Fall Semester 2022
Updated version

Topic two : Truck overview (Slides)

↳ Topic one & two

- imp Definitions :-

* Intermodalism : moving freight by 2 or more modes of transportation.

* TOFC : Trailer on Flat Car (truck & train)
* COFC : Container on Flat Car (sea & train)

↑ terms of intermodalism transportation modes

Single or double

* FTL : "Full truck load", the entire Capacity of the truck is dedicated to one Shipper (Customer)

→ So wether you fill it or not, it's dedicated to the Shipper from origin to destination.

* LTL : "less than truck load", the Space inside the trailer (truck) is divided potentially among multiple Shippers.

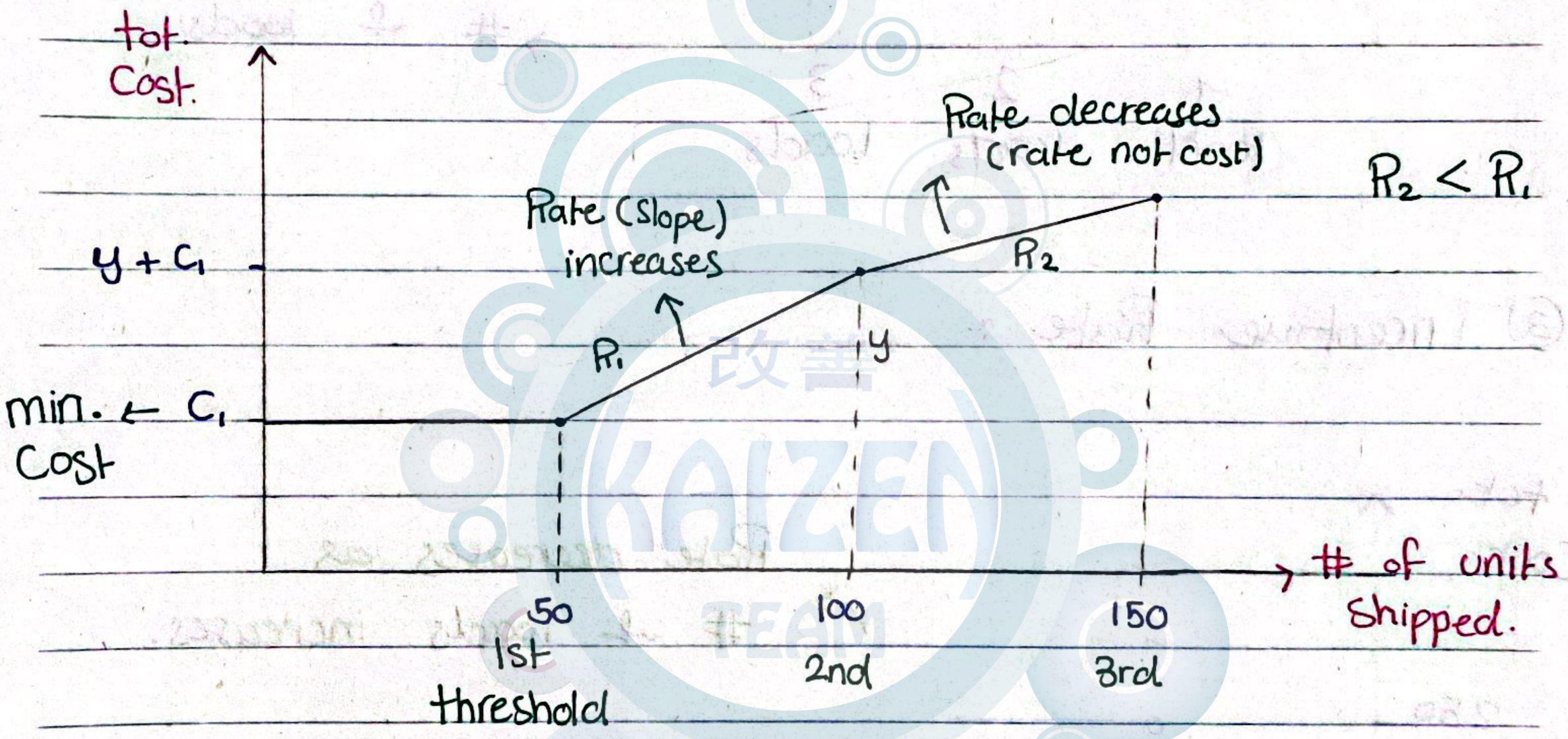
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Topic Three : Transportation Rates and Costs.

* EOS : Economic of Scale
→ the marginal cost decreases as the quantity shipped increase.

1 Rate Structure - Related to Shipment Size

① LTL , LCL :- Shipment less than truck / Container load:-



$$R = \begin{cases} \$20/\text{unit} & : X \leq 50 \\ \$10/\text{unit} & : 50 < X \leq 100 \\ \$7/\text{unit} & : 100 < X \leq 50 \\ \$5/\text{unit} & : X > 150 \end{cases}$$

∴ tot. Cost = $20 + (10 * 50) + (7 * 50) + (5 * 20) = \$970$

↳ Considering $X = 170$

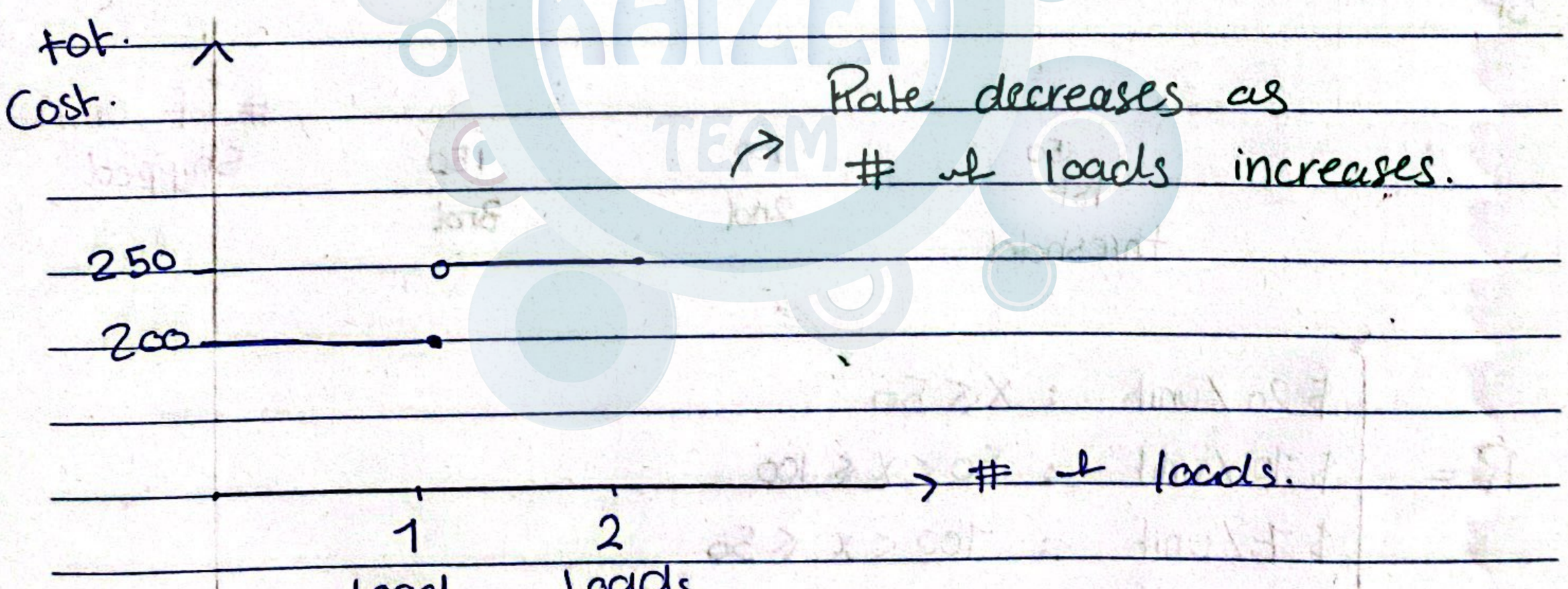
↓ to transfer 170 units *

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② FTL, FCL : Full truck load Case:-



③ Incentive Rate :-



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[2] Rate structure - Related to Distance.

① Uniform rate → rate independent of Distance.

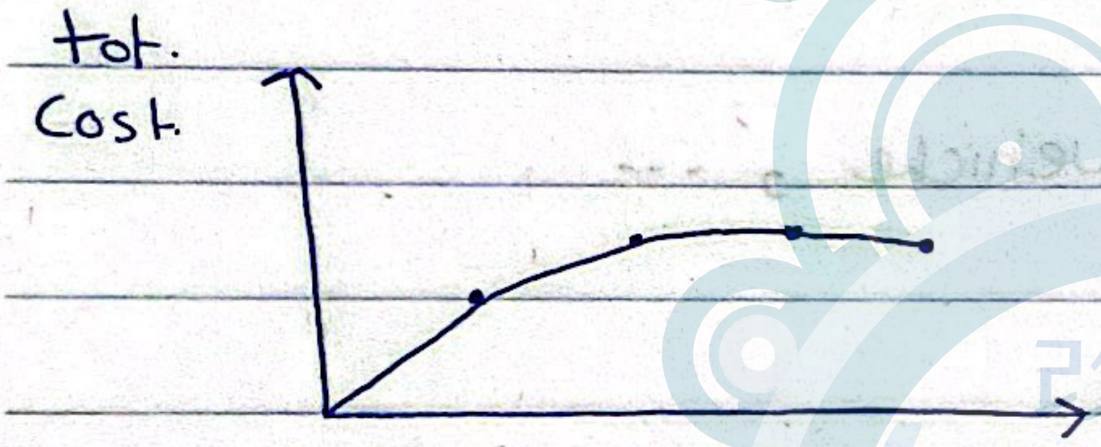
② Propotional Rate → Fixed Cost + variable Cost

Cost ثابت: ذي فتحة الحدار — Taxi

Cost متغير: بحدها بتعتمد على كم المسافة.

③ Tapered Rate → cost increases with Distance But at a decreasing Rate.

ذي شركات الشحن



④ Blanket Rate → Constant rate for certain intervals of Distance.

بيعتمد على المنطقة و الماشين.

[3] Rate structure - Related to Demand.

→ Rate deperels on how the Customer is willing to afford.

[4] Rate structure - Related to Product Shipped.

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* Cost Characteristics by mode of trans. :-

① Fixed Costs → vehicles, equipments, ...

② Variable Costs → Fuel, maintenance, drivers, ...

③ Treminal Costs. → loading & unloading ...

- Comparison (Rail / truck & water / Air) on topic 3 Slides.

* Cost Classification:

① Transportation Cost

→ Cost of movement via vehicle, ...

② Handling Costs

→ Packing, Un-Packing, moving into & out of storage.

③ Holding Costs

→ opportunity cost of capital for time waiting.

④ Facility rent Costs.

→ rent, storage infrastructure and mainteance ...

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⊛ Mode Choice Problem :-

Steps

① Determining the inventory Space cost at the origin (Production Plant)

② Determining the Holding cost at the Orgin

③ Determining the inventory Space cost at the Destination (warehouse)

④ = = Holding Cost at the Destination

⑤ = = Pipeline inventory Cost (∴ intransit inventory Cost)

⑥ = transportation Cost for each mode

⑦ = total Cost for each mode

⊛ $\overline{TC}_{Rail} = \overline{TC}_{rail}(q)$ → optimal quantity. ⌐ tot. Cost as function of q.

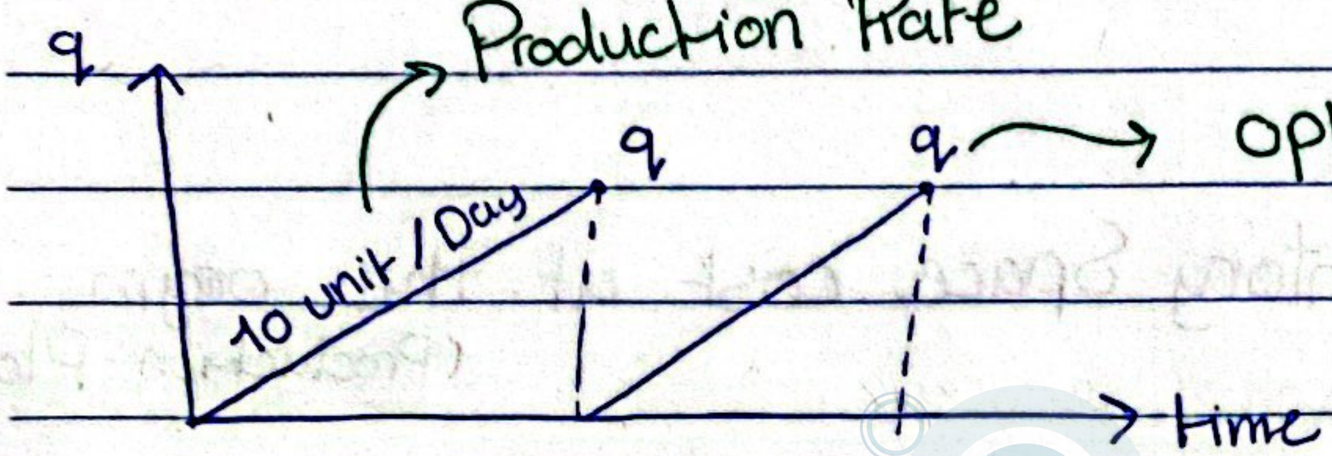
⊛ $\overline{TC}_{truck} = \overline{TC}_{truck}(q)$

⑧ Determine optimal q for each mode at transportation

⑨ = the most economical (optimal) transportation mode. ✱

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* Orgin (Production Plant) :-



هَي بكي ح اشحنوا
فَ بري أحسب
قيمتها

↳ Considering Safety Stock at zero

$SS = 0$.

