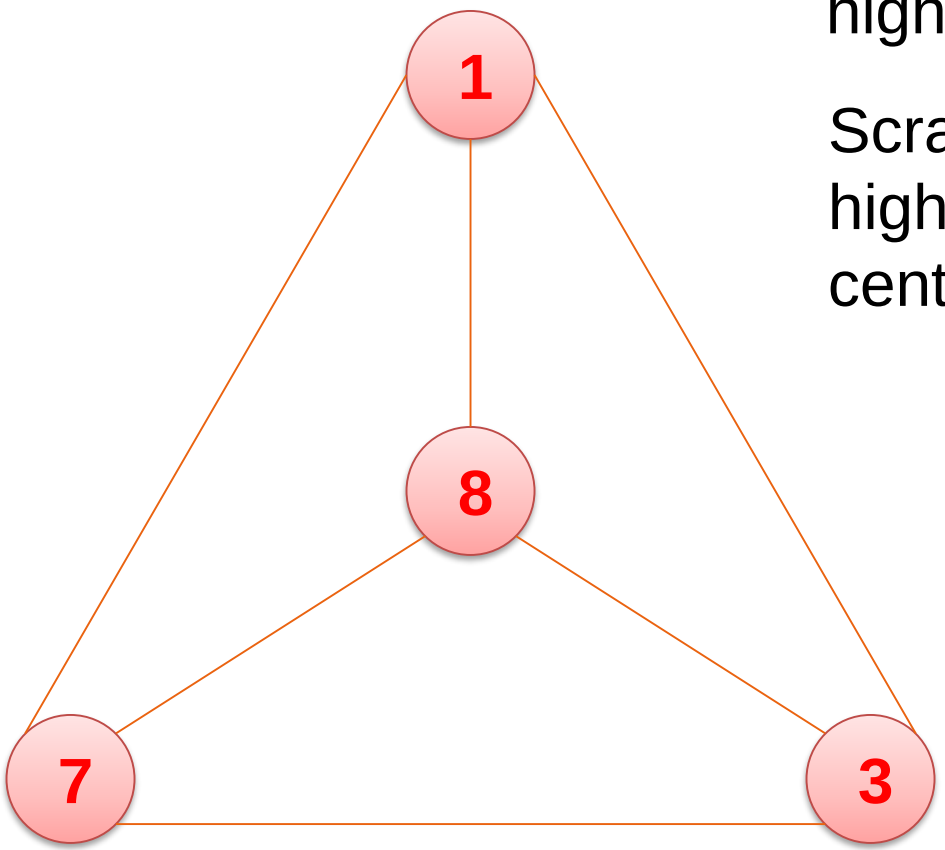
TCR Value Computations

Closeness Values	
V (A)	1000
V (E)	100
V (I)	10
V (O)	1
V (U)	0
V (X)	-1000

Step 1:
Choose 4 workstations of highest TCRs (workstation 8, 1, 7 and 3) to form the first Maximally Planar Graph (MPG).

No.	Workstation	Workstation								Summary						Total Closeness Rating (TCR)	TCR Rank
		1	2	3	4	5	6	7	8	A	E	I	O	U	X		
1	Drilling	-	E	I	A	I	U	U	E	1	2	2	0	2	0	1220	2
2	Bending	E	-	O	I	E	U	U	E	0	3	1	1	2	0	311	5
3	Plastic Molding	I	O	-	O	U	U	U	A	1	0	1	2	3	0	1012	4
4	Painting	A	I	O	-	X	X	A	U	2	0	1	1	1	2	11	6
5	Cutting & Welding	I	E	U	X	-	U	U	E	0	2	1	0	3	1	-790	7
6	Motor & Electronics	U	U	U	X	U	-	E	I	0	1	1	0	4	1	-890	8
7	Final Assembly & Testing	U	U	U	A	U	E	-	O	1	1	0	1	4	0	1101	3
8	Scrap Area	E	E	A	U	E	I	O	-	1	3	1	1	1	0	1311	1

Constructing the REL Graph (Primal Graph)



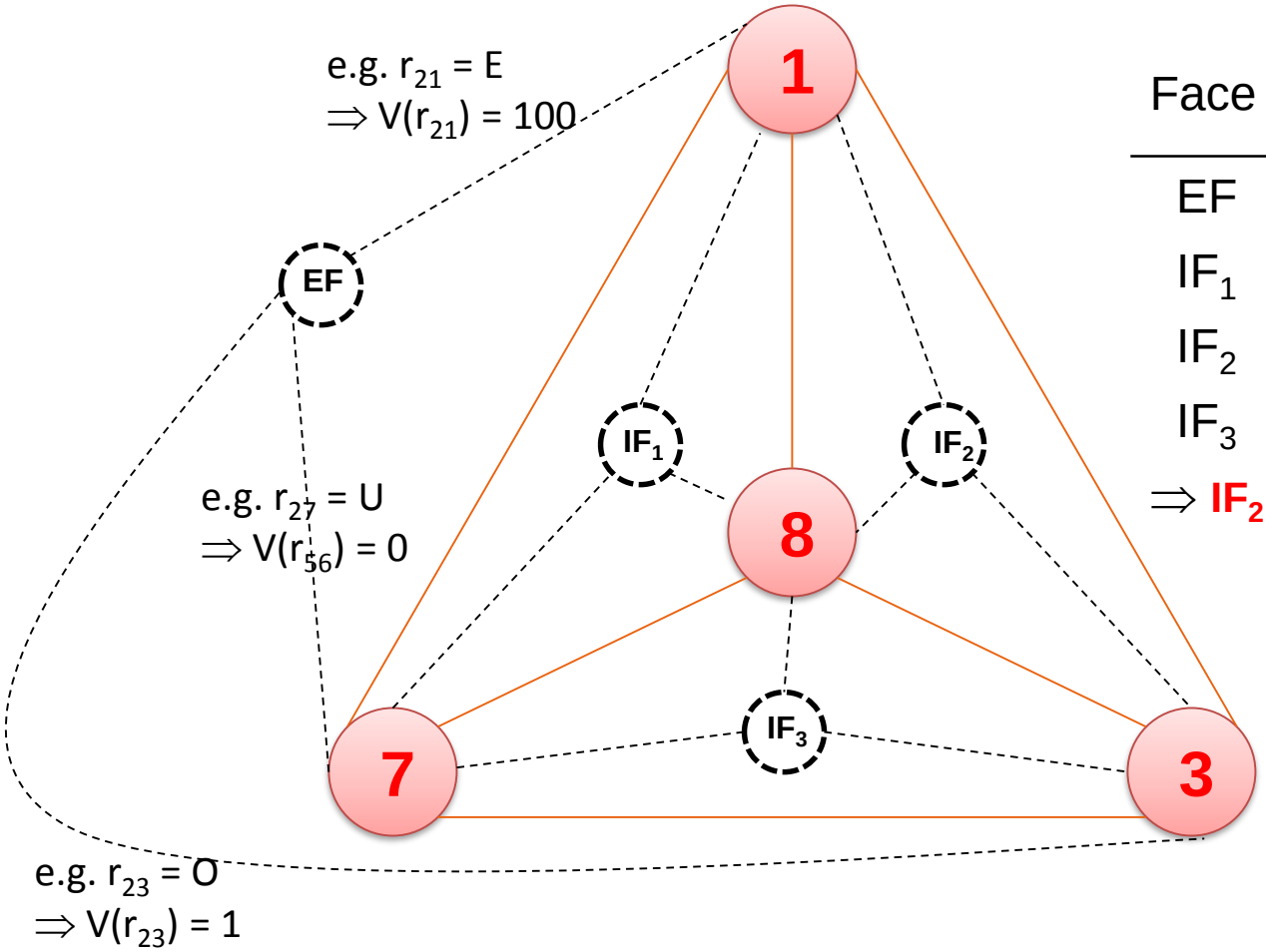
Step 2: Form a tetrahedron with the first workstation (8) having highest TCR - to form an MPG.

Scrap area which has the highest TCR is placed at the central node.

