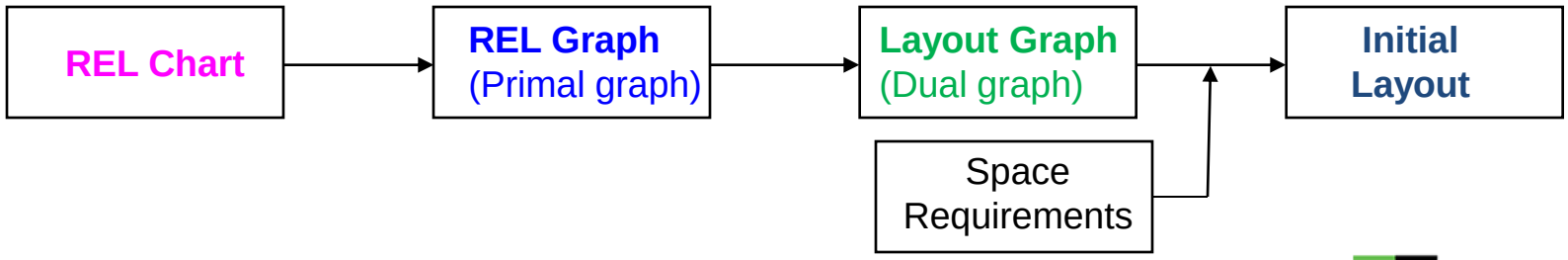
# E212 – Facilities Planning and Design

## P05 – Initial by Graph Based

# Graph Based Layout Construction

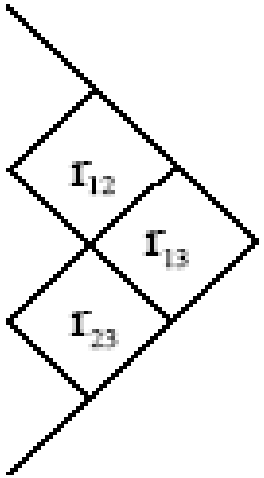
## General Procedure:

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 activity.



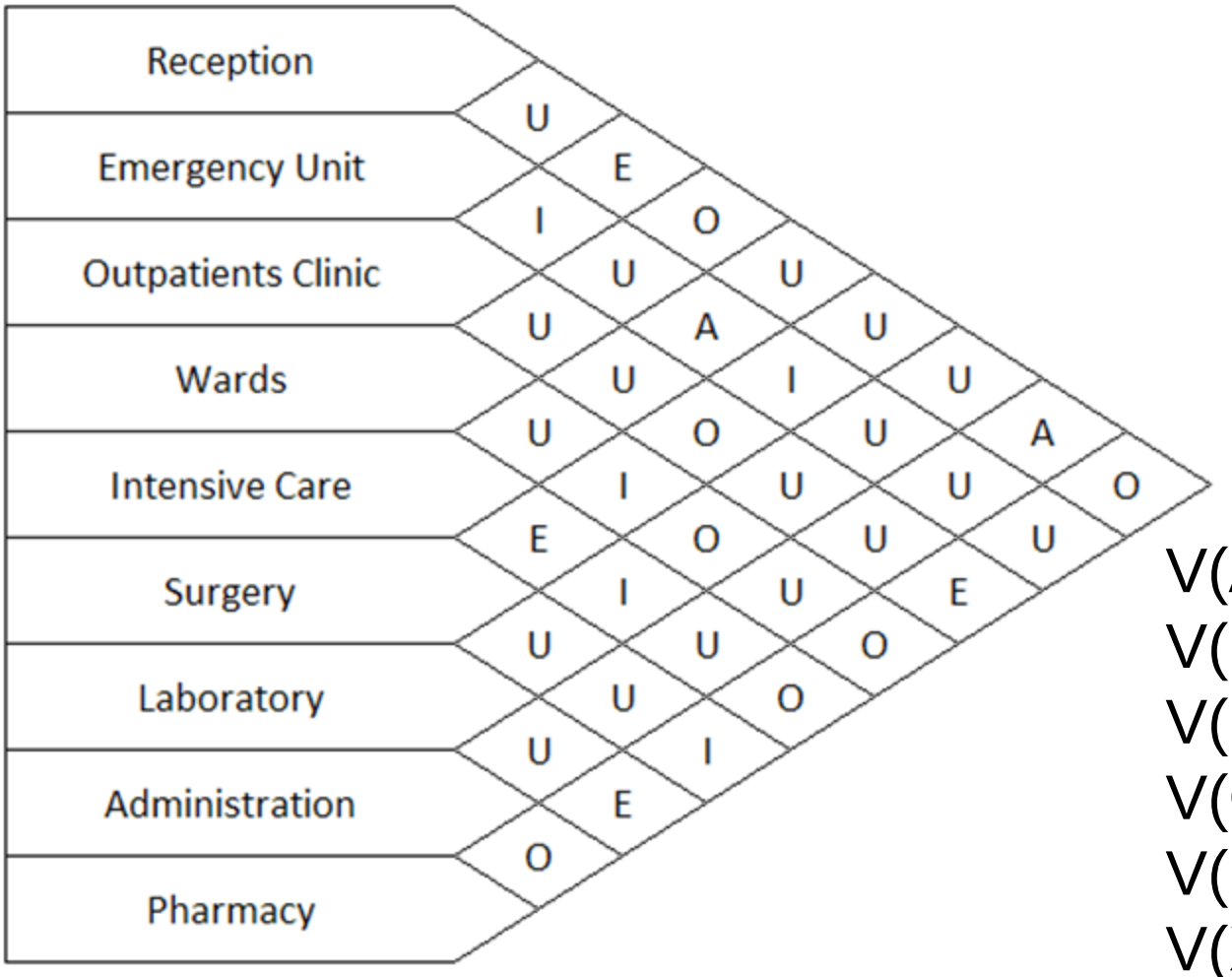
# Recap: REL Chart Construction

- 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.




rij ∈{A, E, I, O, U, X}: Closeness Value (CV) between activities i and j; rij is an ordinal value

# Recap: Example of REL Chart




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

# Recap: Total Closeness Rating

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

| 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 |

# REL Graph Construction

1. Start by identifying FOUR (4) departments of the highest Total Closeness Rating (TCR).
2. Each department is represented by a *node (or circle, or vertex)*.
3. 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)*.