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In-class Example

Choosing a Transportation Mode

Hypothetical company has:

- 1 plant, producing 1 product
- 1 warehouse, storing the product from which customers supplied directly
- Plant keeps 0 safety stock inventory, warehouse maintains 100 units
- Average customer demand rate at warehouse: 10 units/day
- Plant produces 10 units/day

Suppose we would like to compare two modes of transportation for moving product from the plant to the warehouse. We want to make a mode choice decision that minimizes total cost.

Rail:

- Shipments in railcars containing at most 400 units
- Cost: $1200 / carload
- Transit time: 20 days

Truck:

- Truckloads of at most 100 units
- Cost: $700 / truckload
- Transit time: 3 days Inventory costs

Inventory cost:

Value of items at plant: $500 / unit

Value of items at warehouse: $512 / unit

Inventory holding cost rate: 25% of value per year held

Plant space cost: $20 / unit*year

Warehouse space cost: $25 / unit*year

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Goal :

- Our goal is to determine the optimal shipment size q for each mode, and the total cost of the optimally configured system.

Assumptions:

- Assume for now that we will never ship more than a single railcar or a single truckload at a time when minimizing cost

1. What are the annual inventory holding costs at the production plant? (Include the space and holding cost in this calculation.)

2. What are the annual inventory holding costs at the warehouse (Include the space and holding cost in this calculation.)

3. What are the pipeline inventory costs for each mode?

4. What are the transportation costs for each mode?

5. What are the total cost equations for each mode of transportation?

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In-class Example one :-

Step 1 : inventory space cost at origin.

Space cost = $20/~~unit~~. year * q ~~(unit)~~

= $20 q / year #

Step 2 : Holding cost at origin.

Inventory Holding cost = inventory holding cost Rate → given 25%.

* value of item x at origin → given 500

* Avg. # of units held in the inventory → $\frac{q}{2}$ =

= 0.25 * 500 * (q/2) = 62.5 q #

now; inventory Cost = Space Cost + holding Cost

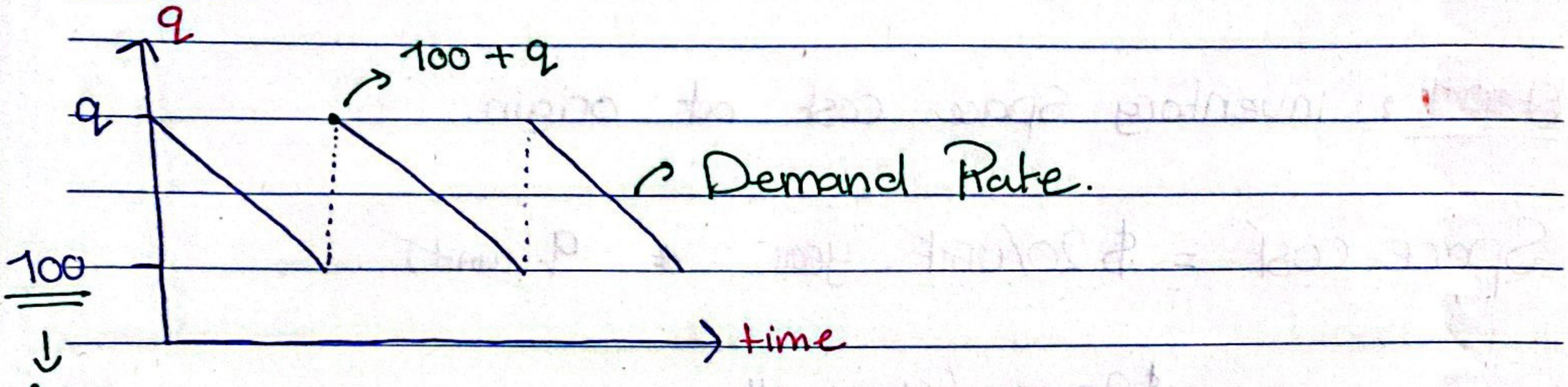
↙ Step 1 + Step 2

= 20 q / year + 62.5 q

= 82.5 q / year #

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Step ③ : inventory Space cost at Destination (WH)



↓
Safety Stock
موجود بال Destination.

So, inventory Space cost at Dest. =

= $25 / unit . year * (100 + q)
↳ max q ممكن يكون موجودة.

= $(2500 + 25q) / year.

Step ④ : Holding Cost at Destination (WH)

holding Cost at Destination (warehouse)

$$= 0.25 * 512 * \left(100 + \frac{q}{2}\right)$$

$$= 64q + 12,800 \text{ / year.}$$

⑤ now tot. inventory Cost at WH.

= Step 3 + Step 4

= 2500 + 25q + 64q + 12,800

= 89q + 15,300 #

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Step ⑤

pipeline Inventory → inventory cost in-transit.

* P.I = 25% * value of item intransit.

* value of item in transit = $\frac{\text{its value at orgin} + \text{its value at Dest.}}{2}$ ← Avg.

$= \frac{500 + 512}{2} = 506\ \$ / year.$

* Holding Cost Pipeline intransit = 25% * 506 = $126.5 / unit.year

↳ Doesn't depend on Shipment Size, it depends on the mode of transportation.

imp
* 10 unit / Day → 365 day / year. ⇒ 3650 units / year

لـ بدي أنقلهم كاملين، إما عـ الـ truck أو عـ الـ Rail.

* now given :-

- Rail : capacity = 400 units, Cost = 1200 / Car, time intransit = 20 Days.
- Truck : Capacity = 100 units. Cost = 700 / truck, time intransit = 3 Days.

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⊛ Pipeline Inventory Cost by Rail ($ / year)

$$= 3650 \frac{\text{unit}}{\text{year}} * 20 \text{ days} * \frac{1 \text{ year}}{365 \text{ days}} * \frac{126.5 \$}{\text{unit . year}}$$

$= \$\ 25300 \cdot / \text{year}. \#$

⊛ Pipeline Inventory Cost by truck ($ / year)

$$= 3650 \frac{\text{unit}}{\text{year}} * 3 \text{ days} * \frac{1 \text{ year}}{365 \text{ day}} * \frac{126.5 \$}{\text{unit year}}$$

$= 3795 \$ / \text{year} . \#$

↳ Pipeline inventory cost is constant (not as function of q) ← ما رح يتأثر بـ q لأنه كل ما يصير عندي رح أوزعها

Step 6 : transportation cost for each mode.

- Transportation cost depends on:
  - # of Shipments (علاقة طردية)
  - transportation mode

$$\# \text{ of Shipments} = \frac{3650}{q}$$

↳ train, truck $[q_{train} \neq q_{truck}]$

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⊛ Transportation Cost by Rail

$= \frac{1200\ \$}{\text{Railcar}} * \frac{3650\ \text{unit/year}}{q_{rail}} = \frac{4{,}380{,}000\ \$ / \text{year}}{q}$ #

⊛ Transportation Cost by Truck

$= \frac{700\ \$}{\text{Truckcar}} * \frac{3650\ \text{unit/year}}{q_{truck}} = \frac{2{,}555{,}000\ \$ / \text{year}}{q}$ #

Step 7 Total cost for each mode

⊛ total Cost for Rail / truck :-

= inventory cost at origin (holding + Space) step 2 ⊕ inventory cost at Destination (holding + Space) step 4

⊕ Pipeline inventory cost step 5 ⊕ $\overline{\text{Transportation Cost}}$ step 6

① $\overline{TC}$ for Rail $= \overline{TC}(q) = 82.5q + 15300 + 89q + 25300 + \frac{4380000}{q_{rail}}$

② $\overline{TC}$ for truck $= \overline{TC}(q) = 82.5q + 15300 + 89q + 3795 + \frac{2{,}555{,}000}{q_{truck}}$

Step 8 Determine optimal q for each mode

⇒ Derive $\overline{TC}$ eq. ⇝ q optimal when $\frac{d\overline{TC}}{dq} = 0$ # with respect to q

⊛ total Cost equation :

$f(x) = \frac{A}{X} + BX + C$ ⇝ $X^* = \sqrt{\frac{A}{B}}$ ← q

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* To find q_{Rail} (optimal) $\rightarrow \frac{d\,\overline{TC}_{rail}}{q} = 0$

$\Rightarrow 82.5 + 0 + 89 + 0 - \frac{4380000}{q^2} = 0$

$q_{rail} = 160$ units # < 400 capacity ✓

by sub. q_{rail} into $\overline{TC}_{rail}(q)$ Eq.

↳ $\overline{TC}_{rail} = 95,415$ \$ / year.

* To Find q_{truck} (optimal) $\rightarrow \frac{d\,\overline{TC}_{truck}}{q} = 0$

$\Rightarrow 82.5 + 0 + 89 + 0 - \frac{2,555,000}{q^2} = 0$

$q_{truck} = 122$ # > 100 capacity !

So 2 trucks needed.

by Sub q_{truck} into $\overline{TC}_{truck}(q)$ Eq. Step 9 :- Ans.

↳ $\overline{TC}_{truck} = 61,795$ \$ / year ← lower cost by truck mode ✓

of trucks needed $= \frac{3650}{100} = 36.5 = 37$ truck.

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Sunday
30/10

* we already discussed different modes of transportation
  - for mode selection → we break down the cost into different Categories in order to understand total Cost of Particular mode:

→ transportation Cost
→ Handling Cost
→ Holding Cost for the inventory
→ Pipline inventory holding cost.
→ physical facility Cost (space, rent)

→ choose the most economical → optimal mode based on the tot. Cost.

* Uncertainty in Supply &
Sol.
  - Safety Stock → to mitigate the effect of Supply Uncertainty.

* Uncertainty in Demand :-

- when Demand > Avg. Demand $\xrightarrow{\text{Sol.}}$ Safety stock of finished Products. [extra units]

- when Demand < Avg. Demand $\xrightarrow{\text{Sol.}}$ Extra Space to hold undelivered units.

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⊛ Short - Haul transportation

↳ • imp notations and definitions :-

⊛ Network = graph :-

→ include a set of Nodes / vertices and a set of Arcs / edges.

N

A

$G = (N, A)$ → أي graph بعرفه على شكل arcs & nodes.

G ← graph

N ← nodes

A ← arcs.

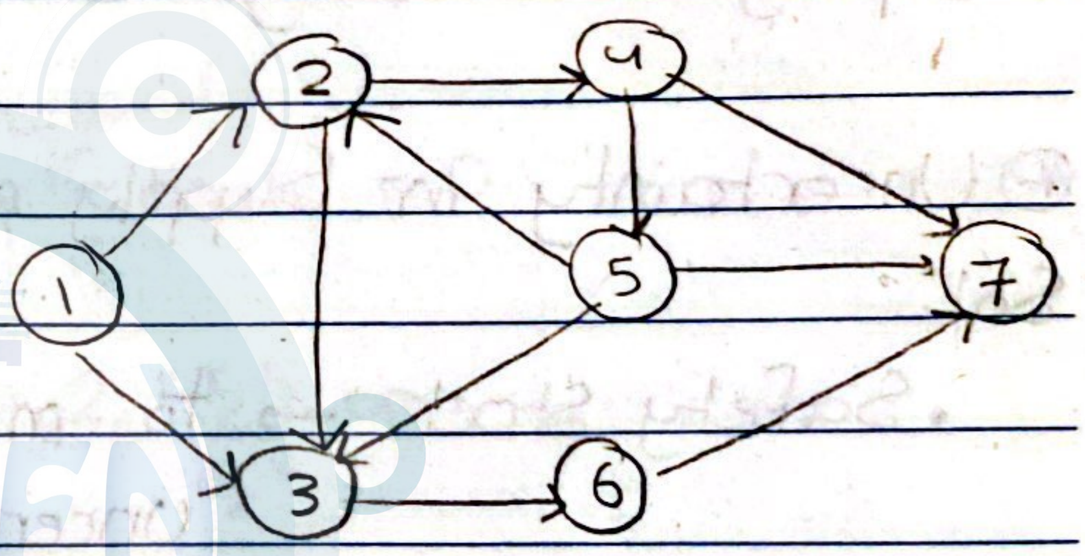
• example

↳ set of nodes.

⊛ $N = \{1, 2, 3, 4, 5, 6, 7\}$

$|N| = 7$

↳ # of nodes.



⊛ $A = [(1,2), (1,3), (2,4), (2,3), (3,5), (3,6), (2,5), (4,5), (4,7), (5,7), (6,7)]$ → Set of Arcs

$|A| = 11$ → # of Arcs.