Constructing the REL Graph (Primal Graph)

Step 3: To place the **next workstation (2)**

Find the Layout Score (LS^a) of workstation (2) at all internal and external faces:



Face	LS^a
EF	E+O+U = 100+1+0 = 101
IF_1	E+U+E = 100+0+100 = 200
IF_2	E+O+E= 100+1+100 = 201
IF_3	O+U+E = 1+0+100 = 101

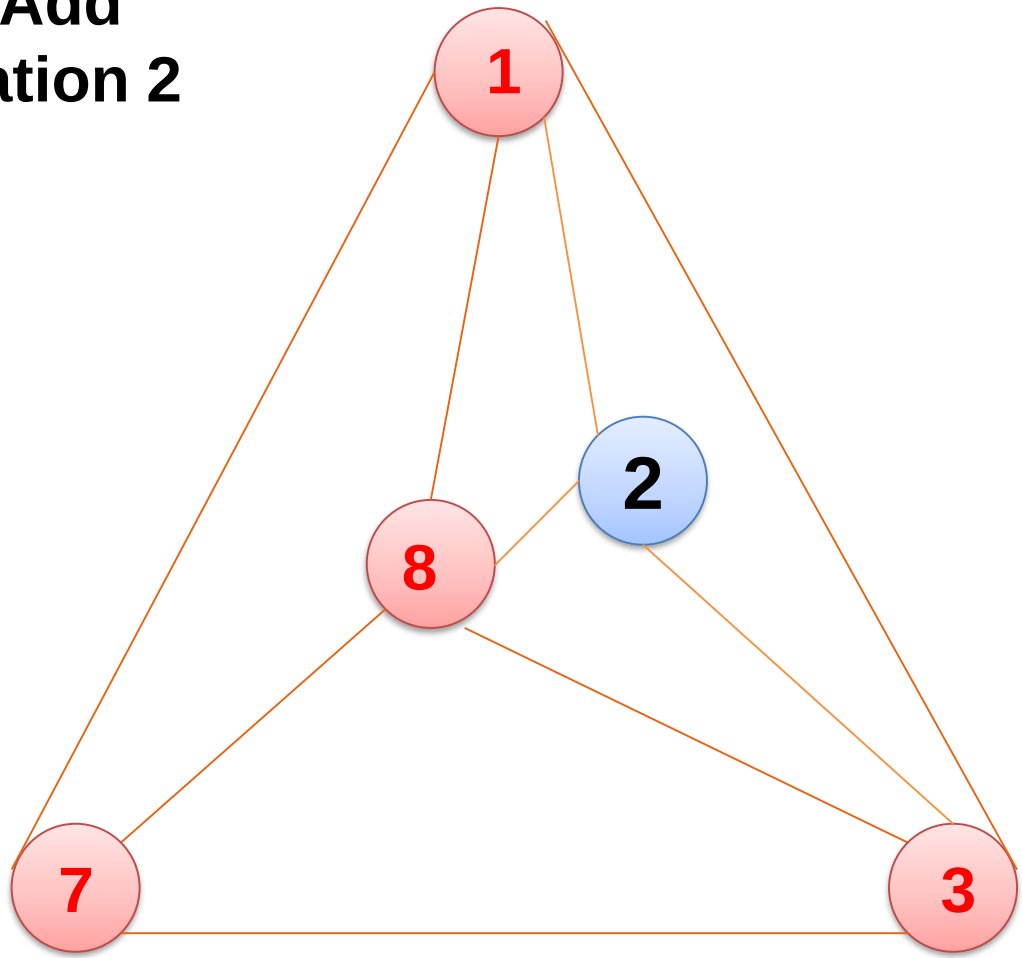
⇒ **IF_2** has the highest Ls^a

Closeness Values	
V (A)	1000
V (E)	100
V (I)	10
V (O)	1
V (U)	0
V (X)	-1000

⇒ Insert workstation 2 in IF_2 (Highest LS^a)

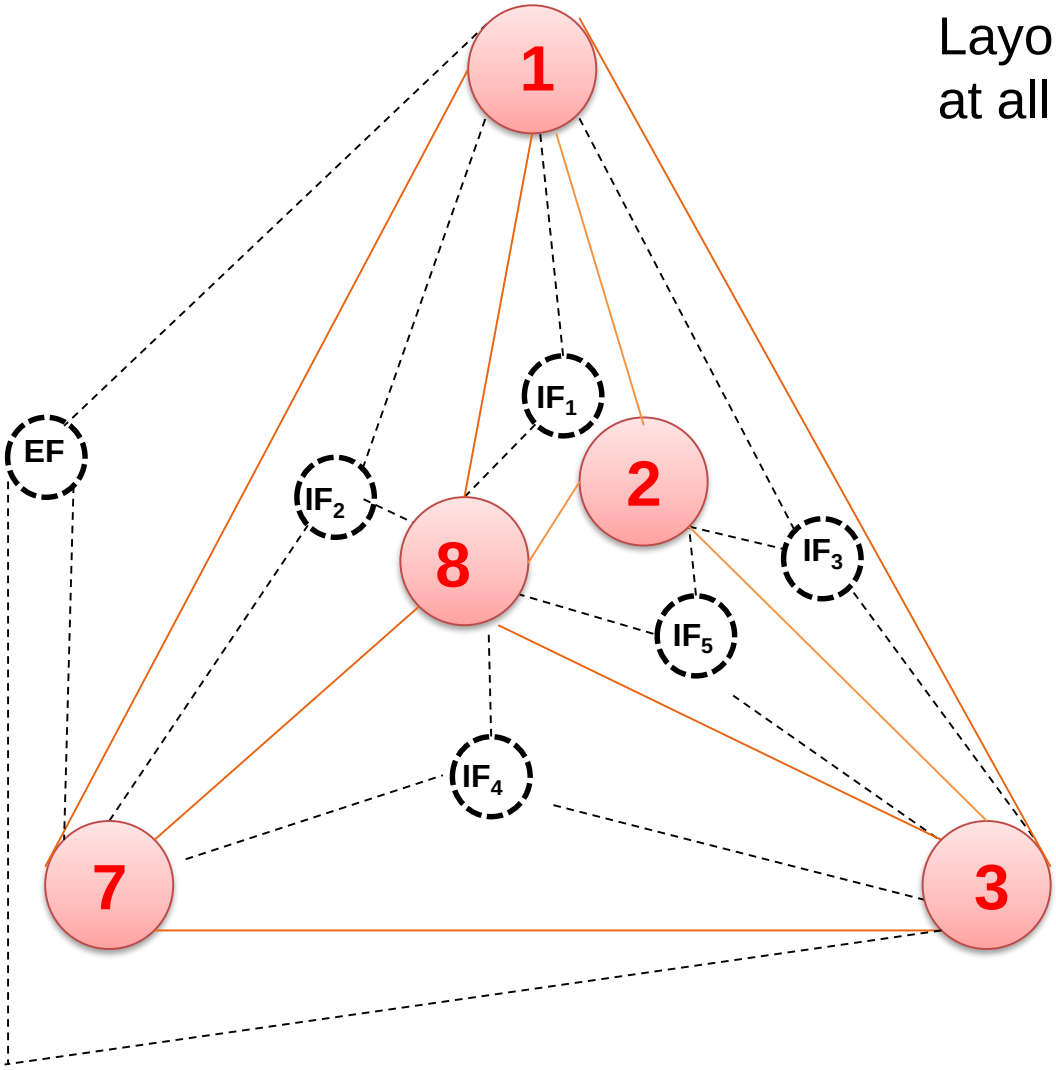
Constructing the REL Graph (Primal Graph)

- **Step 4: Add workstation 2**



Constructing the REL Graph (Primal Graph)

Step 3: To place the **next workstation (4)**



Layout Score (LS^a) of workstation (4) at all internal and external faces:

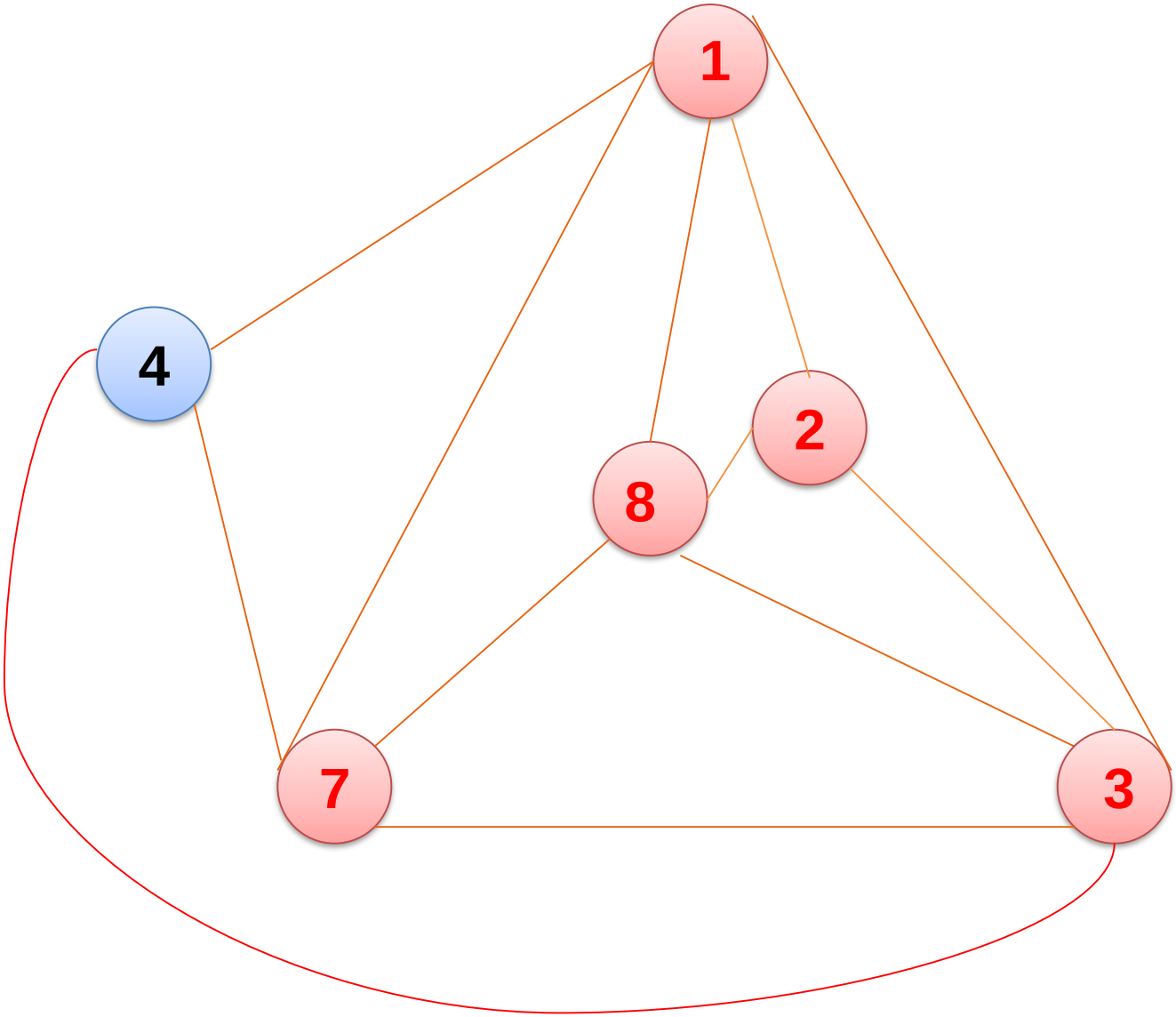
Face	LS^a
EF	A+O+A = 1000+1+1000 = 2001
IF_1	A+I+U = 1000+10+0 = 1010
IF_2	A+A+U = 1000+1000+0 = 2000
IF_3	A+I+O = 1000+10+1 = 1011
IF_4	O+A+U = 1+1000+0 = 1001
IF_5	I+O+U = 10+1+0 = 11

$\Rightarrow$ EF has the highest Ls^a;

$\Rightarrow$ Insert workstation (4) in EF (Highest LS^a)

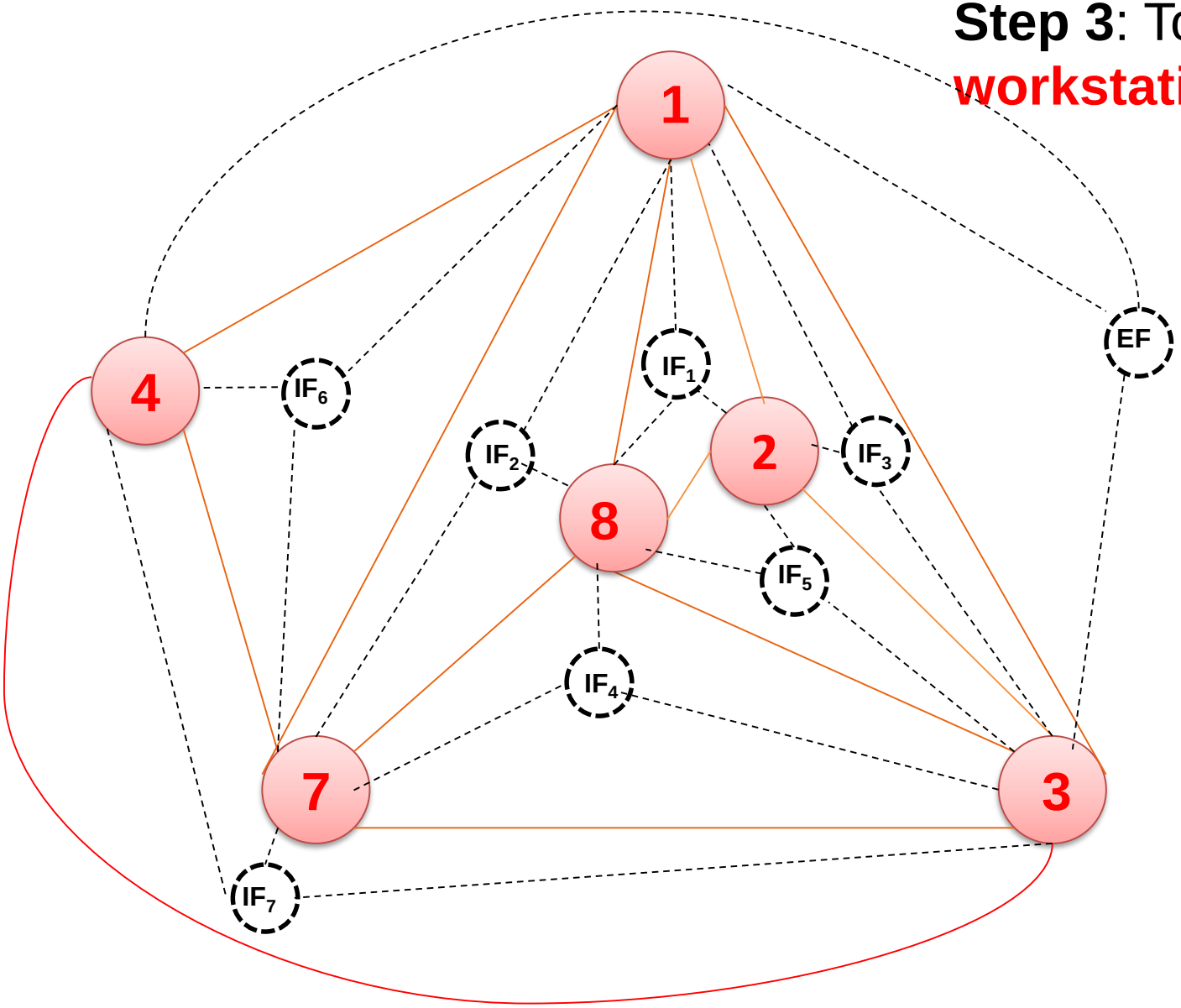
Constructing the REL Graph (Primal Graph)

Step 4: Add workstation 4



Constructing the REL Graph (Primal Graph)

Step 3: To place the **next workstation (5)**



Constructing the REL Graph (Primal Graph)

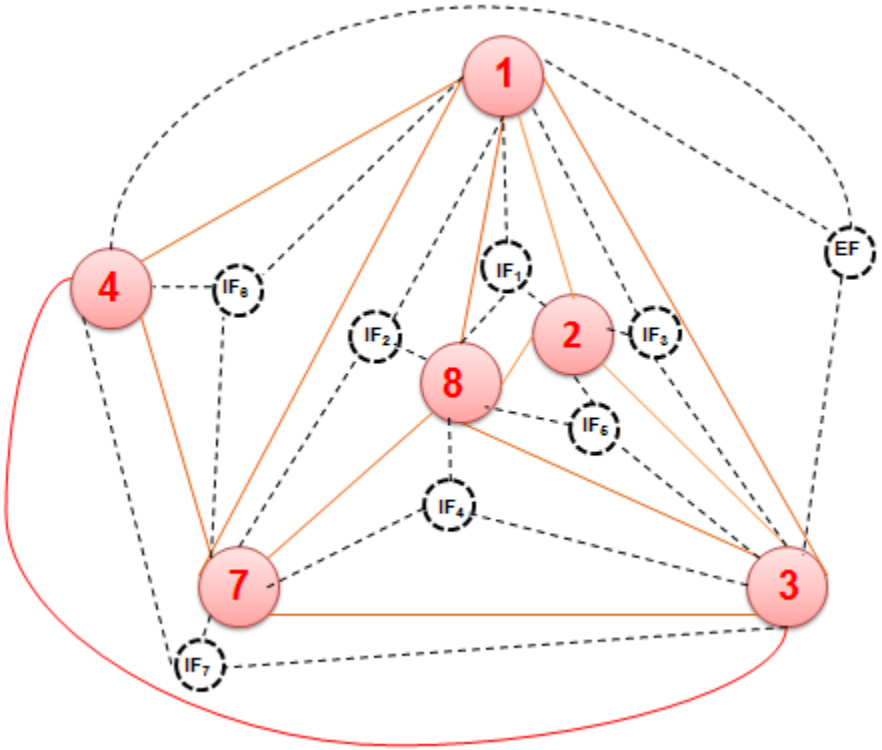
Step 3: To place the **next workstation (5)**