# REL Graph Construction

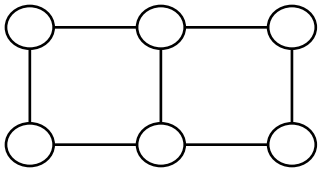
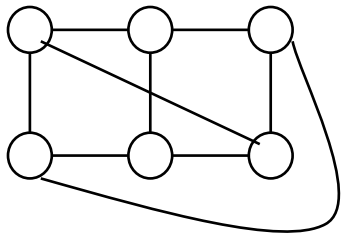
4. Then, choose the next entering department with the next highest TCR (the 5th highest TCR).
5. Select the best location for this entering department, which is the face (can be External or Internal faces) with the maximum possible $LS^a$ (to be Maximally Planar Weighted Graph (MPWG)).
6. Continue Step 1 -5 until all departments are inside the REL graph.

# Layout Graph and Initial Layout

7. Add a final exterior activity (denoted by “EX”) that connects the departments with outside arcs.
8. Construct a Layout Graph, which is the dual of the REL graph.
9. Convert the Layout Graph (Dual Graph) into Block Layout (that represents the initial layout).

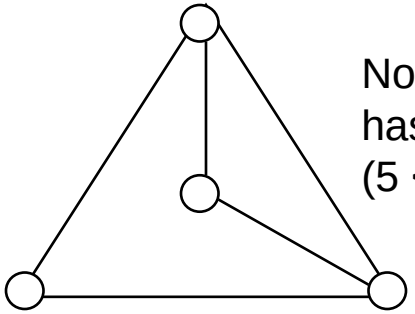
# Requirement: Planar Graph

- A requirement for a layout to satisfy the activity 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.

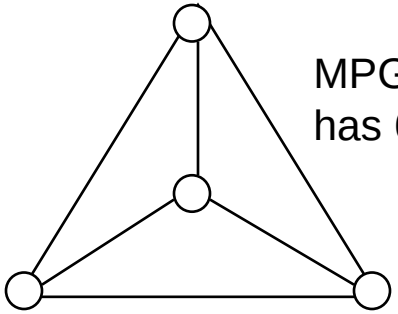
e.g.  Planar  Nonplanar

# Maximally Planar Graph (MPG)

- If 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:

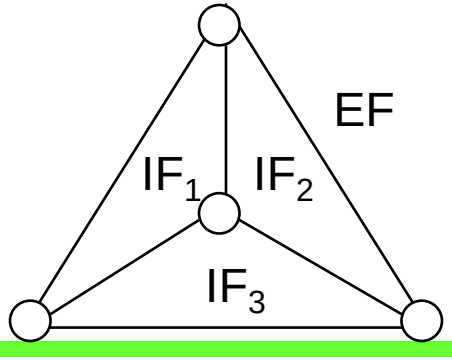


Not MPG since has only 5 arcs ($5 < 6 = 3M-6$)



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)

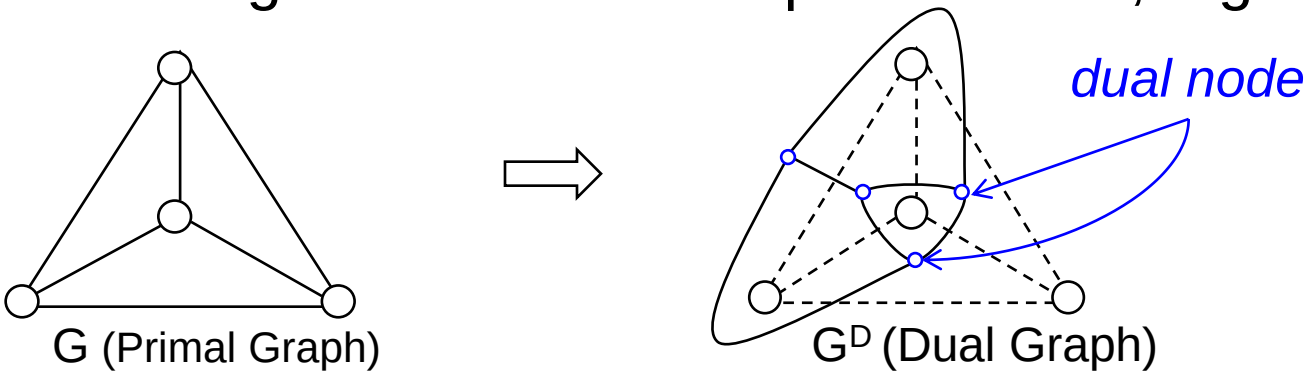
- An MPG whose sum of arc weights is as large as any other possible MPG is called a **Maximally Planar Weighted Graph (MPWG)**.

- 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 $LS^a_{UB}$.

- 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 $LS^a_{UB}$).

# 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.:

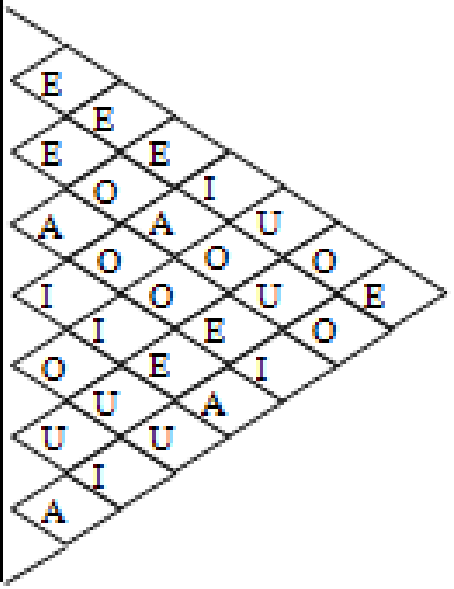



- If the REL Graph (also known as Primal Graph) is a planar graph, its Layout Graph (also known as Dual Graph) will also be planar.

# P05 Sample Solution

# REL Chart for the New Expansion

| |
|---|
| 1. Receiving |
| 2. Shipping |
| 3. Raw Materials Storage |
| 4. Finished Goods Storage |
| 5. Manufacturing |
| 6. Work-In-Process Storage |
| 7. Assembly |
| 8. Offices |



# TCR Value Computation

| CV Values | |
|---|---|
| V (A) | 256 |
| V (E) | 64 |
| V (I) | 16 |
| V (O) | 4 |
| V (U) | 1 |
| V (X) | -100 |

Choose 4 departments of highest TCR (Department 4, 8, 3, 2) to form the first Maximally Planar Graph (MPG)