Side Note
- node = vertex
- Arc = edge
- graph = Network
- N = set of nodes
- A = set of arcs

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⊛ Direct & Indirect Graphs :-

- Direct graph :
  - → direct arcs →
  - → ordered pair of nodes



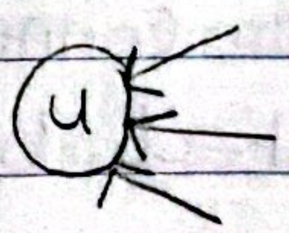
→ not Symmetrical

- Indirect graph :
  - → Indirect arcs —
  - → unordered Pair of nodes.



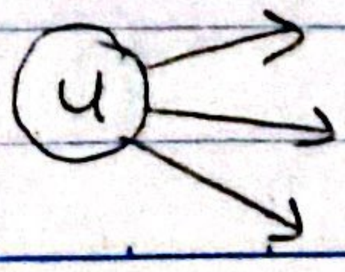
⊛ Degree of the node

- indegree of the node
  - → the number of incoming arcs of the node
  - → for node u : # of arcs which u is the tail or (terminal node.).



indegree = 3.

- out degree of the node
  - → the number of outcoming arcs of the node.
  - → for node u : # of arcs which u is the head (initial node)



outdegree = 3

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• degree of nodes = # of in-degree + # of out degree

• indegree of all nodes = out degree of all nodes = # of arcs

(*) Edges / Arcs may have number of characteristics

• Capacity : max flow on the arc



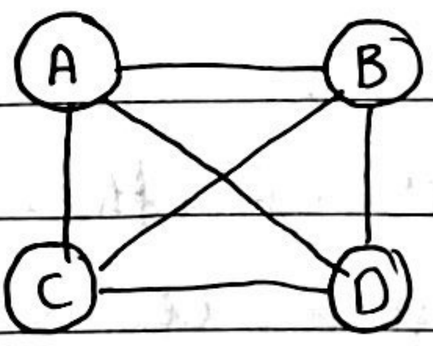
$U_{ij} \neq U_{ji}$

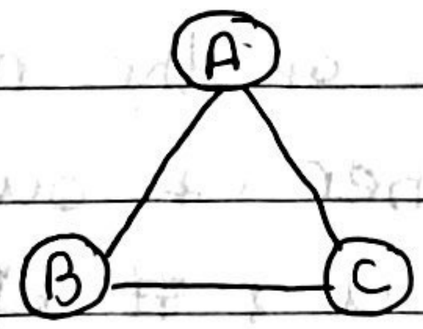
or • Cost : time / Distance / cos$ ($C_{ij} \neq C_{ji}$)

(*) Complete Graph

→ is a simple undirected graph in which a distinct vertices (nodes) are connected by a unique arc / edge.

→ graph G is connected when each node / vertex is connected by every node.





→ there is a direct arc bet. every 2 nodes.

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→ number of arcs out from each node in a complete graph :

= # of nodes − 1 .

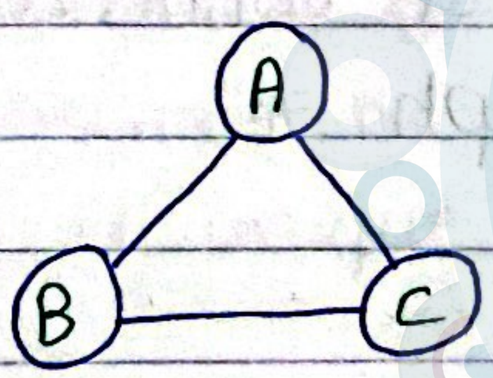
→ number of arcs / edges in a complete graph :

= $\frac{n(n-1)}{2}$, where n is number of nodes.

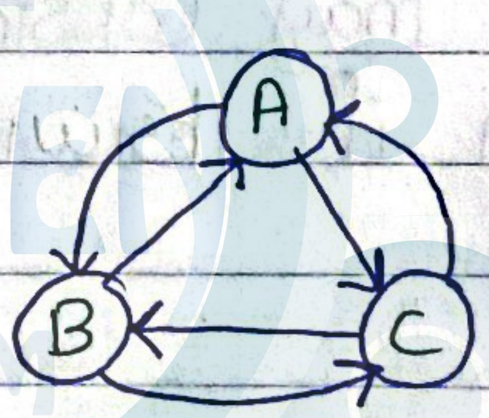
2 لأنه مقسوم على undirected

⊛ Complete di-graph :-

→ is a Complete direct graph



Complete graph



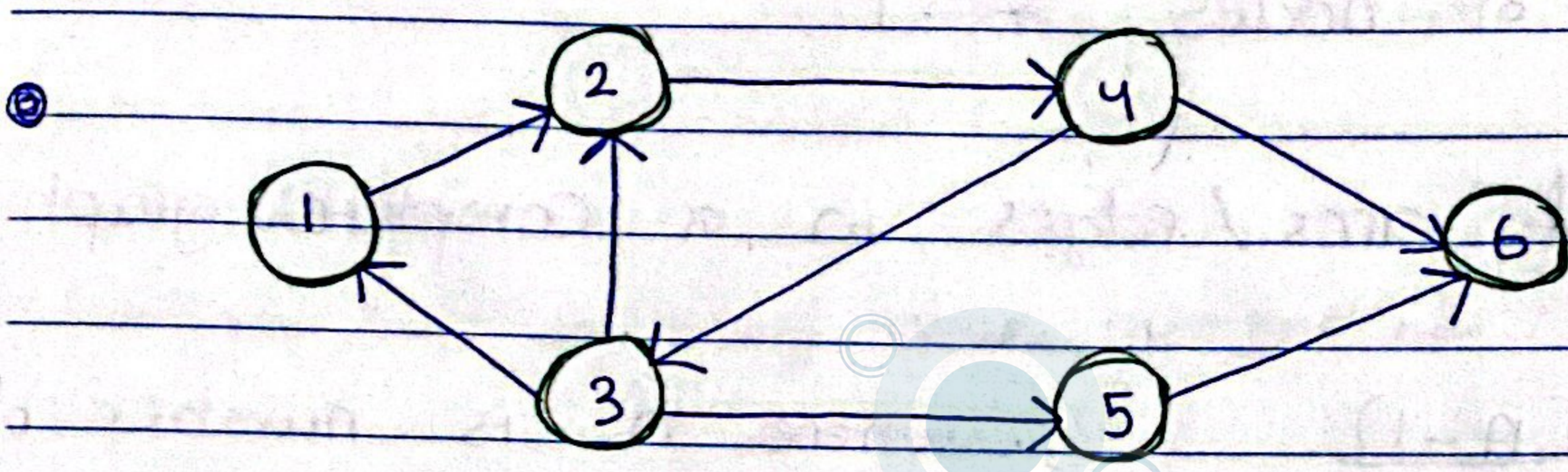
Complete di-graph

⊛ • Connectivity : we say that nodes i and j are Connected , if the graph Contain at least one path from i to j

• A graph is Connected if every pair of its nodes is Connected , otherwise the graph is unconnected

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- Based on Connechivity Definition :-
  every Complete graph is Considered to be Connected . والعكس غير صحيح



Direct graph

↳ Un Connected graph , there is no path between node 5 and node 4 and ... etc.

↳ we may Consider it as a Connected graph if it is indirect

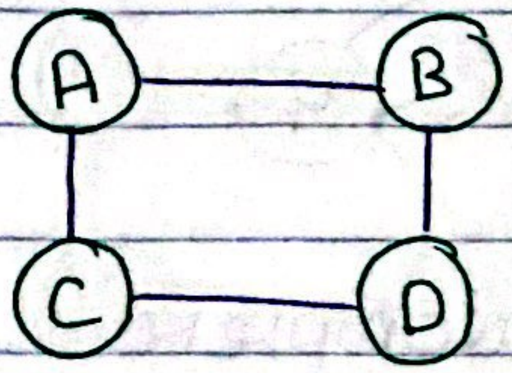
✱ Path :-

- Assume you have n vertices in V , m edges in A.

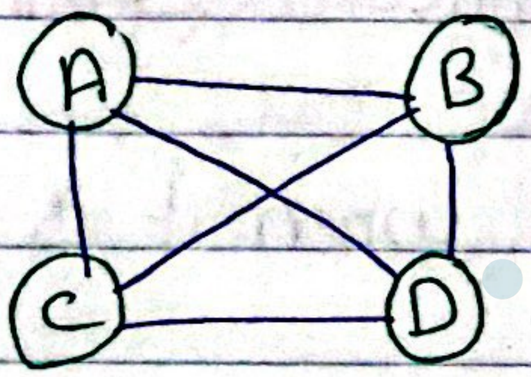
- Path exists from v_0 to v_n if there is a list of vertices : $\{v_0, v_1, \dots, v_n\}$ Such that $(v_i, v_{i+1}) \in A$, For all $0 \leq i \leq n$.

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Tuesday
1/11



→ Connected
→ incomplete
→ in direct.

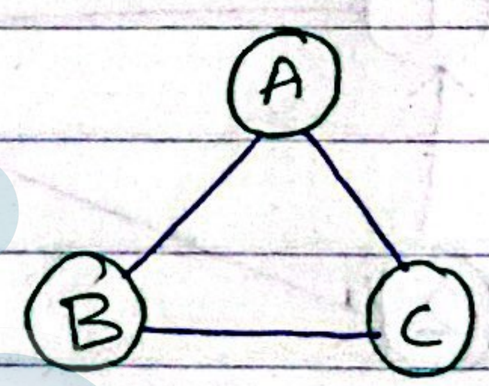


→ Connected
→ Complete
→ in direct.

Recall :-

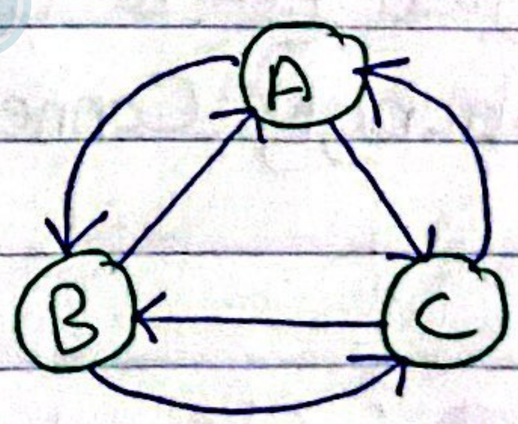
Complete graph:

→ Undirected graph in which a distinct nodes are connected by a unique arc.

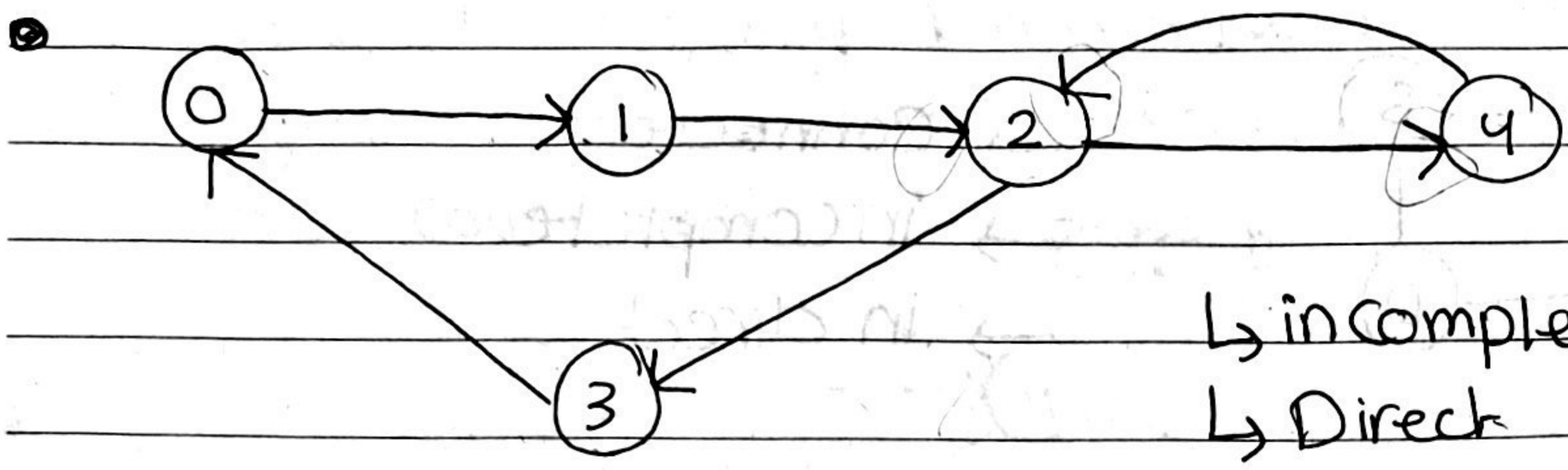


Complete di-graph

→ directed graph in each every pair of nodes is connected by a pair of unique edges (one in each direction)