Layout Score (LS^a) of workstation (5) at all internal and external faces:

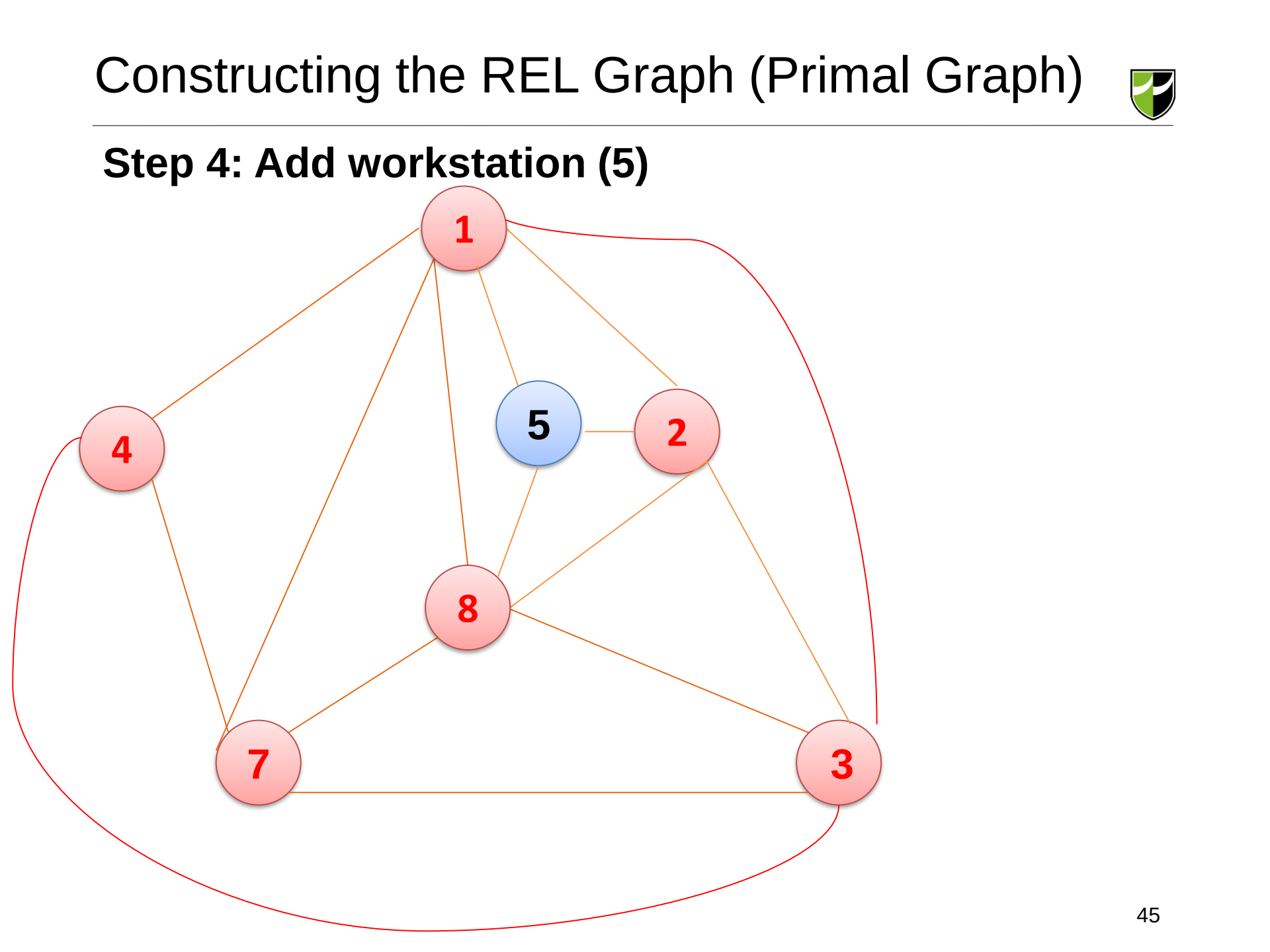
Face	LS^a
EF	I+U+X= 10+0-1000 = -990
IF_1	I+E+E = 10+100+100 = 210
IF_2	I+U+E = 10+0+100 = 110
IF_3	I+E+U = 10+100+0 = 110
IF_4	U+U+E = 0+0+100 = 100
IF_5	E+U+E = 100+0+100 = 200
IF_6	I+X+U = 10-1000+0 = -990
IF_7	U+X+U = 0 -1000+0 = -1000

$\Rightarrow$ IF_1 has the highest Ls^a;

Can choose to insert workstation (5) in IF_1



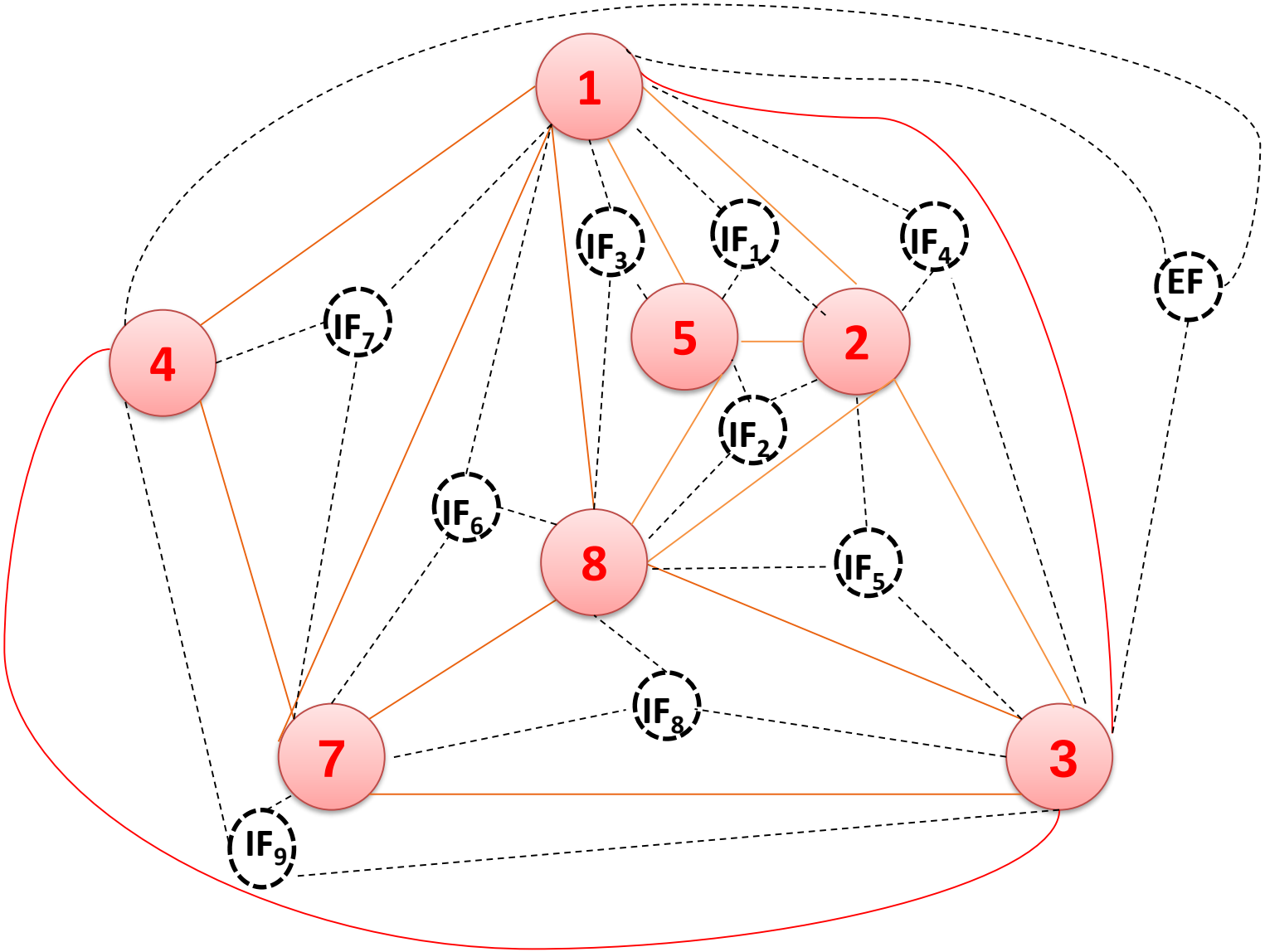
Constructing the REL Graph (Primal Graph)