Partial Adjacency ($\alpha$): 0.5

| Department | Department | | | | | | | | Summary | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | A | E | I | O | U | X | TCR | Rank |
| 1. Receiving | | E | E | E | I | U | O | E | 0 | 4 | 1 | 1 | 1 | 0 | 277 | (7) |
| 2. Shipping | E | | E | O | A | O | U | O | 1 | 2 | 0 | 3 | 2 | 0 | 397 | (4) |
| 3. Raw Materials Storage | E | E | | A | O | O | E | I | 1 | 3 | 1 | 2 | 0 | 0 | 472 | (3) |
| 4. Finished Goods Storage | E | O | A | | I | I | E | A | 2 | 2 | 2 | 1 | 0 | 0 | 676 | (1) |
| 5. Manufacturing | I | A | O | I | | O | U | U | 1 | 0 | 2 | 2 | 2 | 0 | 298 | (6) |
| 6. WIP Storage | U | O | O | I | O | | U | I | 0 | 0 | 2 | 3 | 2 | 0 | 46 | (8) |
| 7. Assembly | O | U | E | E | U | U | | A | 1 | 2 | 0 | 1 | 3 | 0 | 391 | (5) |
| 8. Offices | E | O | I | A | U | I | A | | 2 | 1 | 2 | 1 | 1 | 0 | 613 | (2) |



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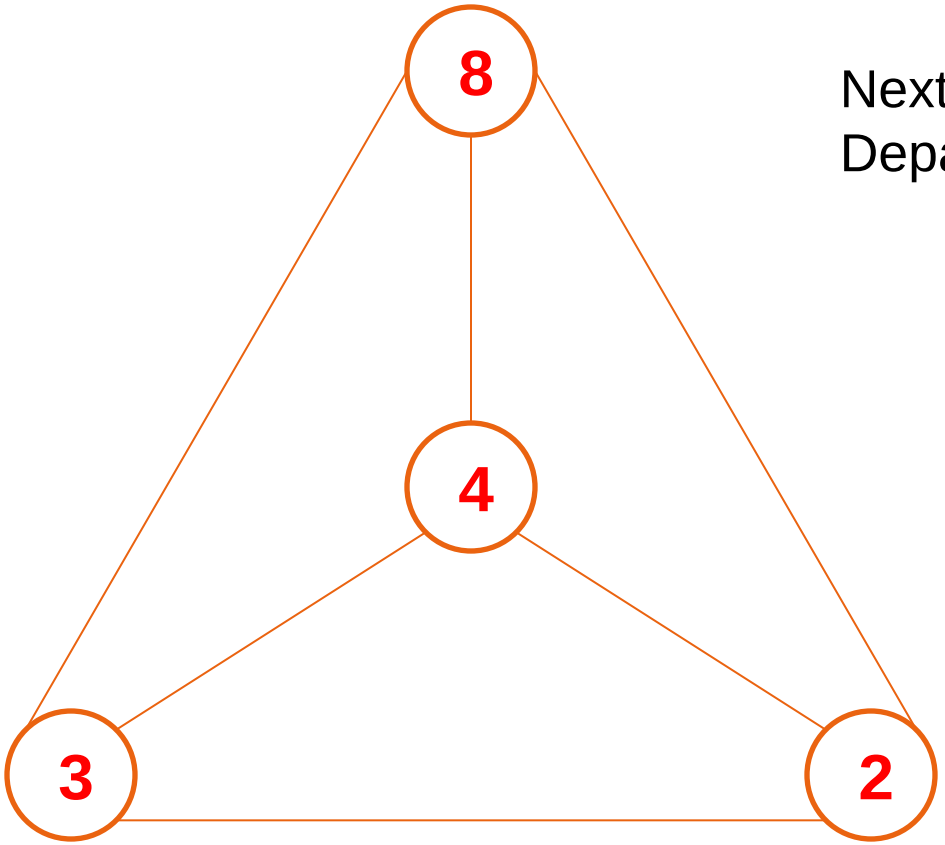
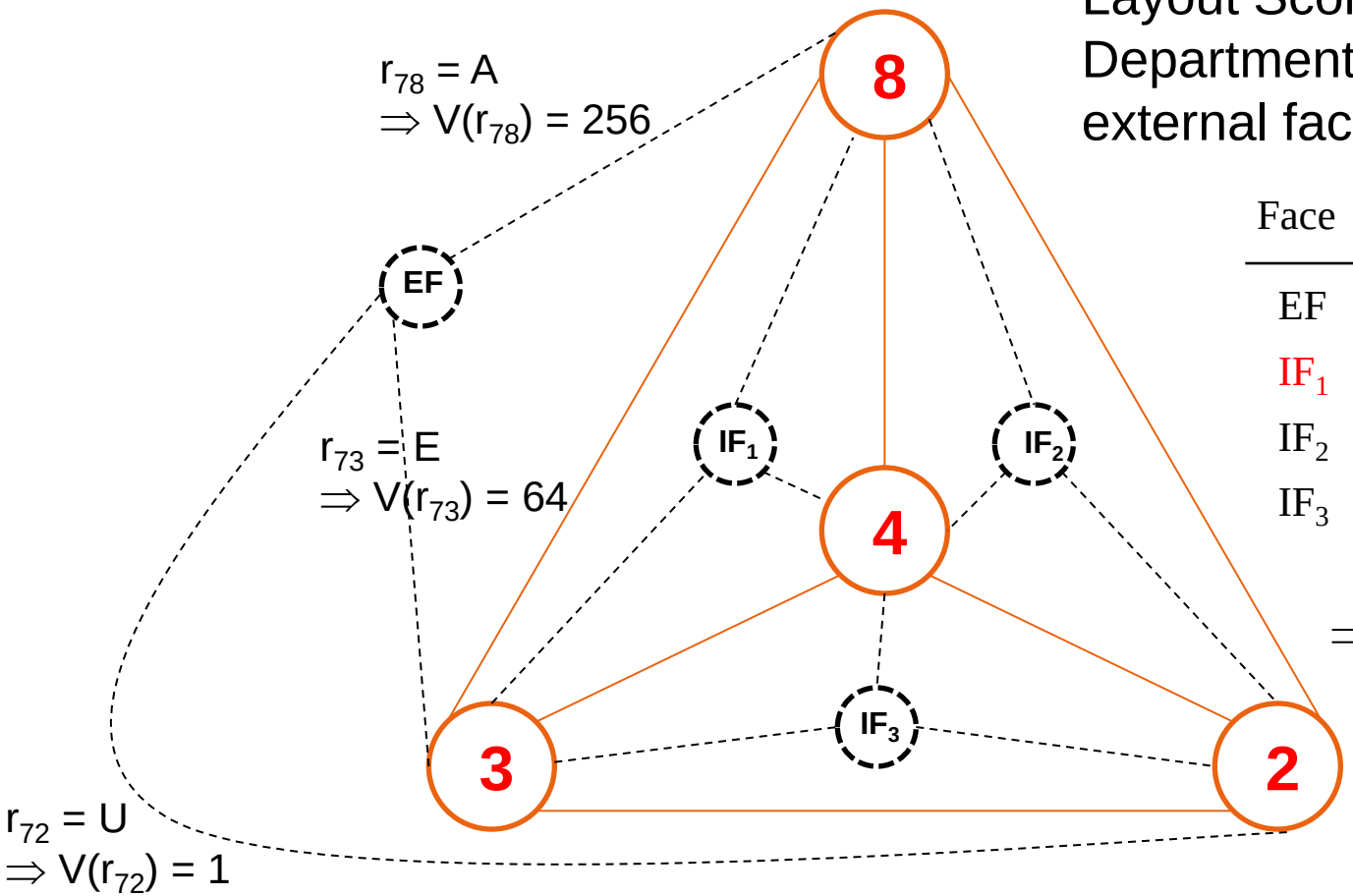
# Relationship (REL) Graph (Primal Graph)