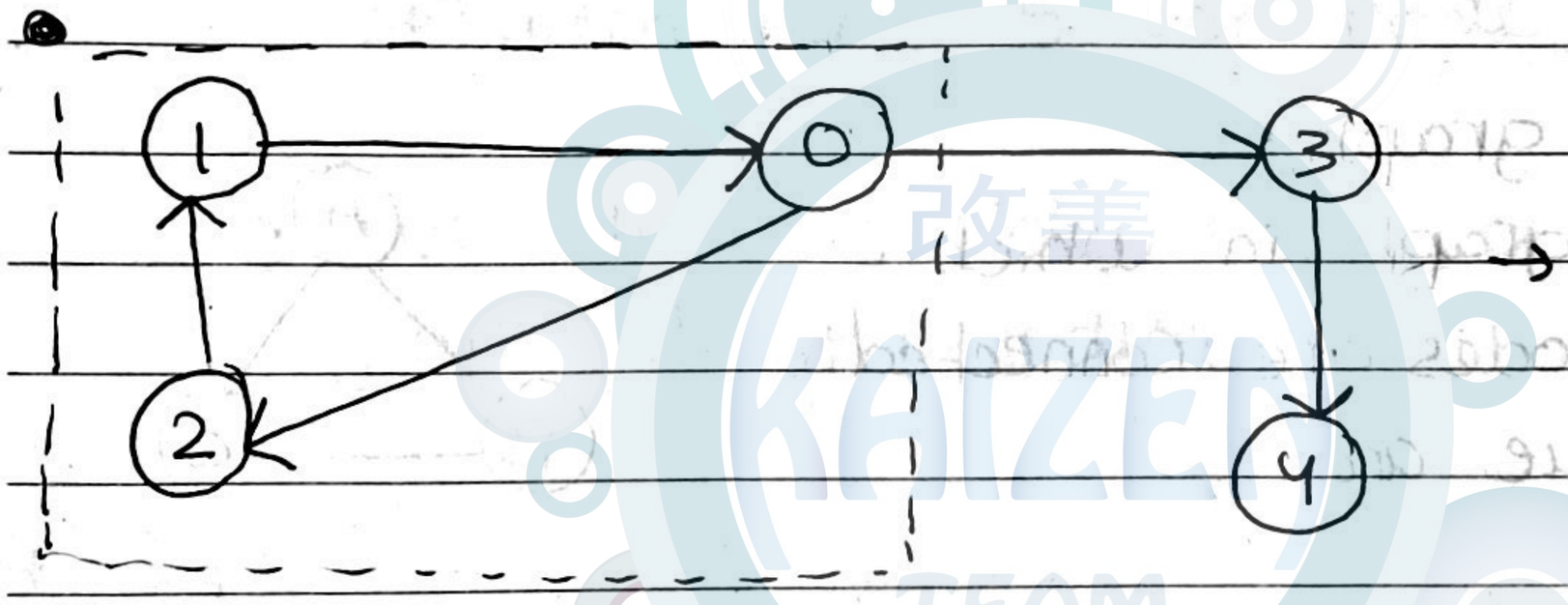
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↳ incomplete

↳ Direct ← Strongly

↳ Connected ← Connected



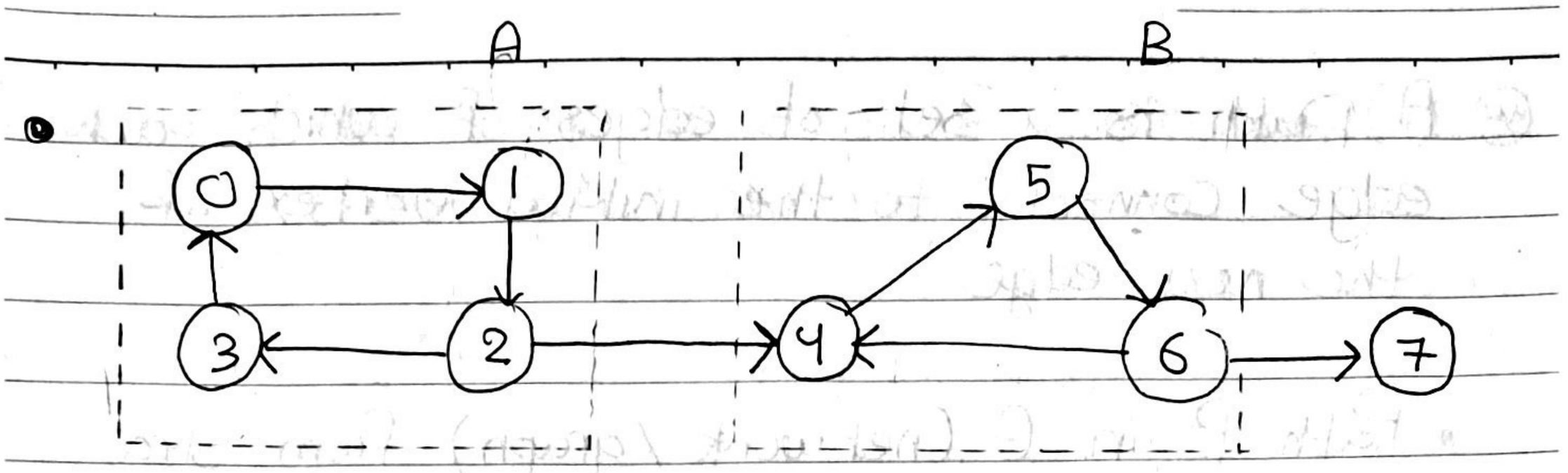
→ not strongly Connected.

لو أخذنا أي الجزئية لحالها فهي تعتبر Strongly Connected.

* "Strongly Connected" is associated with Direct graph, there is a route between each pair of nodes.

* Strongly Connected = Direct + Connected

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↳ Part A is Strongly Connected

↳ Part B is Strongly Connected

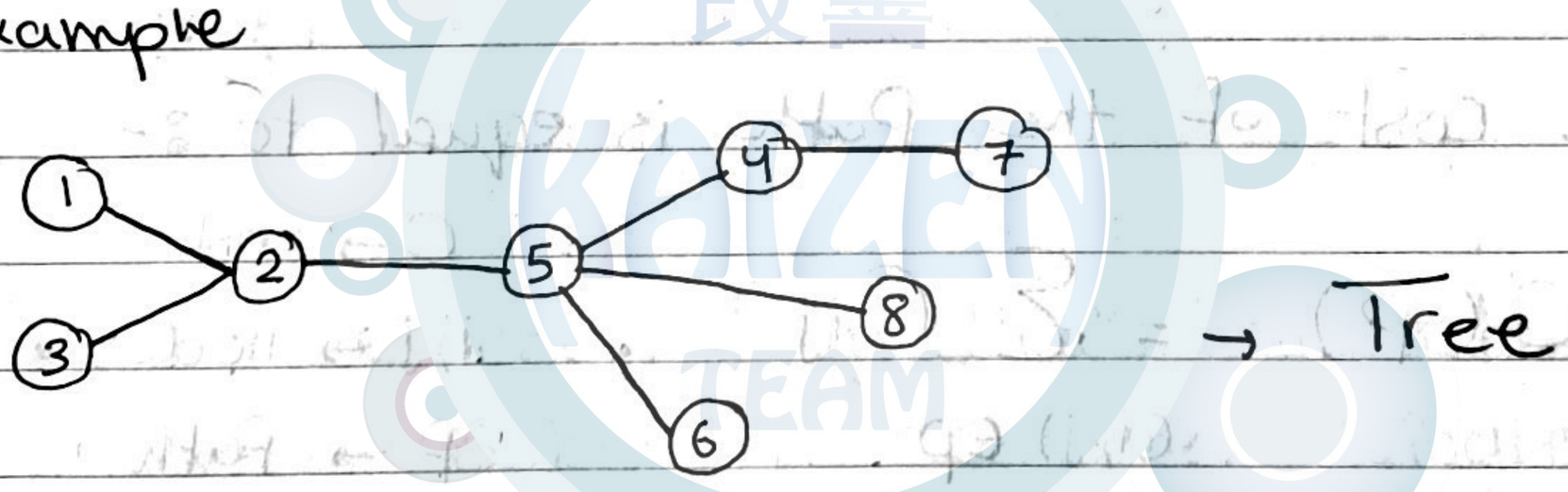
↳ the whole graph is NOT.

⊛ Tree :

→ a tree is a Connected graph that contains no Cycle.

- example

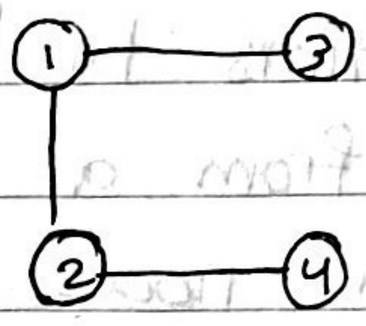
✓



→ Tree

•

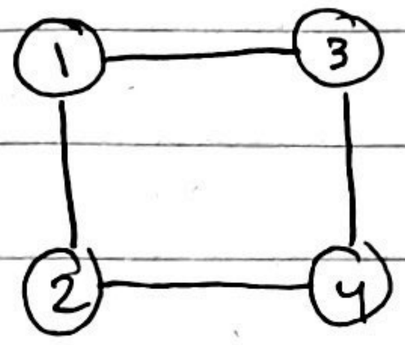
✓



→ Tree

•

X



→ Not a tree

Since it contains a Cycle #

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* A Path is a set of edges of which each edge connects to the initial vertex of the next edge.

- Path P in G (network / graph) from node (S) to Destination node (t) is: an ordered sequences of arcs that Connect S to t.

- $P = \{(S, i), (i, j), \dots, (k, t)\}$

Starting nodes S — destination node t

- the cost of the Path is equal to :-

$$\Rightarrow C(P) = \sum_{(i,j) \in P} C_{ij}$$

C → Cost
i, j → nodes
P → Path

- min cost Path questions : Aims to find the path with min cost from a given Source node (S) to all other nodes (j).

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- Among all Path in graph G connecting (s) to (t), choose p^* such that:

$$C(p^*) \leq C(p)$$

min Cost Path.

↳ Cost of any Path Connecting (s) to (t)

⊛ Single Source Shortest Path Problem :-

- aim to find shortest Path from a Single Source node to all other nodes in the graph.

- 1st method : Dijkstra's algorithm
  → a solution to the Single Source - shortest path problem in graph theory.

⊕ example with steps

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Dijkstra's algorithm

- Requires that $c_{ij} \geq 0$

Initialization:

$$v(j) \leftarrow \begin{cases} 0 & j = s \\ +\infty & \text{otherwise} \end{cases}$$

$$pred(j) \leftarrow \begin{cases} 0 & j = s \\ -1 & \text{otherwise} \end{cases}$$

$PERM = ; \overline{PERM} = N$

Iterations:

while $\overline{PERM} \neq \emptyset$:

1. Let $p \in \overline{PERM}$ be node for which $v(p) = \min\{v(j), j \in \overline{PERM}\}$
2. $PERM \leftarrow PERM \cup \{p\}$
3. $\overline{PERM} \leftarrow \overline{PERM} \setminus \{p\}$
4. For every arc $(p, j) \in A$, $j \in \overline{PERM}$ leading from node p:
   (a) if $v(p) + c_{pj} < v(j)$, then:
   - $v(j) \leftarrow v(p) + c_{pj}$
   - $pred(j) \leftarrow p$

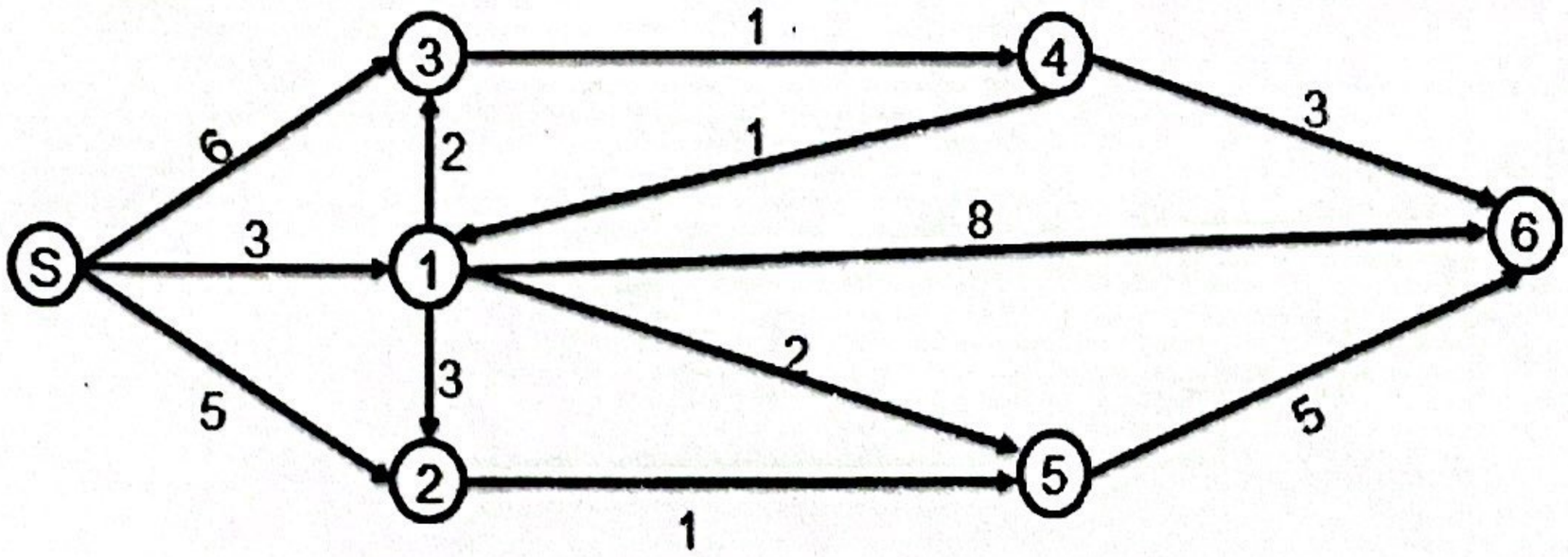
Dijkstra's Algorithm Steps :-

1. Assign to every node a distance value. Set it to zero for our initial node and to infinity for all other nodes.
2. Mark all nodes as unvisited. Set initial node as current.
3. For current node, consider all its unvisited neighbors and calculate their tentative distance (from the initial node). For example, if current node (A) has distance of 6, and an edge connecting it with another node (B) is 2, the distance to B through A will be 6+2=8. If this distance is less than the previously recorded distance (infinity in the beginning, zero for the initial node), overwrite the distance.
4. When we are done considering all neighbors of the current node, mark it as visited. A visited node will not be checked ever again; its distance recorded now is final and minimal.
5. If all nodes have been visited, finish. Otherwise, set the unvisited node with the smallest distance (from the initial node) as the next "current node" and continue from step 3.