Step 4: Add workstation (5)

Constructing the REL Graph (Primal Graph)

Step 3: To place the last **workstation (6)**

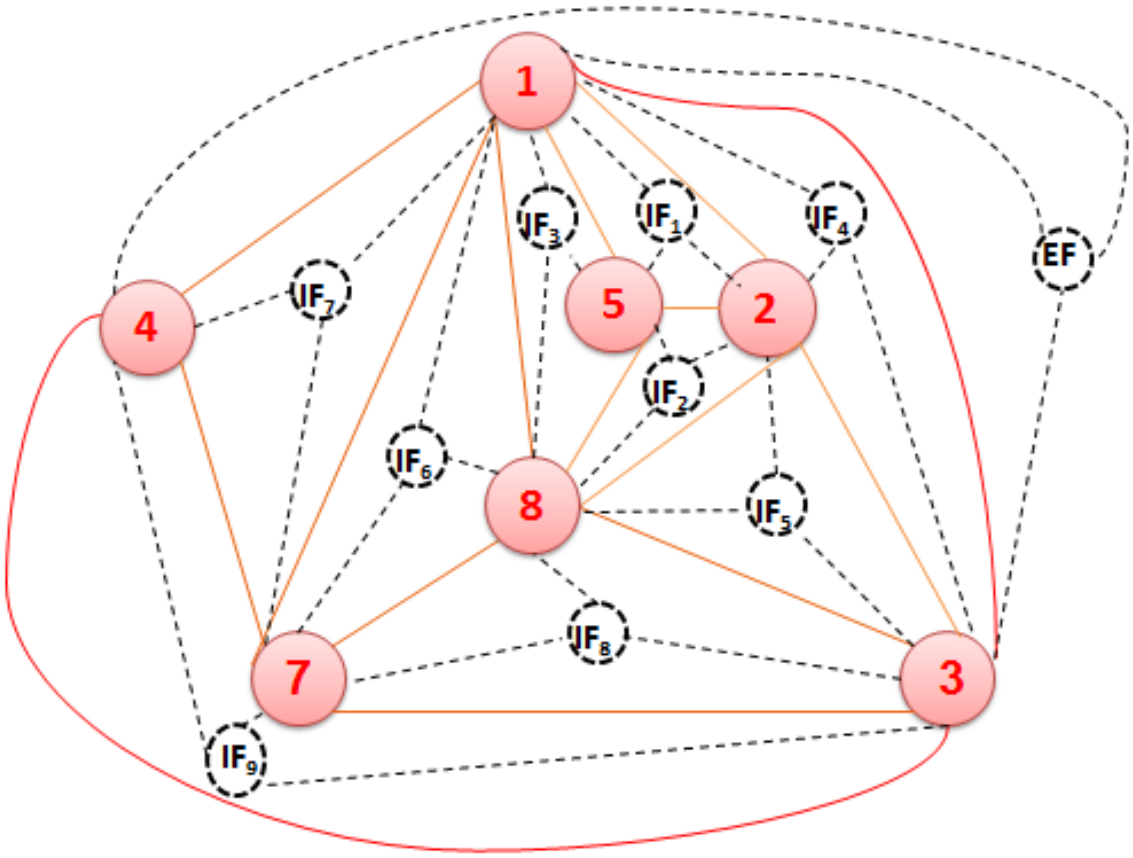


Constructing the REL Graph (Primal Graph)

Step 3: To place the **last workstation (6)**

Layout Score (LS^a) of workstation (6) at all internal and external faces:

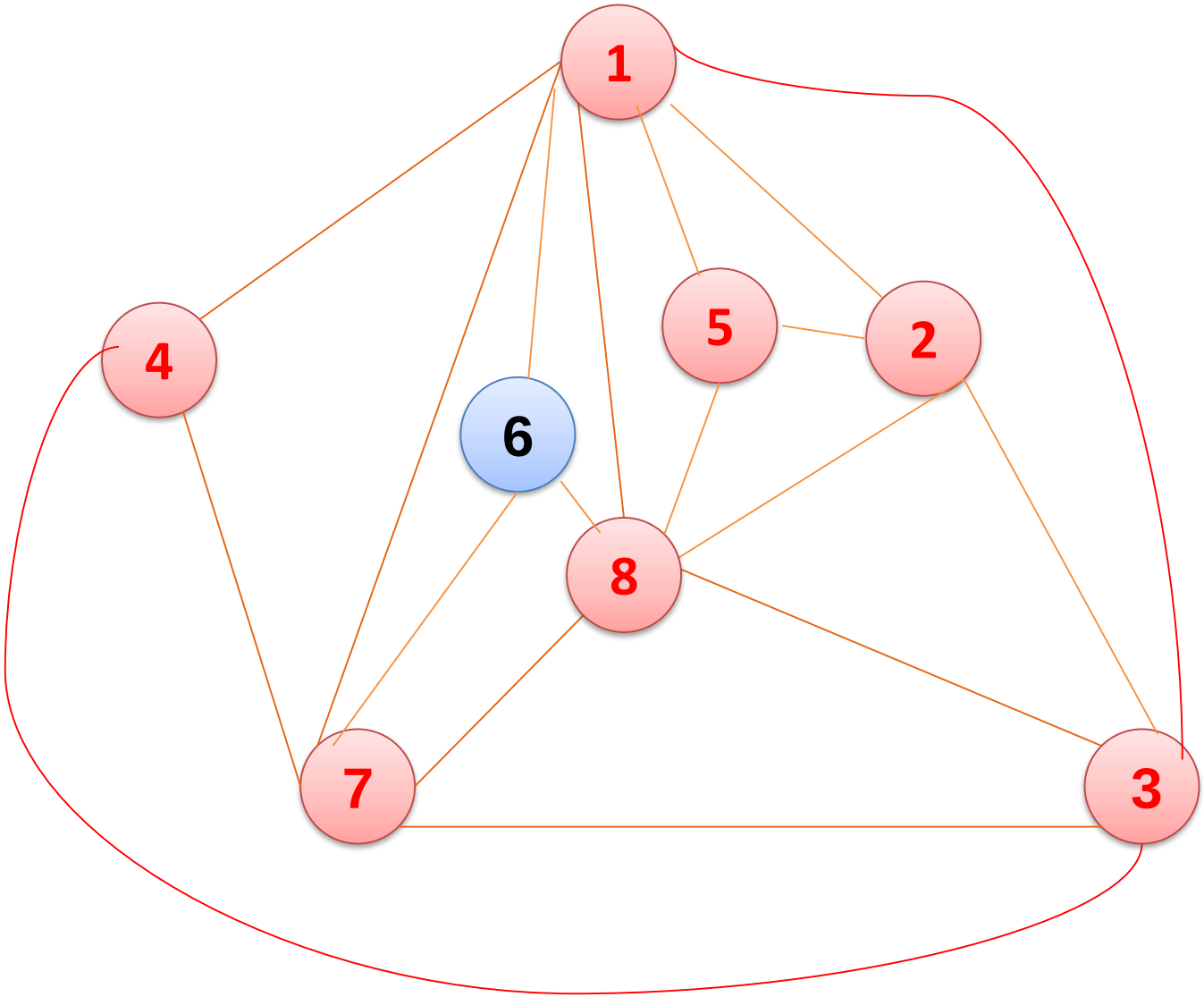
Face	LS^a
EF	U+U+X = 0+0-1000 = -1000
IF_1	U+U+U = 0+0+0= 0
IF_2	U+U+I = 0+0+10 = 10
IF_3	U+U+I = 0+0+10= 10
IF_4	U+U+U = 0+0+0= 0
IF_5	U+U+I = 0+0+10= 10
IF_6	U+E+I = 0+100+10= 110
IF_7	U+X+E = 0-1000+100= -900
IF_8	U+E+I = 0+100+10= 110
IF_9	U+X+E = 0-1000+100 = -900