Next entering department:
Department 7

# REL Graph (Primal Graph)




Layout Score ($LS^a$) of Department 7 at internal and external faces:

| Face | $LS^a$ |
|---|---|
| EF | 1 + 64 + 256 = 321 |
| $IF_1$ | 64 + 64 + 256 = 384 |
| $IF_2$ | 1 + 64 + 256 = 321 |
| $IF_3$ | 1 + 64 +64 = 129 |

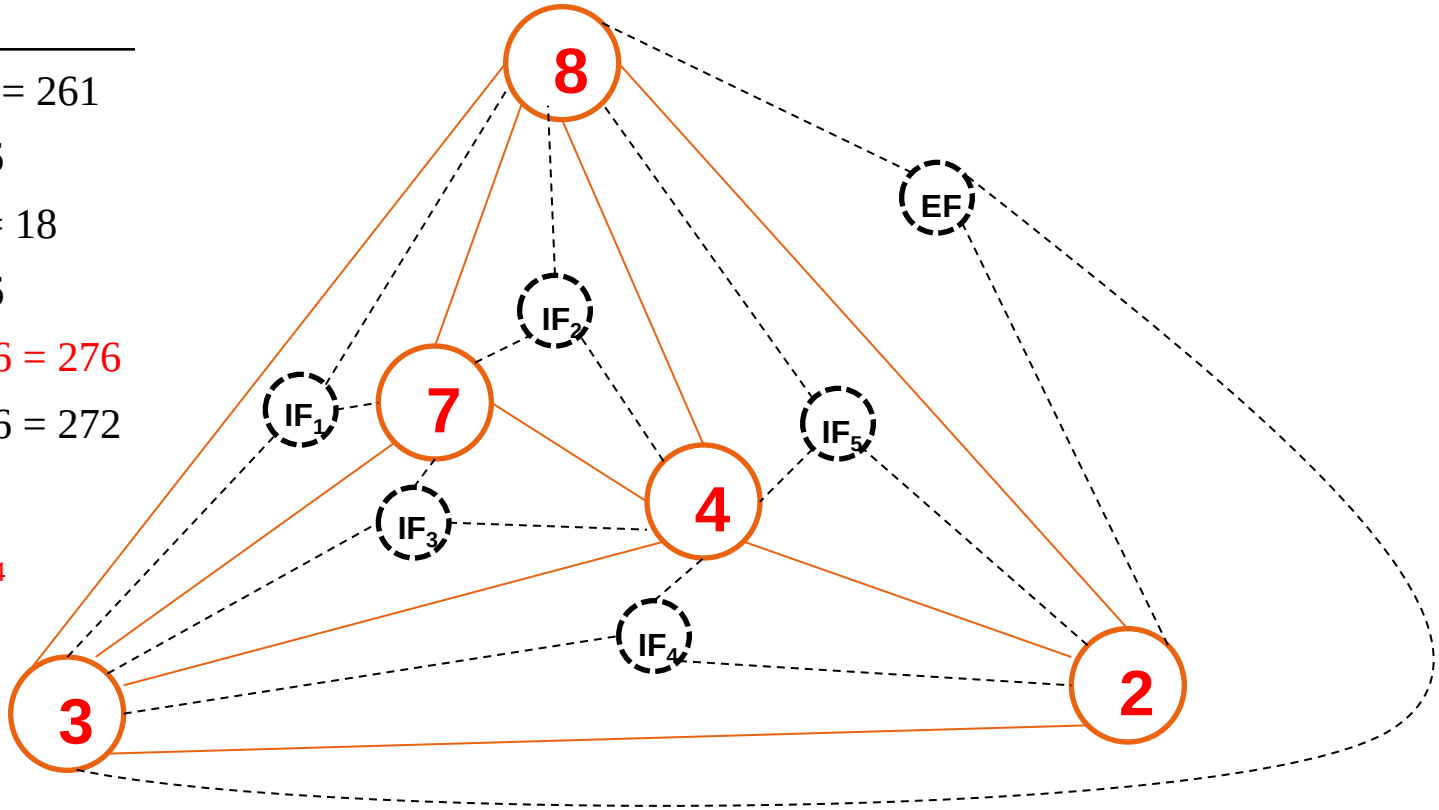
⇒ Insert Dept 7 in $IF_1$

# REL Graph (Primal Graph)

LS$^a$ of next entering department (Department 5):

| Face | LS$^a$ |
|---|---|
| EF | 1 + 4 + 256 = 261 |
| $IF_1$ | 1+ 1 + 4 = 6 |
| $IF_2$ | 1 + 1 + 16 = 18 |
| $IF_3$ | 1 + 1 + 4 =6 |
| $IF_4$ | 4 + 16 + 256 = 276 |
| $IF_5$ | 1 + 16 + 256 = 272 |