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- Example:

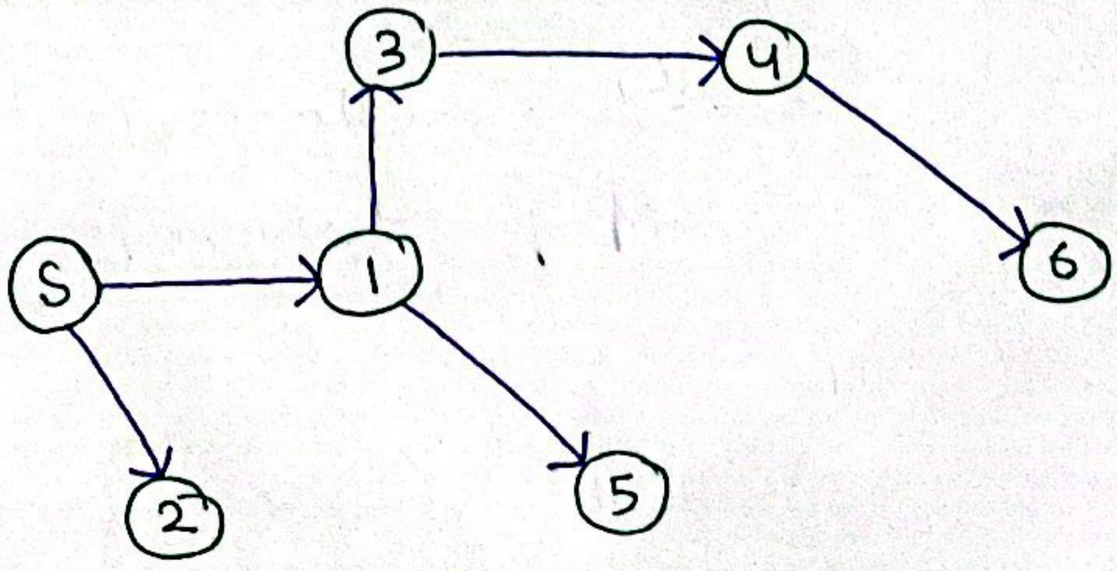
one



↗ initial (starting) node

Iteration	s	1	2	3	4	5	6	P	PERM	PERM
0	0(0)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	—	∅	N
1	0(0)*	3(s)	5(s)	6(s)	∞(-1)	∞(-1)	∞(-1)	s	s	N/{s}
2	—	3(s)*	5(s)	5(1)	∞(-1)	5(1)	11(1)	1	s,1	N/{s,1}
3	—	—	5(s)*	5(1)	∞(-1)	5(1)	11(1)	2	s,1,2	N/{s,1,2}
4	—	—	—	5(1)*	6(3)	5(1)	11(1)	3	s,1,2,3	N/{s,1,2,3}
5	—	—	—	—	6(3)	5(1)*	10(5)	5	s,1,2,3,5	N/{s,1,2,3,5}
6	—	—	—	—	6(3)*	—	9(4)	4	s,1,2,3,5,4	N/{s,1,2,3,5,4}
7	—	—	—	—	—	—	9(4)*	6	N	∅

#



min cost path tree from the

⇒ Single Source (5) to all other nodes.

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Thursday
3/11

Condt. → min cost Path From Source node (S) to node (4) :-

P = [(S,1), (1,3), (3,4)] S-1-3-4 ✗

* more about Dijkstra's algorithm :-
  * Conditions
    1. Used only in Single Source shortest Path Problem

    2. works on both direct and indirect graphs.

    3. all edges must have non-negative Cost/weight.

  * Outputs
    1. $v^*(j)$ ∀ $j \in N$
       - $v^*(j)$ ↵ min Cost From Source to node j
       - ∀ ↵ For all
       - $j \in N$ ↵ for all j in the set of arcs (N)
       - N ↵ nodes

    2. $Pred^*(j)$: the set of N Preceding j on the optimal Path From (S) to (j)
       - Predecessor ↵

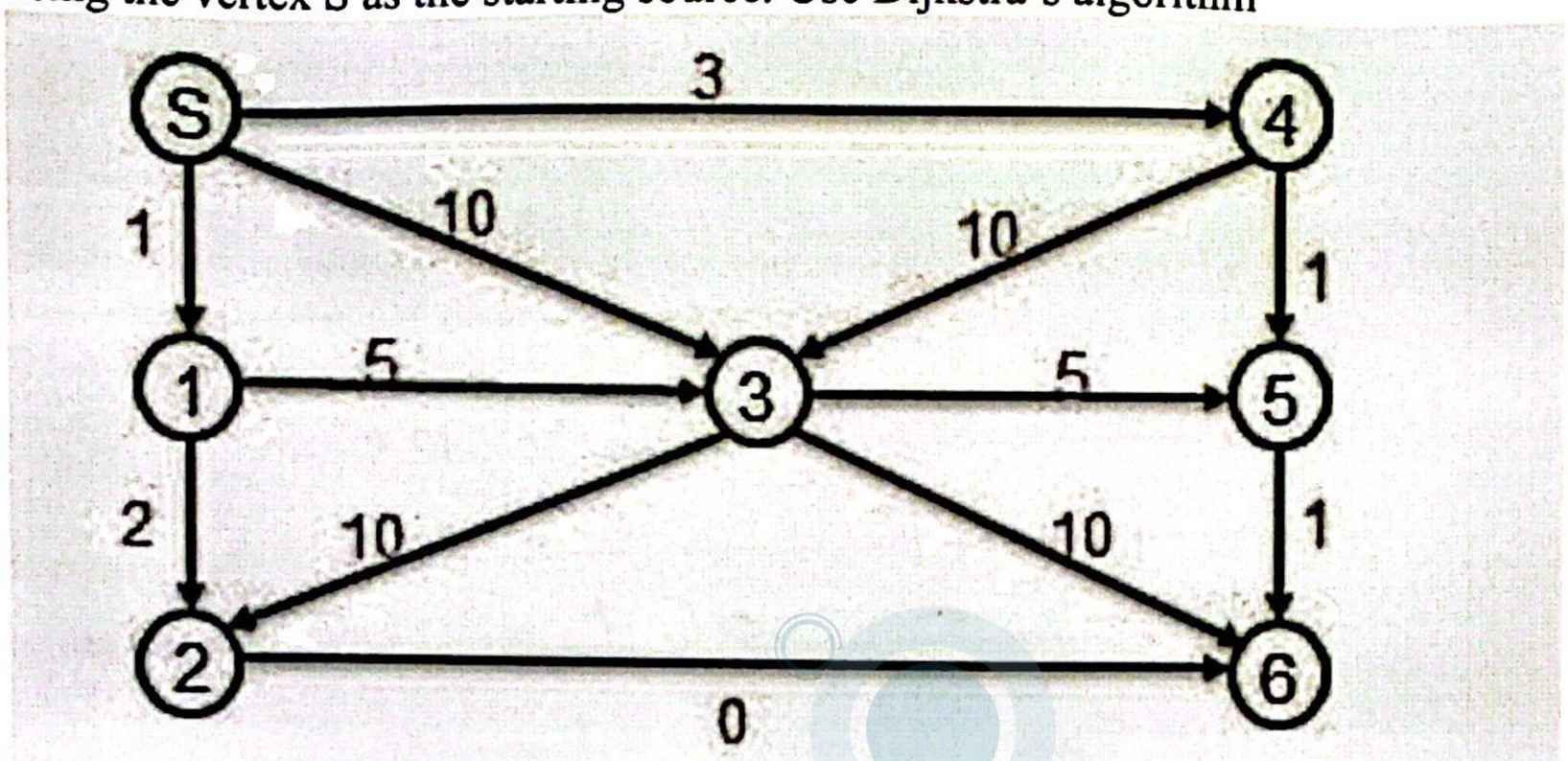
    3. Min Cost Path tree

* Dijkstra determine min. Cost Path tree given a Specific starting node

(1) example 2

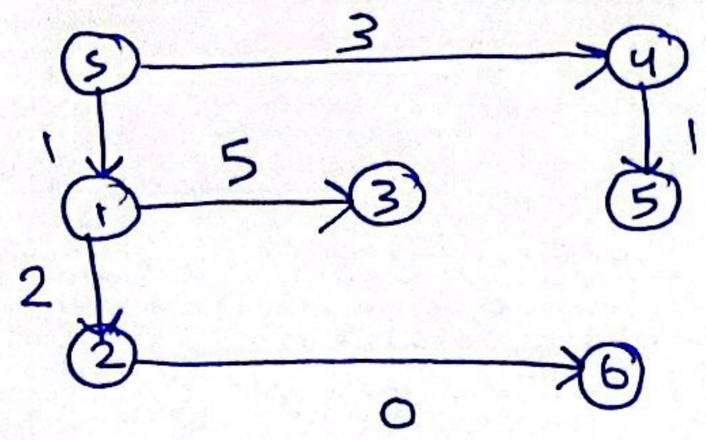
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Example # 2: Given the graph in the Figure shown below, find the shortest paths to all nodes using the vertex S as the starting source. Use Dijkstra's algorithm



Iteration	S	1	2	3	4	5	6	P	PERM	$\overline{PERM}$
0	0(0)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	–	∅	N
1	(0(0)*)	1(S)	∞(-1)	10(S)	3(S)	∞(-1)	∞(-1)	S	S	N/{S}
2	–	1(S)*	3(1)	6(1)	3(S)	∞(-1)	∞(-1)	1	1,S	N/{S,1}
3	–	–	3(1)*	6(1)	3(S)	∞(-1)	3(2)	2	1,2,S	N/{S,1,2}
4	–	–	–	6(1)	3(S)*	4(4)	3(2)	4	1,2,4,S	N/{S,1,2,4}
5	–	–	–	6(1)	–	4(4)	3(2)*	6	1,2,4,6,S	3,5
6	–	–	–	6(1)	–	4(4)*	–	5	1,2,4,6,5,S	3
7	–	–	–	6(1)*	–	–	–	3	N	∅

(*) Min Cost Path tree



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Sunday
6 / 11

* Recall that min. Cost Path tree is one of Dijkstra's algorithm outputs

- this type of tree is called Rooted-out
  لـ يلي بنتج عن الـ Dijkstra
- because it gives the shortest path from one Single Source (S) to all other nodes

* Rooted-out tree [given the Single Source (S) as a starting node] :-

→ is a tree on G such that there is a path exist from (S) to all other nodes.

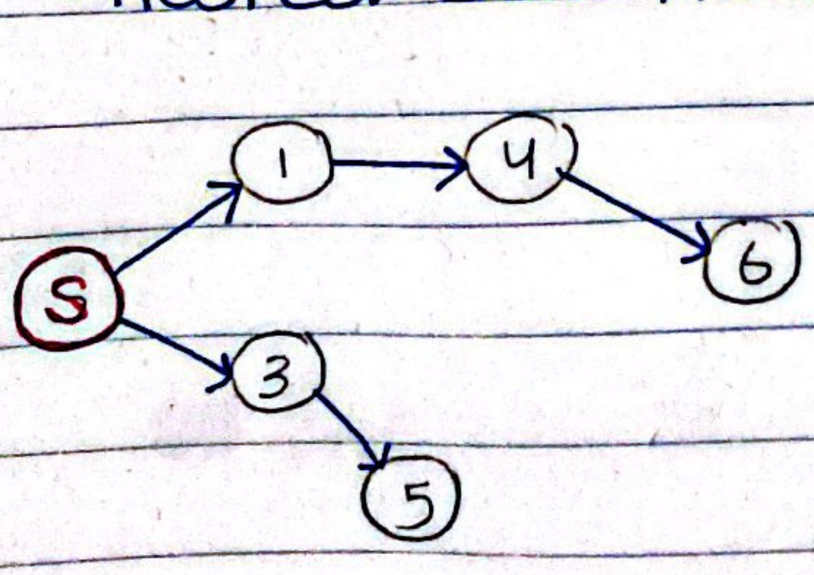
* Rooted-in tree [given one ending node t] :-

→ is a tree on G such that there is a Path exist from any node to node (t).