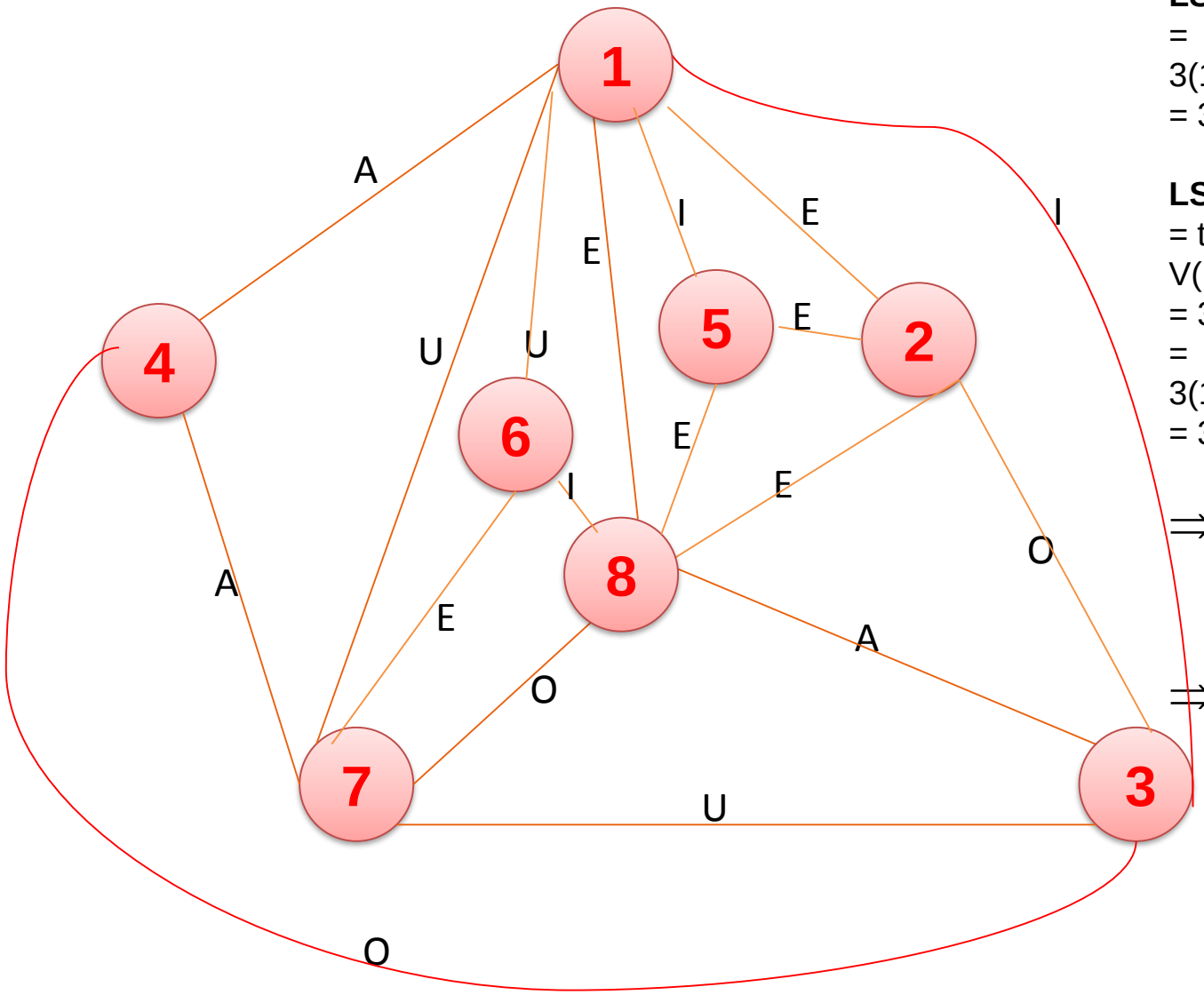
$\Rightarrow$ Insert workstation 6 in IF_6 (Highest LS^a). We choose IF_6.

Final REL Graph (Primal Graph)

Step 4: Add last workstation (6)



Final REL Graph (Primal Graph)



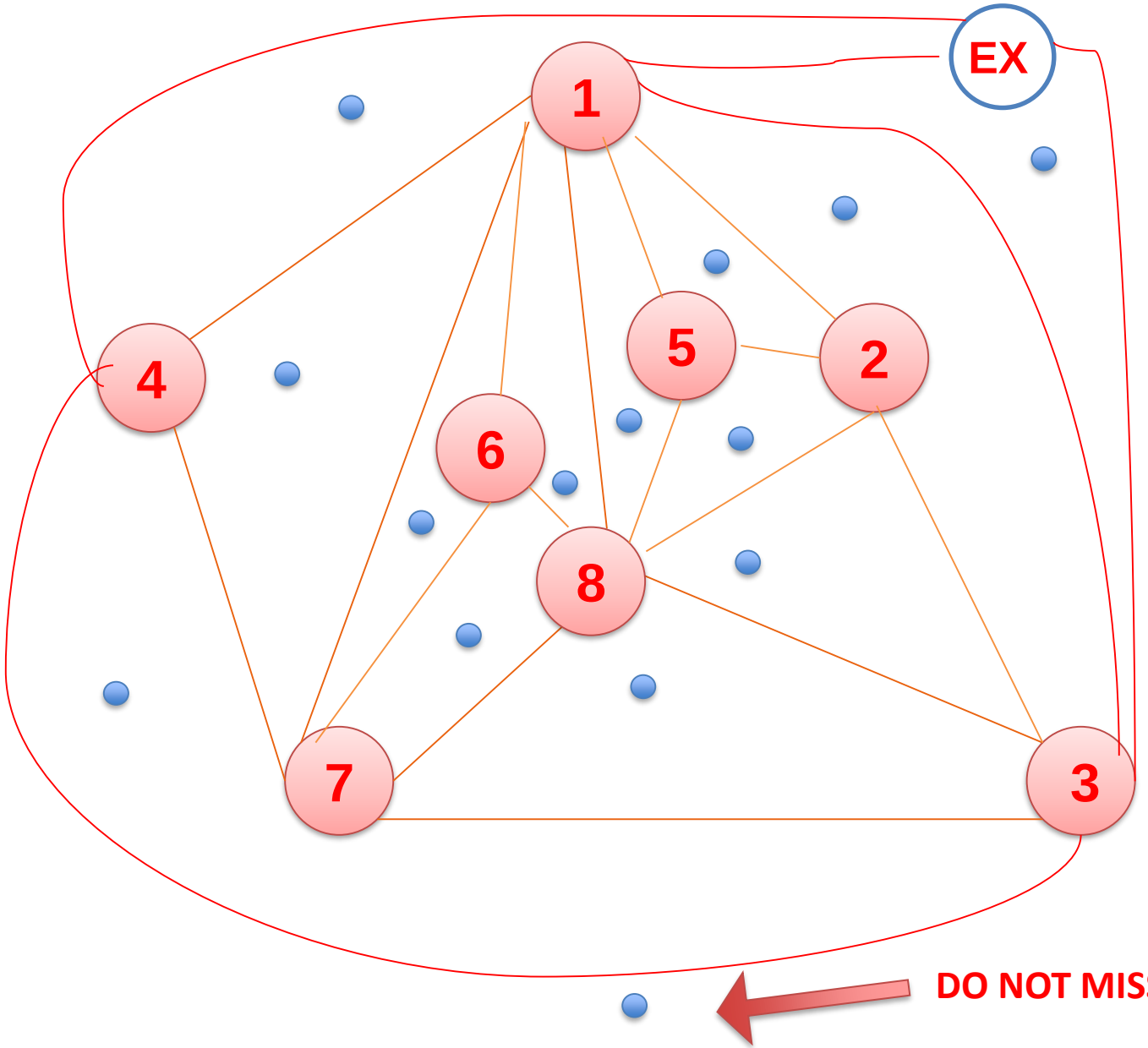
LS^a = 3(A)+6(E)+3(I)+3(O)+3(U)
=
3(1000)+6(100)+3(10)+3(1)+3(0)
= 3633

LS^a_{UB}
= the first 3M-6 (i.e. 18) highest V(rij)s
= 3(A)+6(E)+4(I)+3(O)+2(U)
=
3(1000)+6(100)+4(10)+3(1)+2(0)
= 3643

⇒ Since $LS^a_{UB} > LS^a$, the **final REL Graph is not an MPWG**.