$\Rightarrow$ Insert Dept 5 in $IF_4$

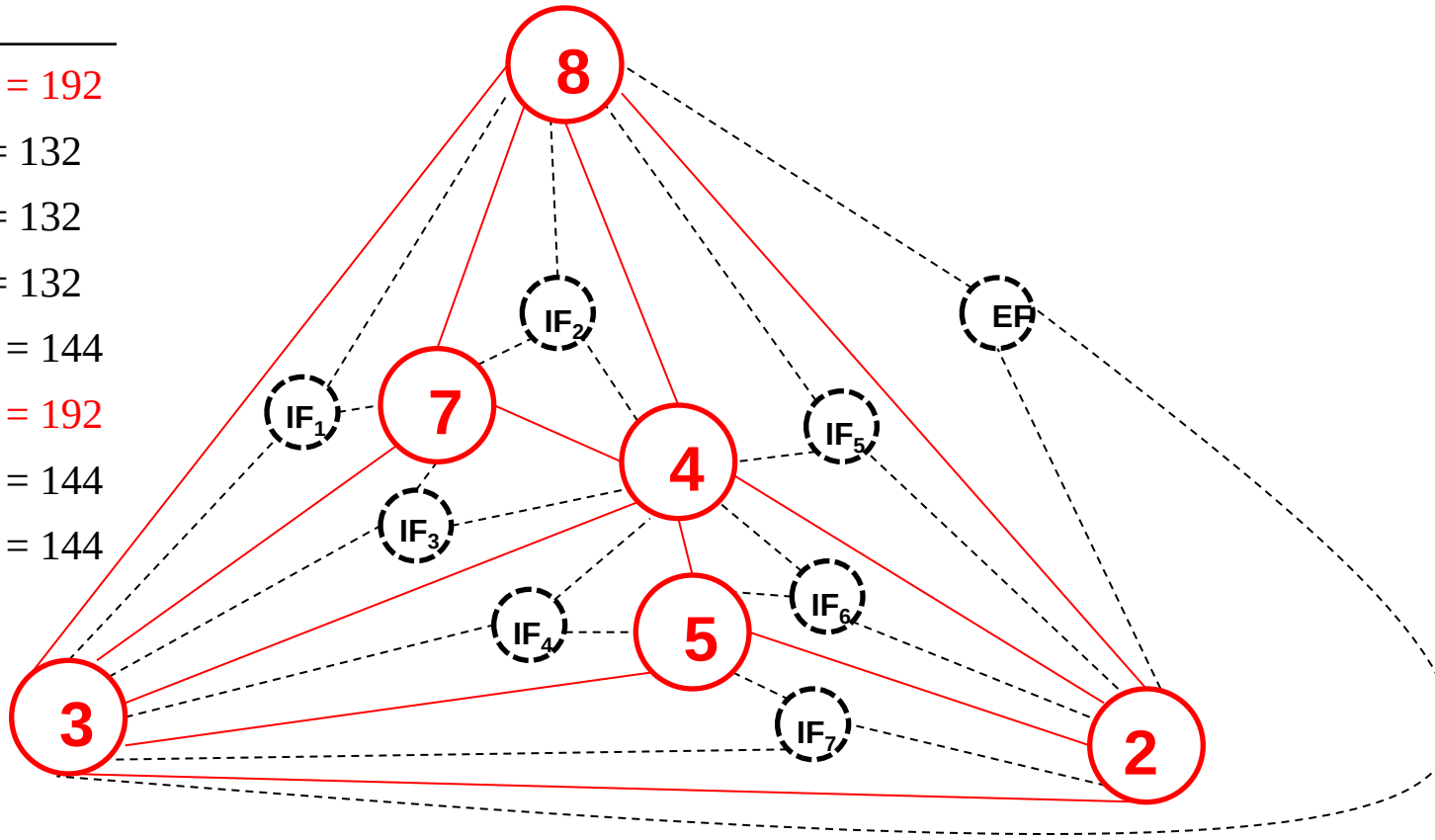


# REL Graph (Primal Graph)

LS$^a$ of next entering department (Department 1):

| Face | LS$^a$ |
|---|---|
| EF | 64 + 64 + 64 = 192 |
| $IF_1$ | 4 + 64 + 64 = 132 |
| $IF_2$ | 4 + 64 + 64 = 132 |
| $IF_3$ | 4 + 64 + 64 = 132 |
| $IF_4$ | 16 + 64 + 64 = 144 |
| $IF_5$ | 64 + 64 + 64 = 192 |
| $IF_6$ | 16 + 64 + 64 = 144 |
| $IF_7$ | 16 + 64 + 64 = 144 |

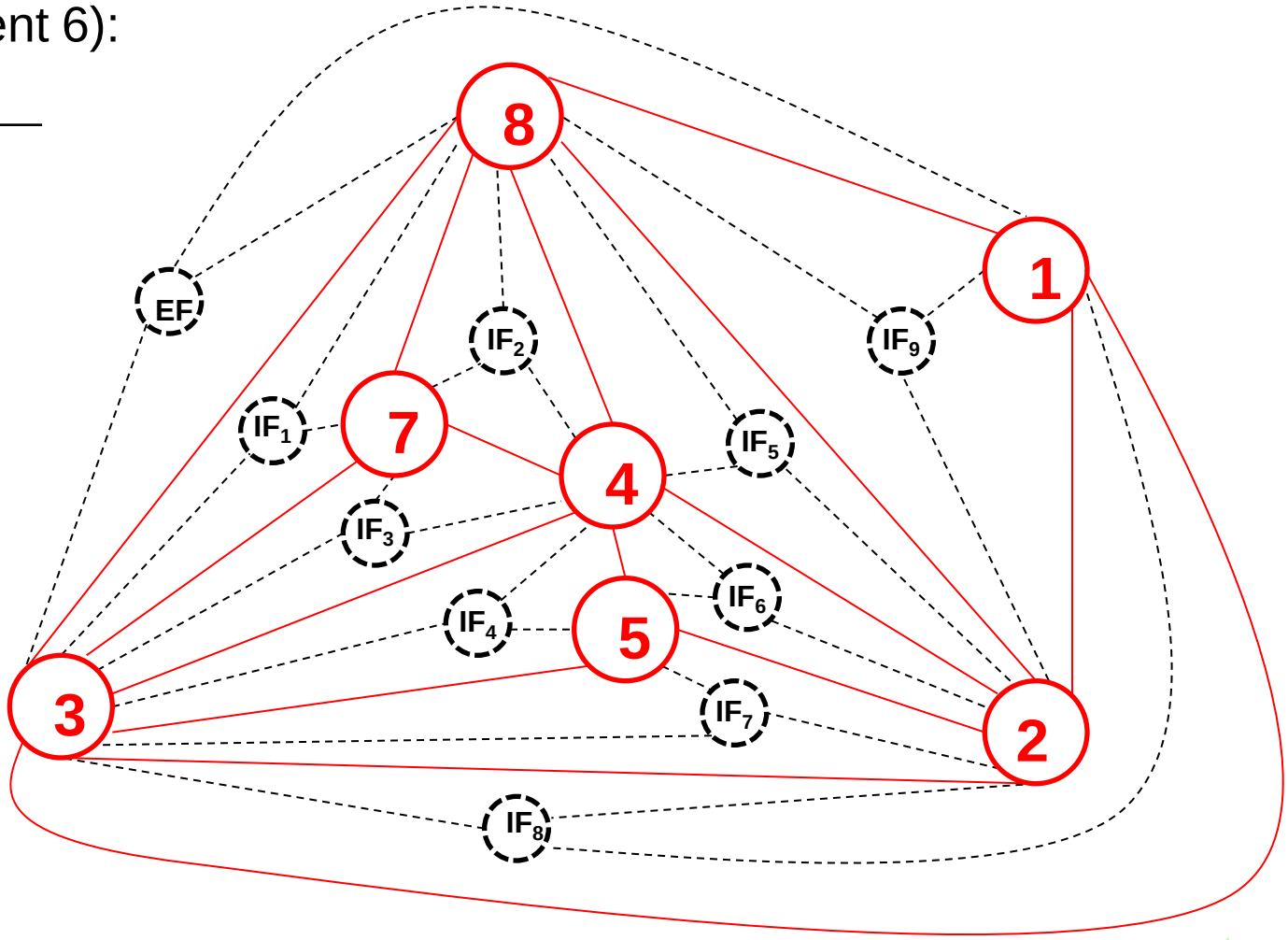
$\Rightarrow$ Insert Dept 1 in EF or $IF_5$