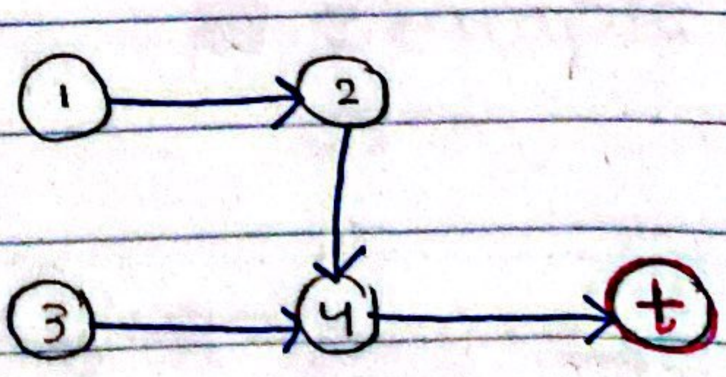
لـ يعني لازم من كل الـ nodes يكون في Path الـ Distination

- Examples :-

- Rooted-out tree



- Rooted-in tree



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⊛ Tree.

- Subnetwork of $G \Rightarrow T$

- $T = (N, A_T)$
  - N: all set of nodes
  - A_T: subset of arcs
    - $A_T \subseteq A$
      - ↳ subset.

- # of ars = # of nodes - 1
  - $A_T = N - 1$

- For undirect tree, a Path exists between all pairs of nodes in N
  - « as long as we ignore the direction »

- No cycle (or loop):

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⊛ Bellman - Ford algorithm « Slides »

- used in direct weighted arcs.
- no requirement for non-negative arc cost.
- PaPes modification

→ if $j \notin$ List (if j doesn't belong to the Current list)

↳ we have 2 cases :-

① If j has never been in the list

List ← List + [j]

القديمة الجديدة

(we add j to the end of the list)

② If j has been in the list

List ← [j] + List

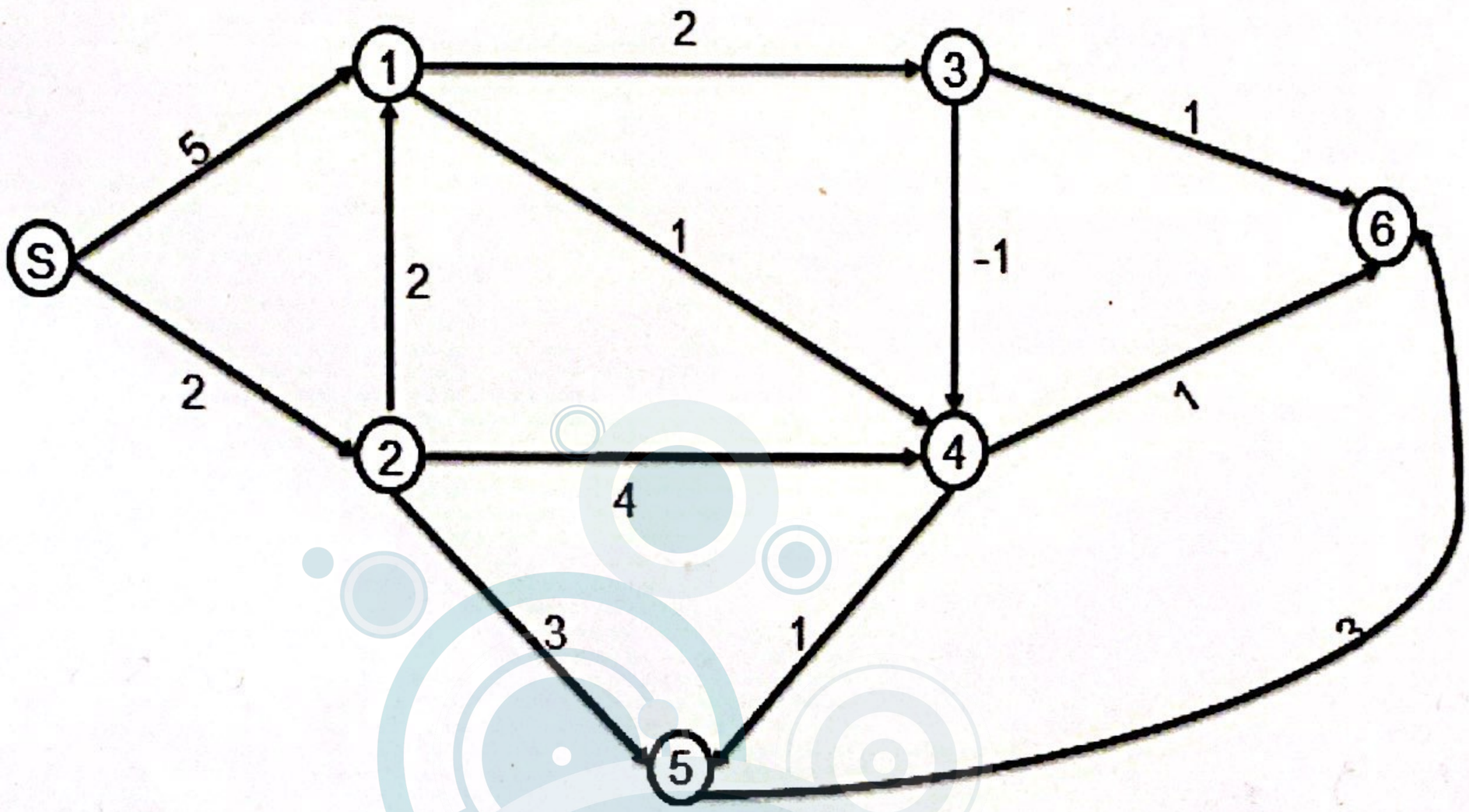
(we add j at the beginning of the list)

⊕ example

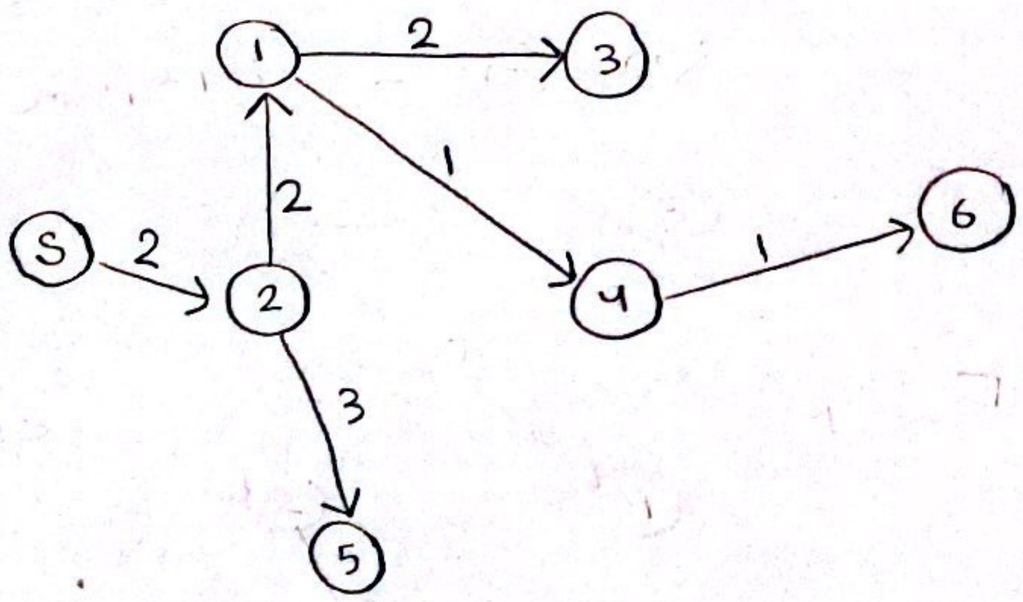
⊕ Bellman & Dijkstra's Pros & Cons →

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Example:
Given the graph in the Figure shown below, find the shortest paths to all nodes using the vertex s as the starting source. Use Bellman-Ford algorithm.



Iteration	s	1	2	3	4	5	6	P	LIST
0	0(s)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	—	S
1	0(0)*	5(S)	2(S)	∞(-1)	∞(-1)	∞(-1)	∞(-1)	S	1,2
2	0(0)	5(S)*	2(S)	7(1)	6(1)	∞(-1)	∞(-1)	1	2,3,4
3	0(0)	4(2)	2(S)*	7(1)	6(1)	5(2)	∞(-1)	2	1,3,4,5
4	0(0)	4(2)*	2(S)	6(1)	5(1)	5(2)	∞(-1)	1	3,4,5
5	0(0)	4(2)	2(S)	6(1)*	5(1)	5(2)	7(3)	3	4,5,6
6	0(0)	4(2)	2(S)	6(1)	5(1)*	5(2)	6(4)	4	5,6
7	0(0)	4(2)	2(S)	6(1)	5(1)	5(2)*	6(4)	5	6
8	0(0)	4(2)	2(S)	6(1)	5(1)	5(2)	6(4)*	6	∅



• what is the Cost of the Path ⑤ to ⑥ ?

P : {(S,2), (2,1), (1,4), (4,6)}

C(P) = 6 #

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Dijkstra's algorithm

- **Pros** الـ Dijkstr أحسن من الـ Bell-man لأنه الـ node يلاقي بوصلها ما برجعلها

1. Achieves fastest running times (theoretically and practically) for dense networks. Typical geographic networks are not dense, though.
2. Can be truncated. Each iteration, one node p is given a permanent, optimal minimum cost label and predecessor. Thus, if you are interested only in paths to some subset of the nodes $T \subset N$, you can stop the algorithm once PERM $\supseteq$ T.

↳ Subset or equal to

- **Cons** الـ bellman أحسن

1. Alternative methods are faster (practically) on sparse networks.
2. Efficient implementations require programming a priority queue (heap).

↳ in Bill-man, the Priority is for the 1st node in the list.
↳ where in Dijkstra there is no Specific Priority.

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Bellman-Ford algorithm

Bellman-Ford algorithm

Sometimes, *label-correcting* algorithm. No requirement of non-negative arc costs. Often more efficient in practice for sparse transportation problems.

***Initialization*:**

$$v(j) \leftarrow \begin{cases} 0 & j = s \\ +\infty & \text{otherwise} \end{cases}$$

$$pred(j) \leftarrow \begin{cases} 0 & j = s \\ -1 & \text{otherwise} \end{cases}$$

$LIST = \{s\}$

***Iterations*:**

while $LIST \neq \emptyset$:

1. Remove node p from top of $LIST$
2. For every arc (p, j) leading from node p:
   (a) if $v(p) + c_{pj} < v(j)$, then:
   - $v(j) \leftarrow v(p) + c_{pj}$
   - $pred(j) \leftarrow p$
   - if $j \notin LIST$, $LIST \leftarrow LIST + \{j\}$

Bellman-Ford algorithm

- Pros
  1. Achieves fastest running times (practically) for sparse networks, especially when implemented with Pape's Modification.
  2. Very simple to implement.
- Cons
  1. Labels and predecessors not optimal until full completion of algorithm.
  2. Running time may be slow on dense networks due to frequent label updates.

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Tuesday
8/11

⊛ Multi-label algorithm.

- In some Problems we want to find path that balance multiple objectives.

- for example we might want to find the path with min. distance that doesn't exceed a time limit. → (multi-label)

- or we might want to find the path with min distance that doesn't exceed a time limit (time constraint)

- in multi-label we have 2 measures of Cost: Distance & time.

- nodes are given labels with 2 components

$$(d_k , t_k)^{i}_{k}$$

i ↝ node
k ↝ label #

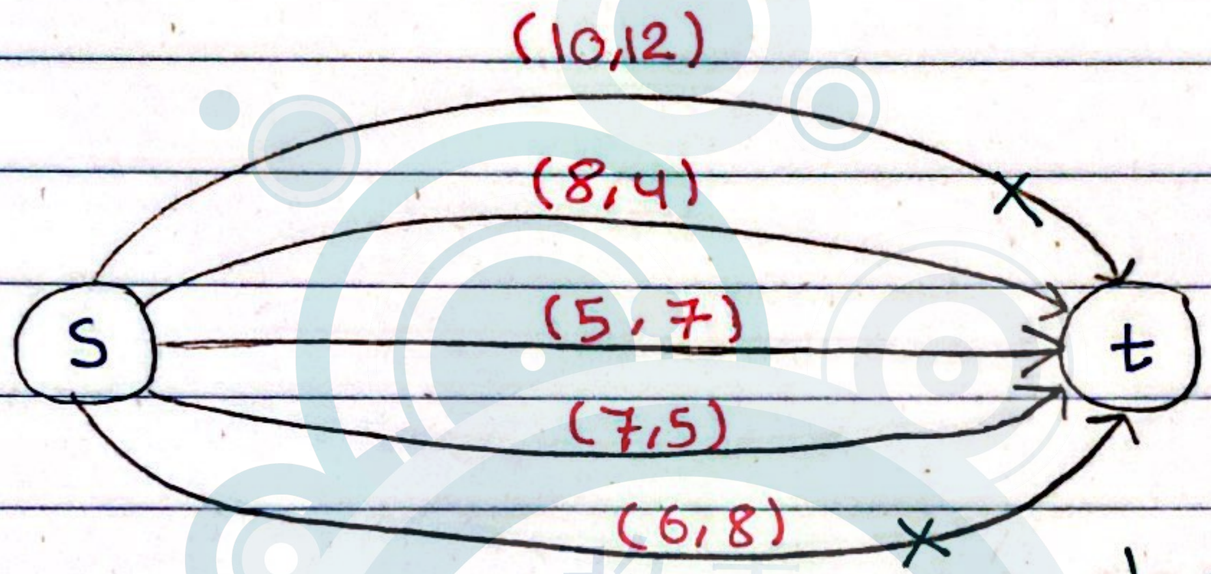
where : d_k : 1st cost Component (tot. Distance) required to reach node (i) from the Source node (s).

t_k : 2nd Cost Component (tot. time) required to reach node (i) along Some path from node (s)

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- Example
  - node may have multiple label resulting from different paths.