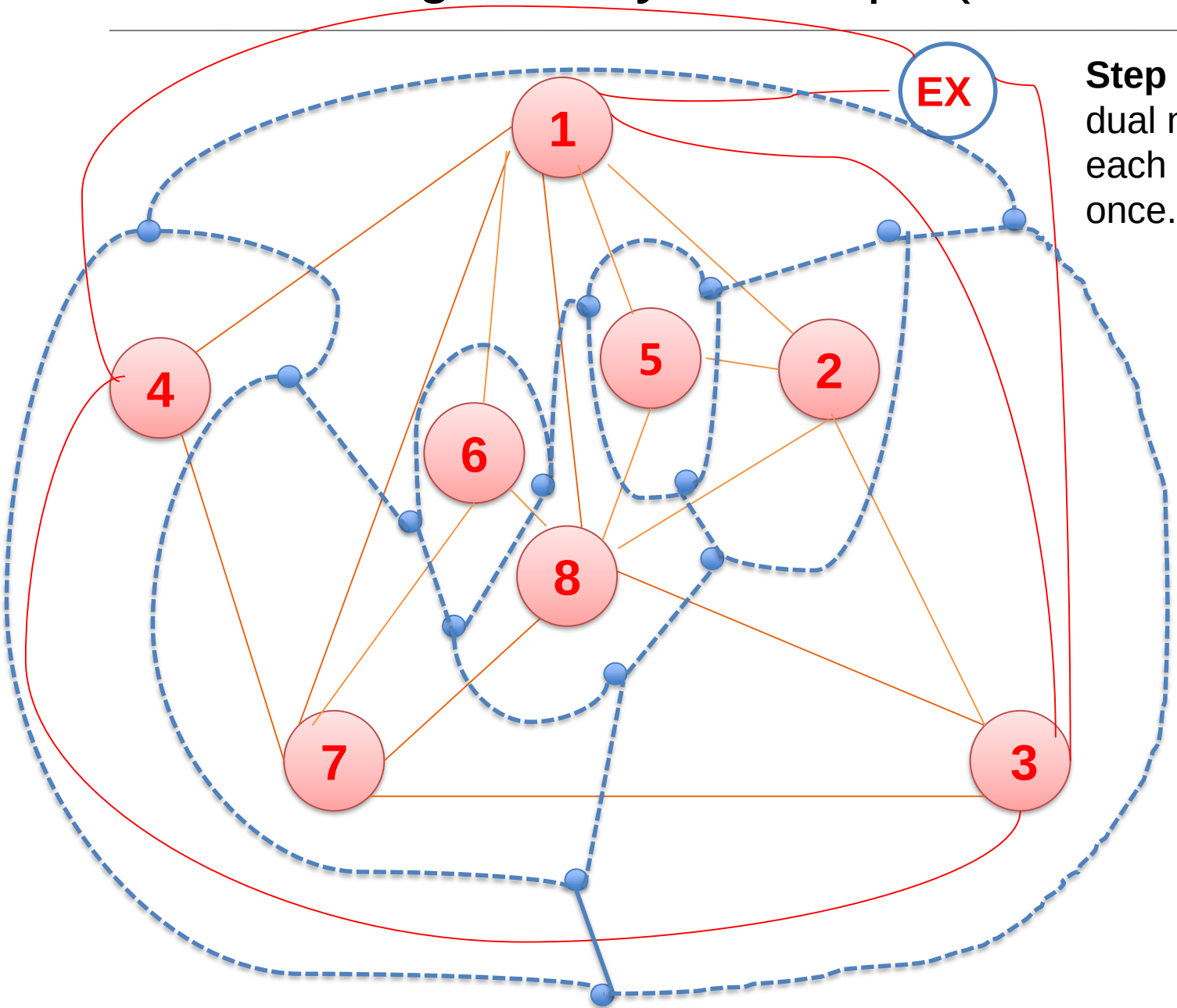
⇒ it **mean that it might not be optimal**.

Constructing the Layout Graph (Dual Graph)



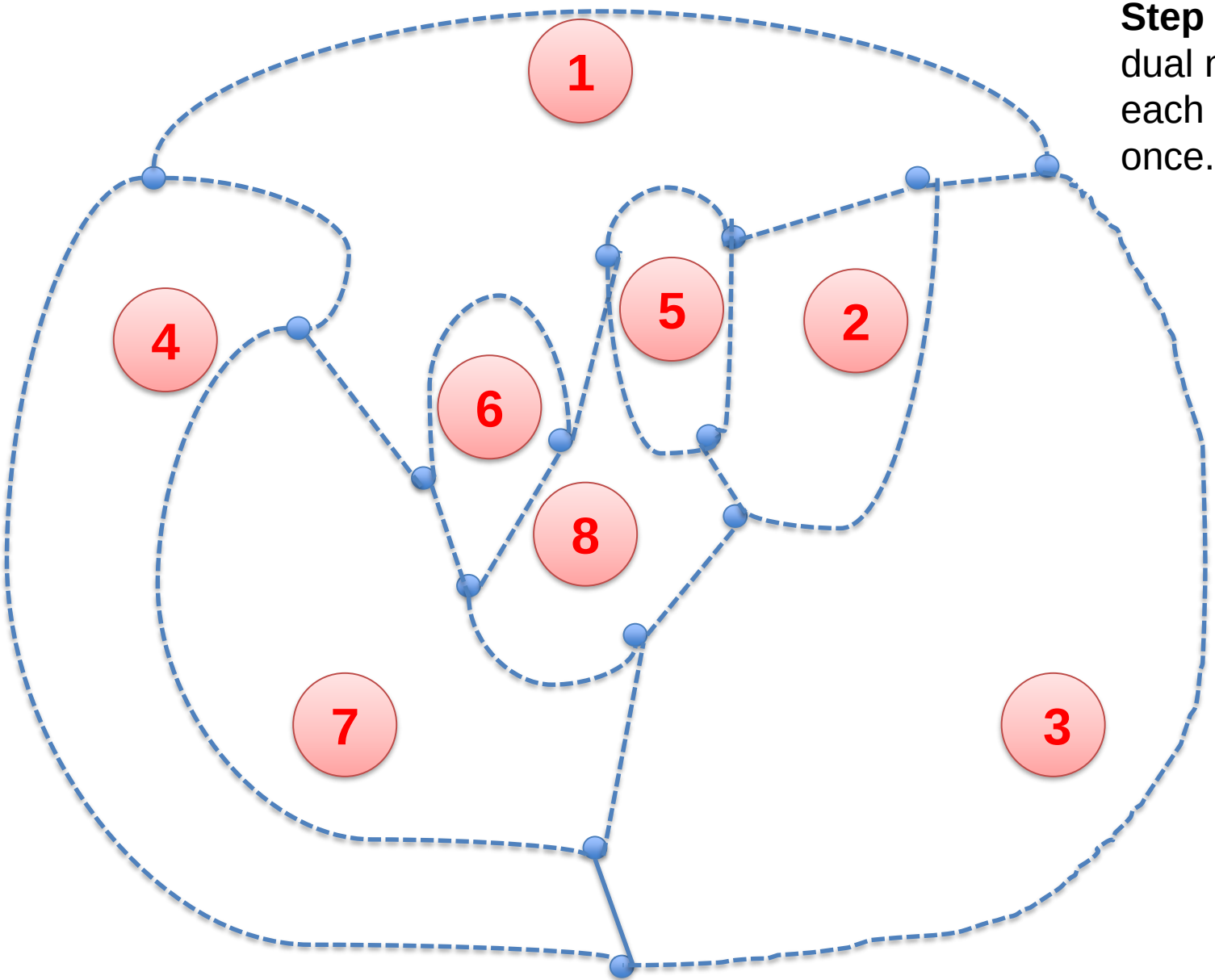
Step 6: Add an External Point (EX), and connect it to the nearest 3 departments (without crossing any arcs).

Constructing the Layout Graph (Dual Graph)



Step 7: Join up all the dual nodes by crossing each arc (red line) only once.