# REL Graph (Primal Graph)

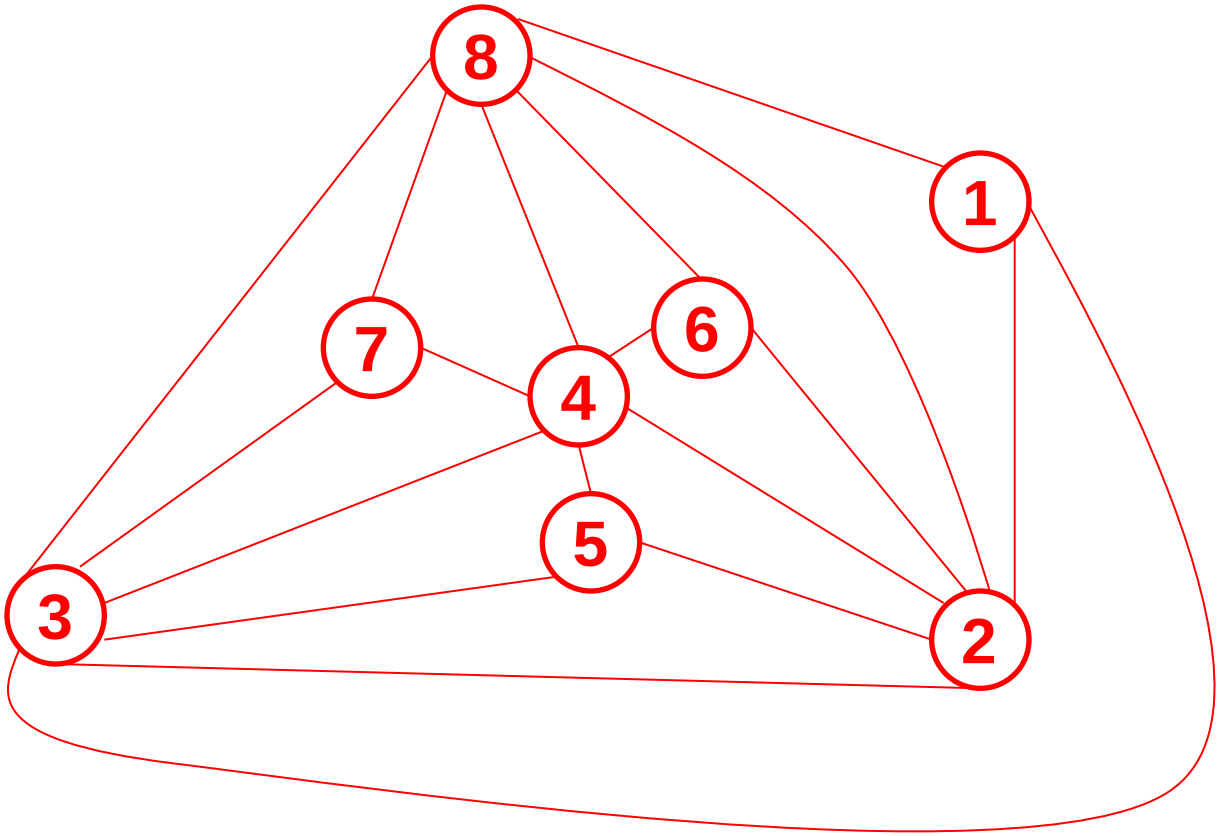
$LS^a$ of next entering department (Department 6):

| Face | $LS^a$ |
|---|---|
| EF | 1 + 4 + 16 = 21 |
| $IF_1$ | 1 + 4 + 16 = 21 |
| $IF_2$ | 1 + 16 + 16 = 33 |
| $IF_3$ | 1 + 4 + 16 = 21 |
| $IF_4$ | 4 + 4 + 16 = 24 |
| $IF_5$ | 4 + 16 + 16 = 36 |
| $IF_6$ | 4 + 16 + 4 = 24 |
| $IF_7$ | 4 + 4 + 4 =12 |
| $IF_8$ | 1 + 4 + 4 = 9 |
| $IF_9$ | 1 + 4 + 16 = 21 |