  - one path to a node may have longer distance but shorter time than other paths.



↳ dominated by (5,7).

↳ we will never choose (10,12) or (6,8) label / path, because (5,7) dominate both of them

↳ however we can't easily choose between (8,4) and (5,7).

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Sunday
13/11

Multi-label algorithm

Initialization:

Initially, the origin node s is given label $(0,0)_1^s$. (The subscript indicates the reference number $k = 1$ for this label, and the superscript indicates that this label exists at node s) All other nodes receive no labels. The predecessor for this label, $pred(1)$ is 0.

$LIST = \{(0,0)_1^s\}$ $r = 2$

Iterations:

while $LIST \neq \emptyset$:

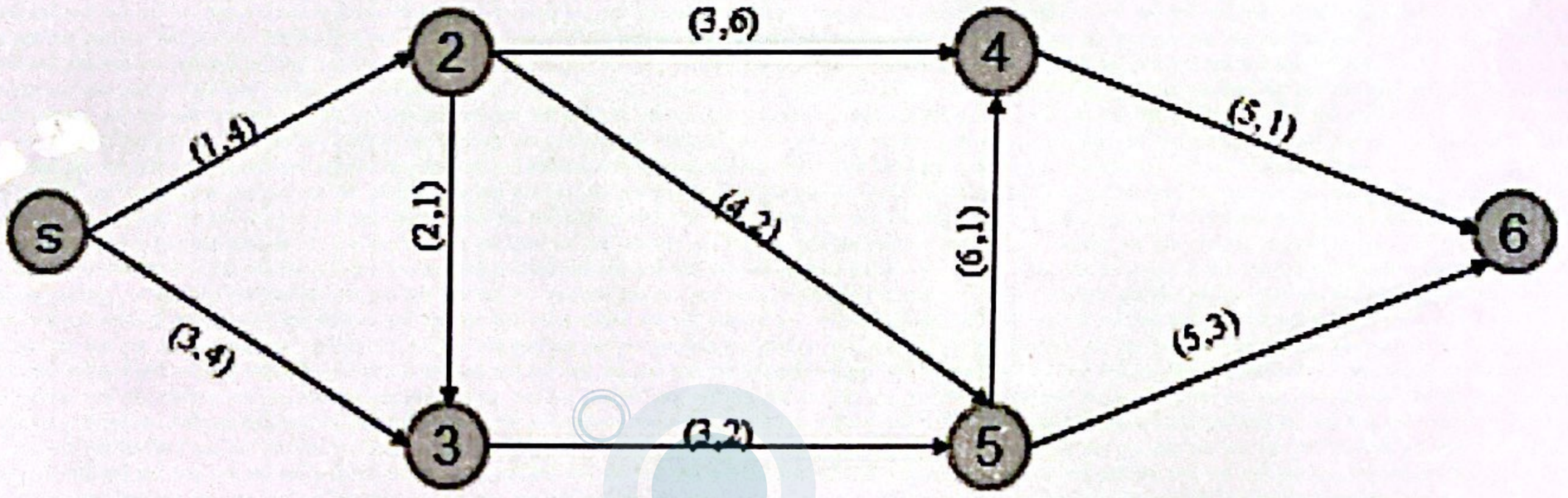
1. Remove label k from the beginning of the list. Suppose label k has components $(d_k, t_k)_k^p$, so that it exists at node p
2. For every arc (p, j) leading from node p:
   (a) Create a new label r at node j where $(d_r, t_r) = (d_k + d_{pj}, t_k + t_{pj})_r^j$
   (b) Define $pred(r) = k$
   (c) Add label r to the end of the $LIST$
   (d) Compare label r to each existing label (d_q, t_q) currently at node j:
      i. If $d_r \geq d_q$ -and- $t_r \geq t_q$, then label r is dominated by (d_q, t_q). Discard the new label, and remove it from $LIST$.
      ii. Else If $d_q \geq d_r$ -and- $t_q \geq t_r$, then label r dominates label q. Discard the label (d_q, t_q), and if necessary remove it from $LIST$.
      iii. Else retain both labels

Stopping criterion:

When no labels remain in $LIST$, this indicates that no remaining label corrections can be found, and all of the paths have been found.

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Example: Given the graph in the Figure shown below, find the shortest paths to all nodes using the vertex s as the starting source. Use **Multi-label algorithm**



	S	2	3	4	5	6	LIST
Labels	$(0,0)^S_1$ Pred(1)=0	$(1,4)^2_2$ Pred(2)=1	$(3,4)^3_3$ Pred(3)=1	$(4,10)^4_5$ Pred(5)=2	$(5,6)^5_6$ Pred(6)=2	$(9,11)^6_8$ Pred(8)=5	$(0,0)^S_1$ X $(1,4)^2_2$ X
			$(3,5)^3_4$ X Pred(4)=2	$(11,7)^4_{10}$ Pred(10)=6	$(6,6)^5_7$ X Pred(7)=3	$(10,9)^6_9$ Pred(9)=6	$(3,4)^3_3$ X $(3,5)^3_4$ X
						$(16,8)^6_{11}$ Pred(11)=10	$(4,10)^4_5$ X $(5,6)^5_6$ X $(6,6)^5_7$ X $(9,11)^6_8$ X $(10,9)^6_9$ X $(6,6)^5_7$ X $(11,7)^4_{10}$ X $(16,8)^6_{11}$ X $\emptyset$

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Sunday
13/11

Multi-label algorithm

Initialization:

Initially, the origin node s is given label $(0,0)_1^s$. (The subscript indicates the reference number $k = 1$ for this label, and the superscript indicates that this label exists at node s) All other nodes receive no labels. The predecessor for this label, $pred(1)$ is 0.

$LIST = \{(0,0)_1^s\}$ $r = 2$

Iterations:

while $LIST \neq \emptyset$:

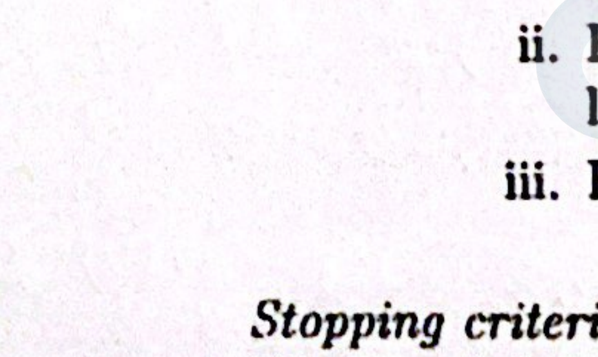
1. Remove label k from the beginning of the list. Suppose label k has components $(d_k, t_k)_k^p$, so that it exists at node p
2. For every arc (p, j) leading from node p:
   (a) Create a new label r at node j where $(d_r, t_r) = (d_k + d_{pj}, t_k + t_{pj})_r^j$
   (b) Define $pred(r) = k$
   (c) Add label r to the end of the $LIST$
   (d) Compare label r to each existing label (d_q, t_q) currently at node j:
      i. If $d_r \geq d_q$ -and- $t_r \geq t_q$, then label r is dominated by (d_q, t_q). Discard the new label, and remove it from $LIST$.
      ii. Else If $d_q \geq d_r$ -and- $t_q \geq t_r$, then label r dominates label q. Discard the label (d_q, t_q), and if necessary remove it from $LIST$.
      iii. Else retain both labels

Stopping criterion:

When no labels remain in $LIST$, this indicates that no remaining label corrections can be found, and all of the paths have been found.

Sol. from (S) → (6) ⟹ 3 Paths. (min. cost path from (S) → (6))

Path 1



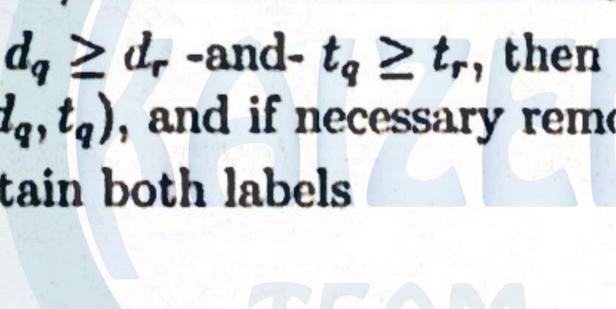
Same as Path $(9,11)_8^6$ So

Correct

1 + 3 + 5 = 9

4 + 6 + 1 = 11

Path 2

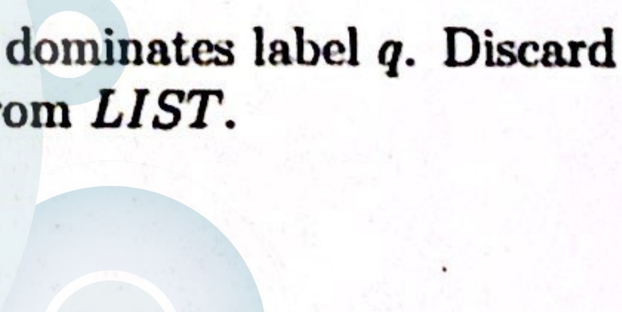


Same as Path $(10,9)_9^6$

1 + 4 + 5 = 10

3 + 2 + 4 = 9

Path 3



Same as Path $(16,8)_{11}^6$

5 + 6 + 4 + 1 = 16

1 + 1 + 2 + 4 = 8

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Tuesday
15/11

Recall :

- Tree : Subnetwork → $T = (N, A_T)$

$$|A_T| = |N| - 1$$

⊛ Minimum Spanning Tree (MST) or (T^*):

- In a network where each arc (i,j) has C_{ij} : the MST is a tree such that the tot. cost of arcs in the tree is minimized.

- mathematically :-

$$T^* = \underset{T \in G}{\arg\min} \left[\sum_{(i,j) \in T} C_{ij} \right]$$

→ among all of the tree in our graph G, it's the one that minimizes the cost of arcs tree (tot. cost).

⊛ There are 2 algorithms to Find the MST :-

① Kruskal's algorithm "Optimization problem."

② Prim's algorithm

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1 ⊛ Kruskal's algorithm :-

- initialization : Tree = ∅
- iterations :-

① Sort arcs in non-decreasing order of Cij into LIST.

② while |TREE| < n-1 :-

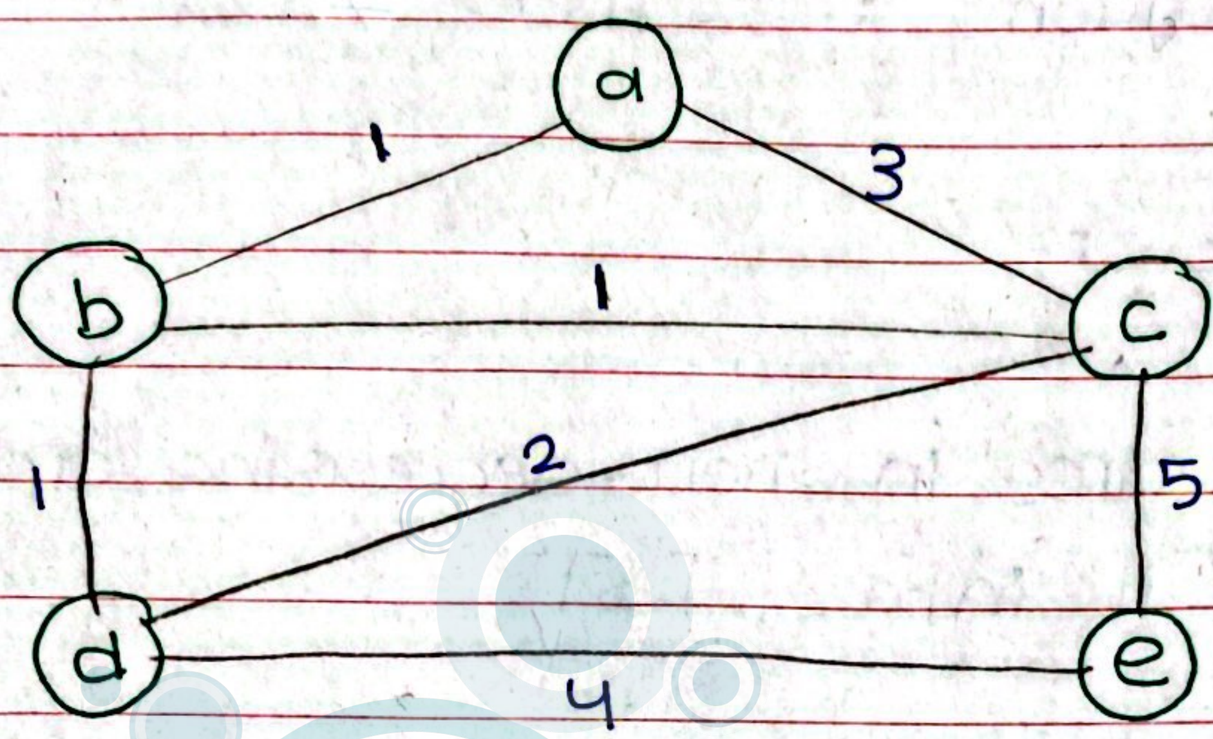
a) Remove arc (i,j) from the top of the LIST.