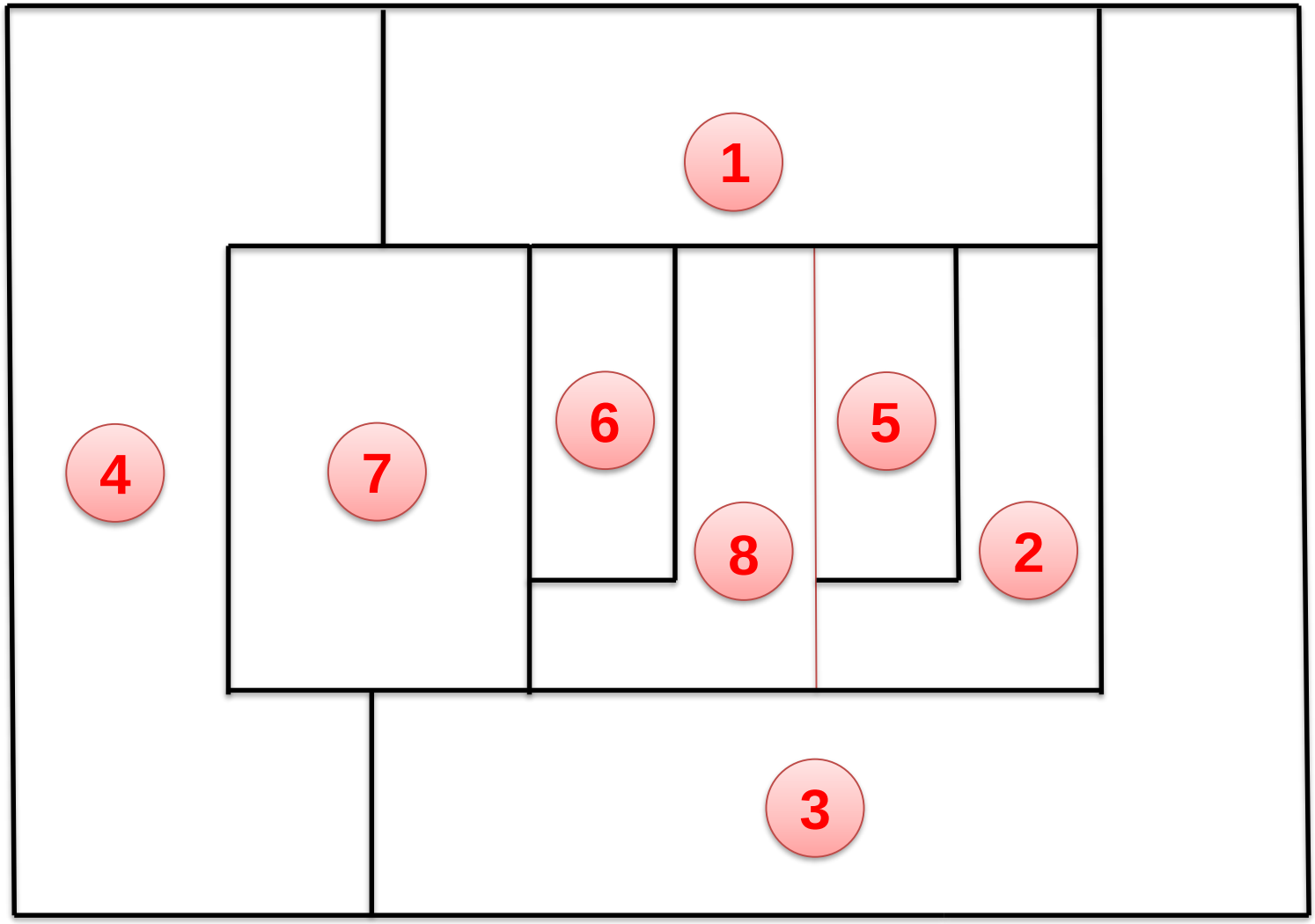
Constructing the Layout Graph (Dual Graph)



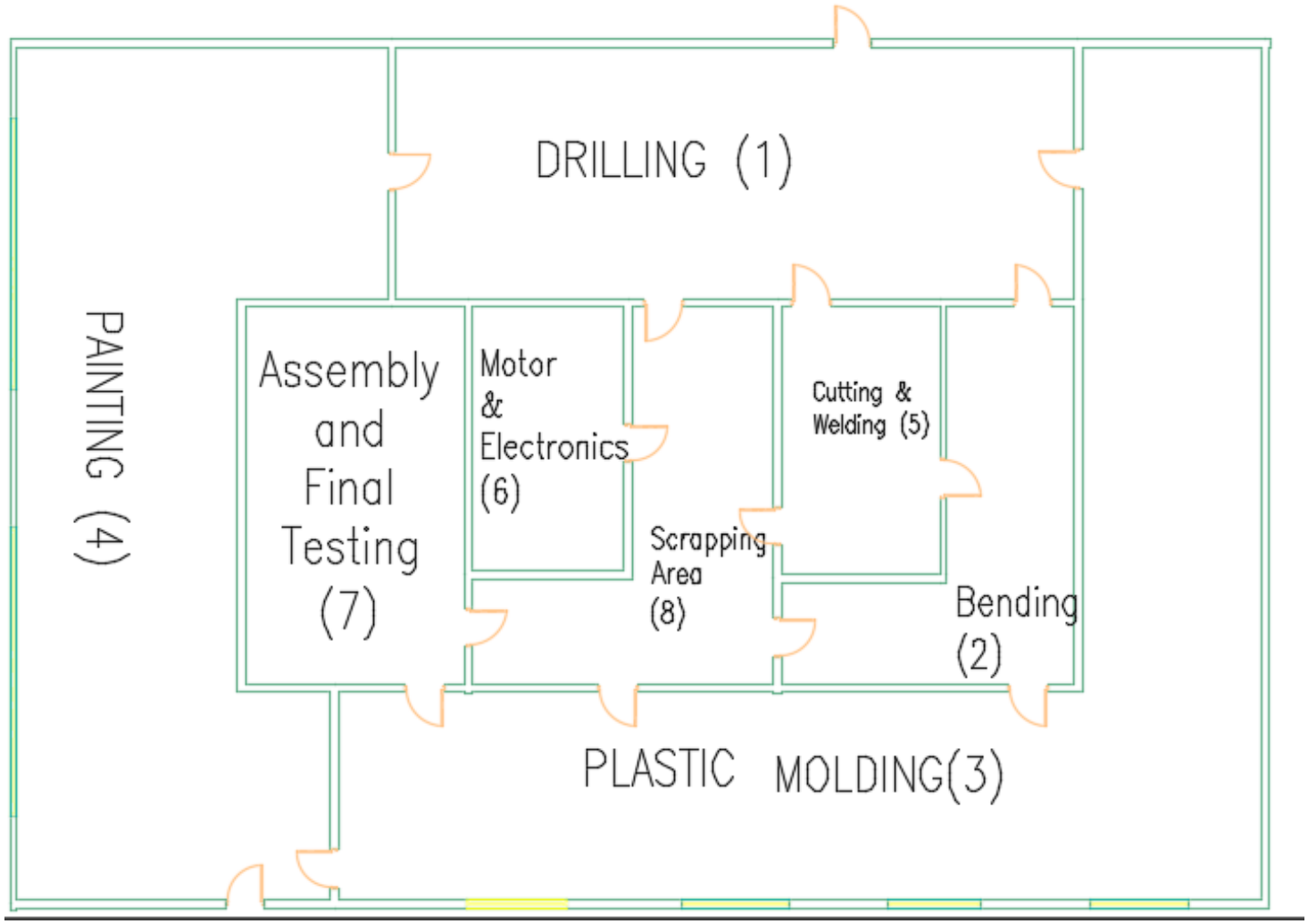
Step 7: Join up all the dual nodes by crossing each arc (red line) only once.

Block Layout (Initial Layout)

Step 8: Finally, adjust the layout graph into an initial block diagram.



AUTOCAD DRAWING (LAYOUT)



Possible Considerations

- Possible improvement for the process:
  - Consider quantitative relation
  - Compare total transportation works
  - Exchange department locations to reduce the total transportation works

Additional Practical Considerations

- Location of building core (Structural columns, Staircase, etc.)
- Size of department
- Shape of building
- Location of loading/unloading bay (same place, location of road leading to the plant)

Learning Objectives

- Derive a Relationship (REL) Chart and create a TCR Table for a facility.

- Construct a planar graph of the REL chart by using Graph-Based approach.

- Draft out a facility layout using AutoCAD.

Overview of E212 Facilities Planning and Design