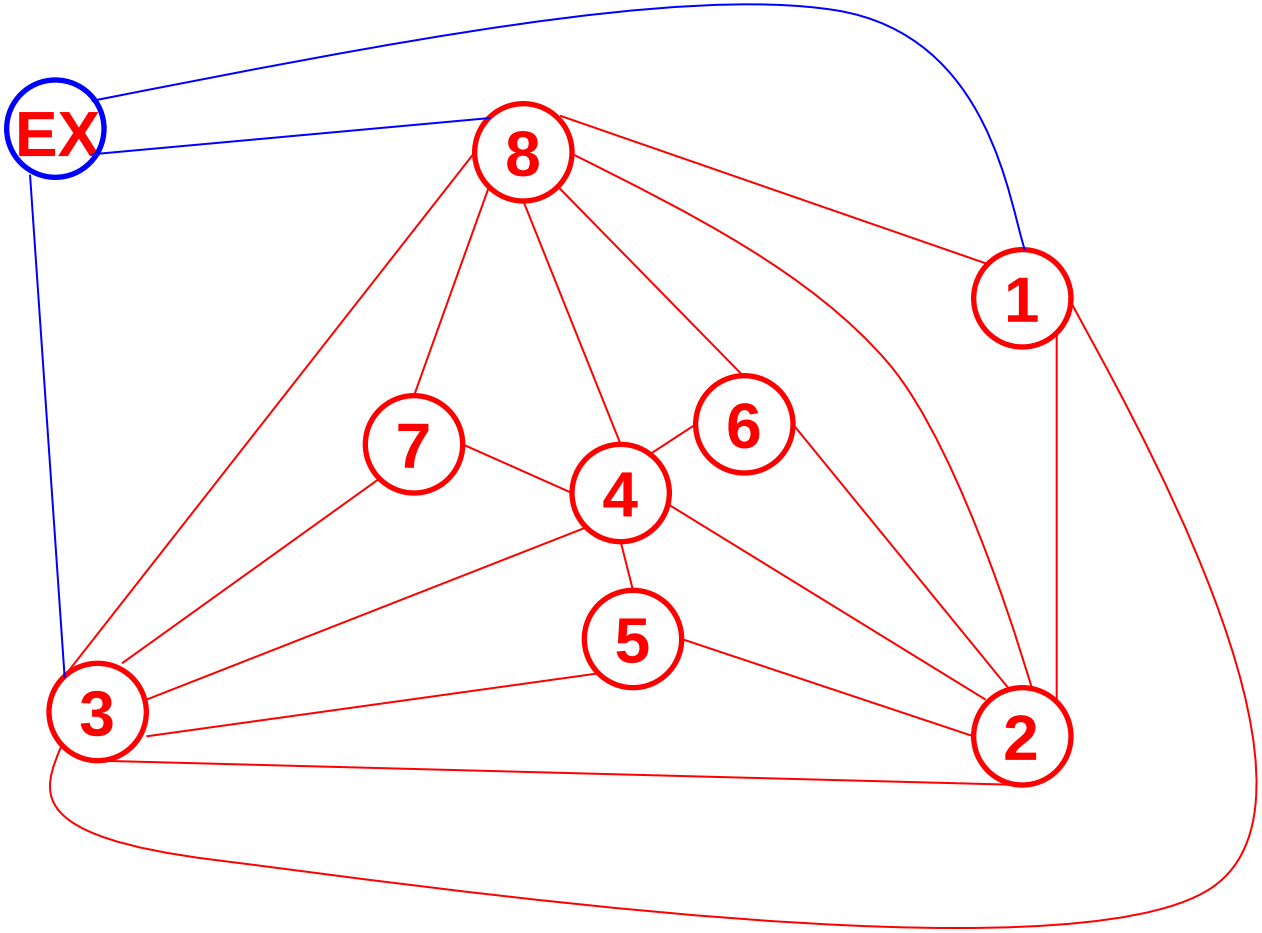



⇒ Insert Dept 6 in $IF_5$

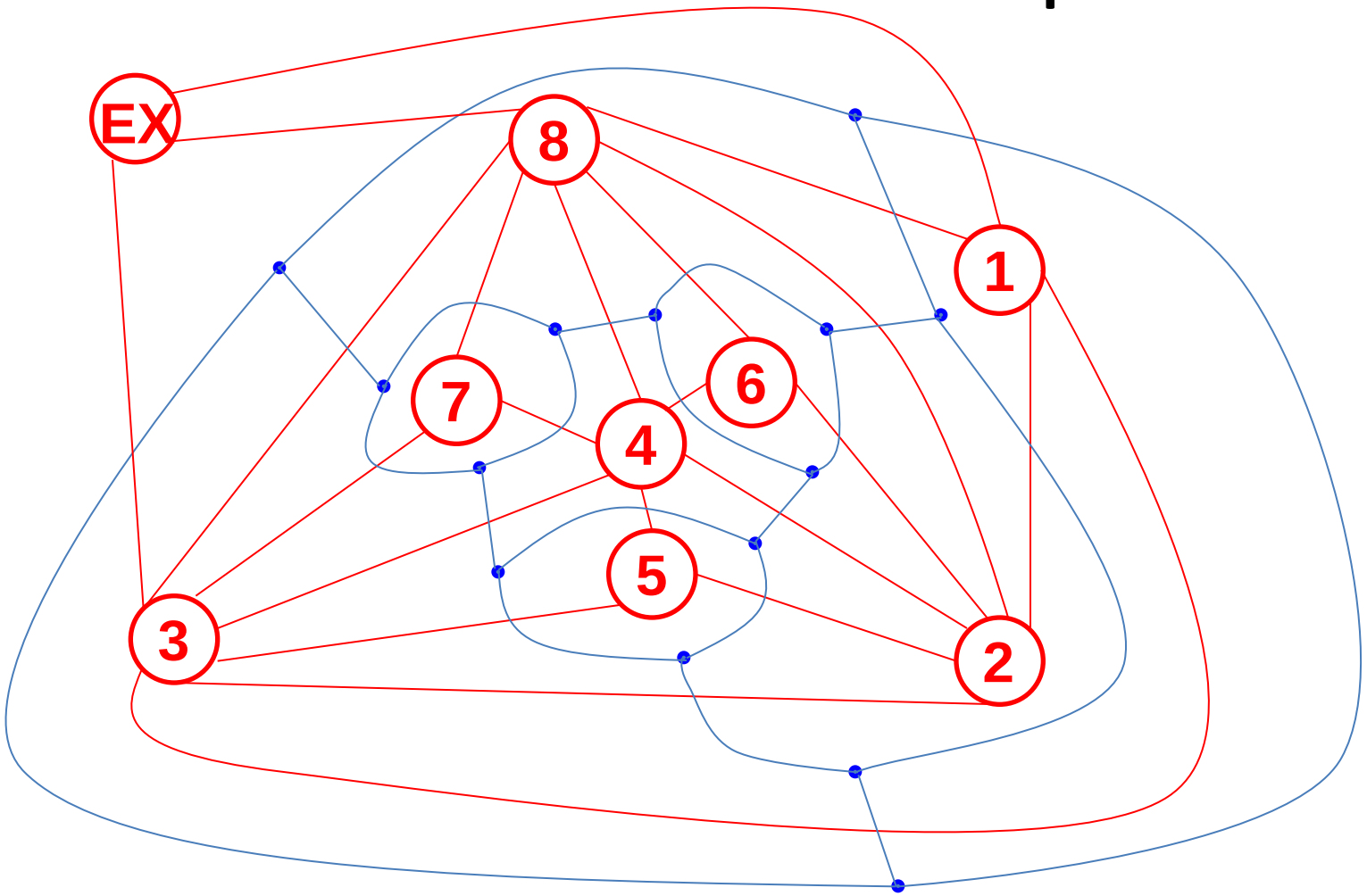
# Final REL Graph (Primal Graph)



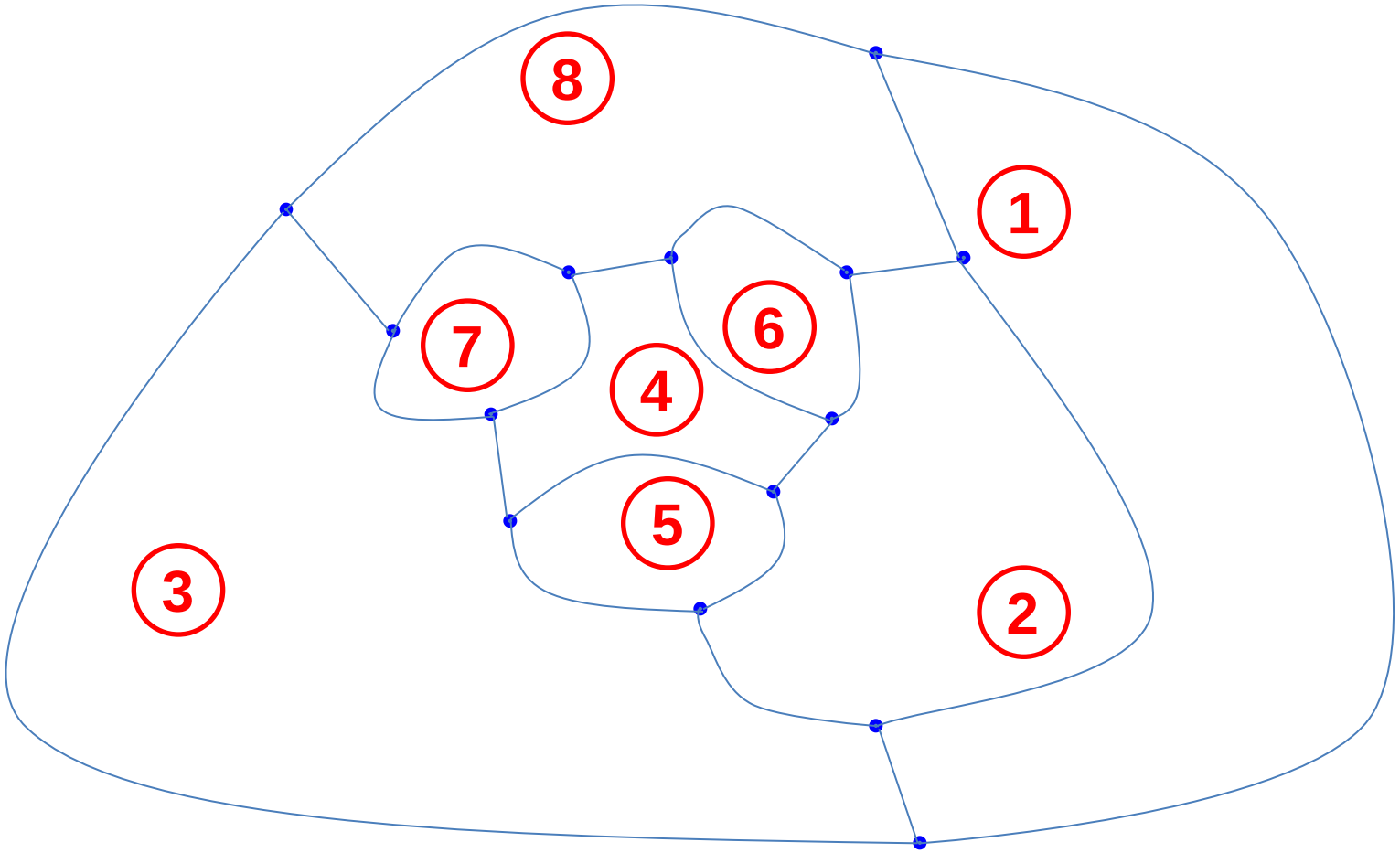
# Add an External Point (EX)



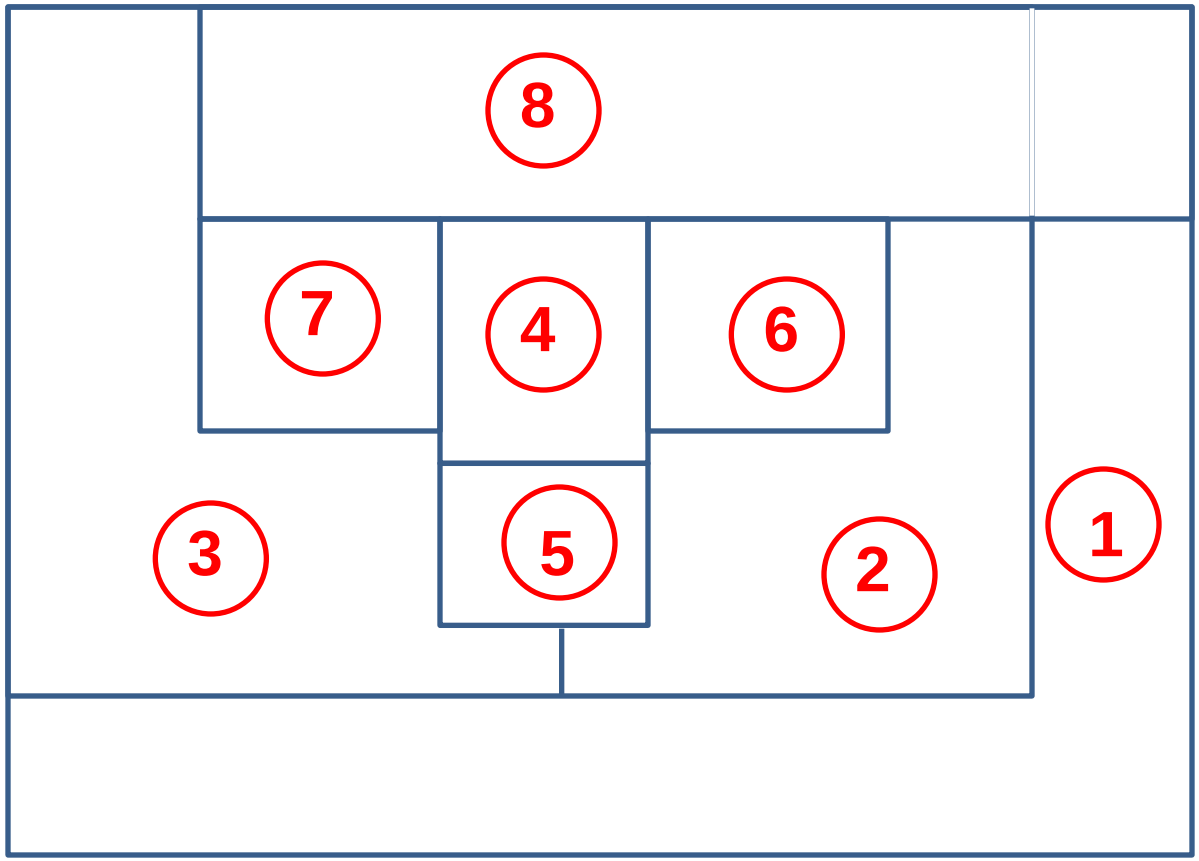
# Dual of REL Graph



# Layout Graph (Dual Graph)



# Block Layout



# Possible Considerations

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

# Learning Objective

- Obtain a TCR table for the facility
- Obtain an initial layout using the graph based approach, where a Block Layout is constructed from 1) REL Chart, followed by 2) REL Graph (Primal Graph) and 3) Layout Graph (Dual Graph).
- Graph-based layout construction emphasizes the importance of constructing a planar graph of the REL chart if Block Layout is to be constructed to satisfy the relationships.