b) add arc (i,j) to the tree, if doing so does not create a cycle

③ T* ← Tree #

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⊛ Example

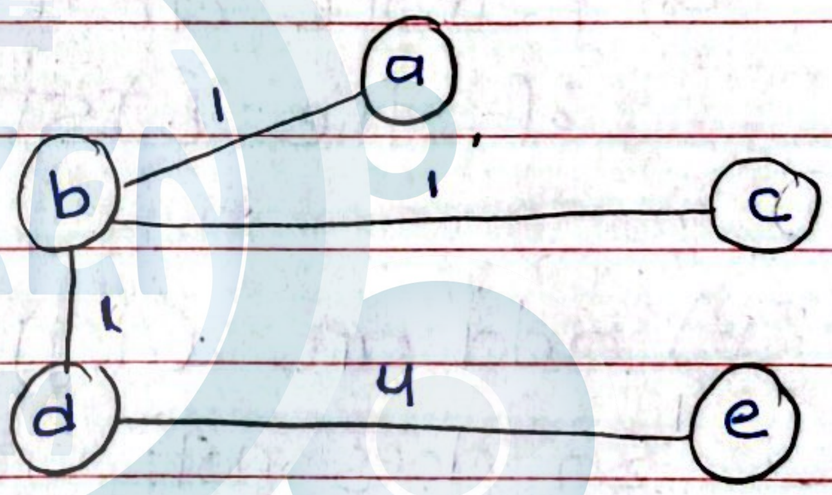


LIST :

(a,b) 1
(b,d) 1
(b,c) 1
(d,c) 2
(a,c) 3
(d,e) 4
(c,e) 5 → stop.

→

⊛ MST :



#

tot. Cost = 7 #

لما iteration لما بوقف ال ← # of arcs = n-1

ممكن يكون في أكتر من MST ←
بس بالنهاية كلهم بيطلعو
tot. Cost نفس ال

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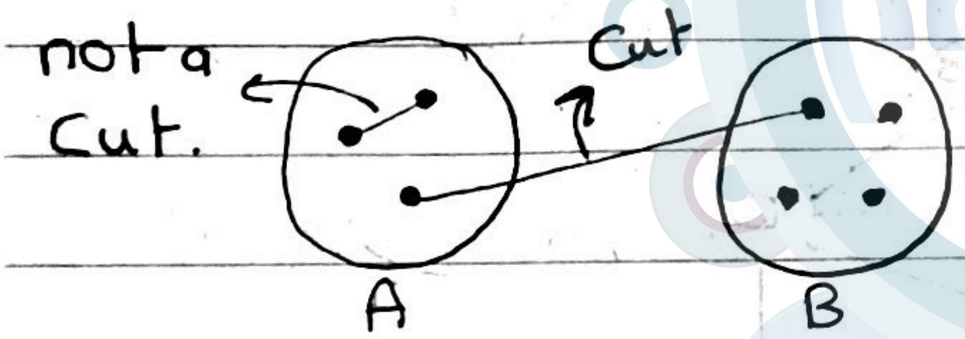
2 ⊛ Prim's algorithm

- Cuts in the network « مبأها »

- Suppose the Nodes in N are Partitioned in two independent Subsets, A & B Such that:

$$A \cup B = N$$
$$A \cap B = \emptyset$$

- then the Cutset (A,B) is given by all arcs (i,j) such that $i \in A$ and $j \in B$ or $i \in B$, $j \in A$.



- Prim's algorithm

: initialization : $\overline{TREE} = \emptyset$

$A = \{1\}$, $B = N / \{1\}$

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- iteration : while |TREE| < n-1

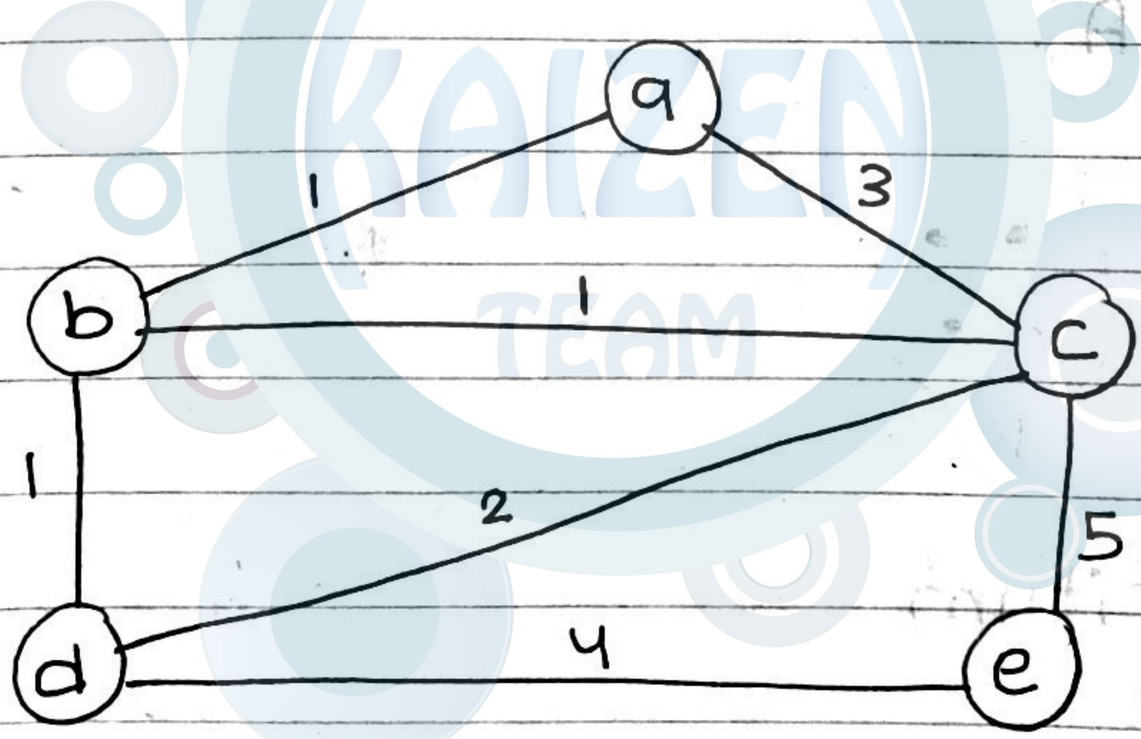
① Find arc (i,j) in (A,B) with min C_{ij}. ← Cost.

② Add this arc to the TREE

③ Remove j from B and add it to A.

at the end, $T^* \leftarrow$ TREE #

@example :-



عادي ممكن نختار أي node تانية

→ A = [c]

B = [a, b, d, e]

TREE = ∅

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* A = {c, b}
  B = {a, d, e}

TREE = {(c, b)}

→ now look at arcs ac, ab, ce, bd, cd and choose one.
  3 1 5 1 2
  ✓ ✓
  A و لـ يكي جزء منهم بـ
  B الثاني بـ

→ add arc ab ← لأنّه أقل واحد

So * A = {a, b, c}
     B = {d, e}

TREE = {(c, b), (a, b)}

* ما بضيف ال arc يلي
* Cycle بعمل

→ now look at arcs ce, cd, bd
                   5   2   1
                           ✓

* A = {a, b, c, d}
  B = {e}

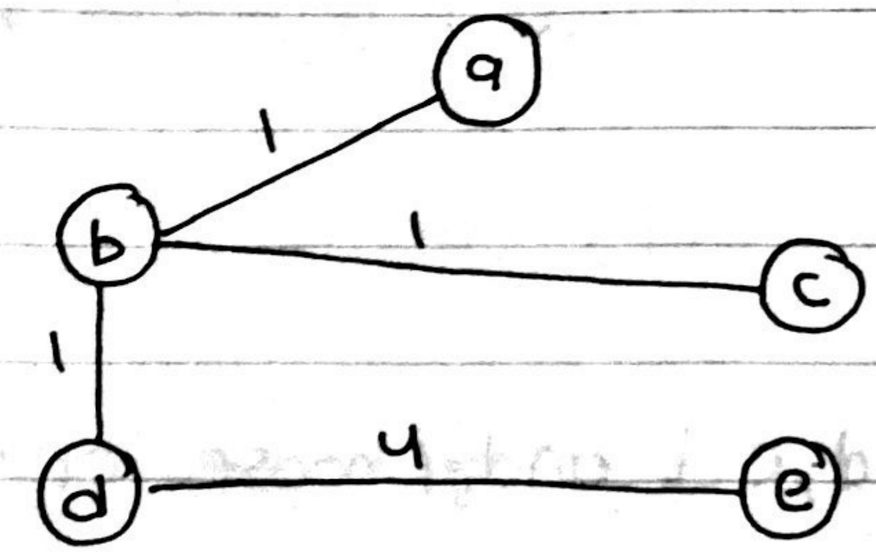
TREE = {(c, b), (a, b), (b, d)}

* A = {a, b, c, d, e}
  B = ∅ → هون بوقف

TREE = {(c, b), (a, b), (b, d), (d, e)} cost = 7 #

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MST :-



tot. Cost = 7 #

مادة الميد #

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改善

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Thursday
17/11

⊛ Short-haul transportation : Single vechile routing.

. Setting : we want to visit number of locations, Starting from and returning to a depot with minimum tot. travel cost (time, distance, cost).

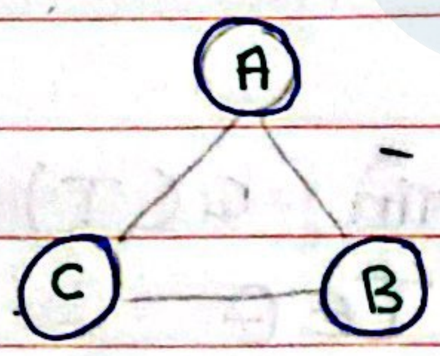
. Question: in what order should the locations be visited ?

. Answer : Sequence of locations
↳ this sequence is called "tour".

. Assumption :
- we start with a complete, undirected network

$$G = (N, A) \rightarrow \#\text{ of arcs} = \frac{n * (n-1)}{2}$$

- The graph satisfies triangle inequality



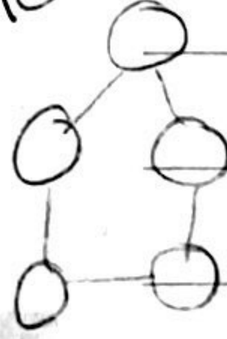
$$AC + CB \geq AB$$

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- TSP → Travel Saleman Problem

- TSP tour is a visitation sequence of all Nodes in N.

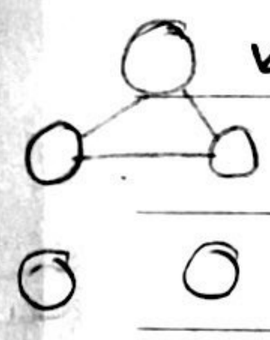
Tour



$T = [V_1, V_2, V_3, \dots, V_n, V_1]$, $V_i \in N$

لـ رح أرجع لنقطة البداية

- Subtour : is a sequence of nodes with Common start and end, such that not all nodes in N are visited.



$= [V_1, V_2, \dots, V_q, V_1]$, $1 < q < N$

لـ برضو رح أرجع لنقطة البداية بس ما بكون زرت كل ال nodes

- Total Cost :

$$C(T) = \sum_{i=1}^{n-1} C_{vi, vi+1} + C_{vn, V_1}$$

→ Simply : Sum. For the costs of arcs that belong to the tour.

- Optimal tour = TSP^* = $\underset{T \in G}{\text{Argmin}}\ C(T)$

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• TSP → Optimization Problem → tour with min. cost.

↳ IP formulation (integer Problem formulation)

[1] Decision variable :

$$X_{ij} = \begin{cases} 1 & : \text{if arc } (i,j) \text{ belong to the tour} \\ 0 & : \text{otherwise} \end{cases}$$

arc bet (i) & (j)

[2] objective : Minimize $\sum C_{ij} \cdot X_{ij}$

[3] Constraint (sub. to) : → node لكل

• $\sum_{i \in N/[j]} X_{ij} = 1 \quad \forall j \in N$ → unique arc entering node j

• $\sum_{j \in N/[i]} X_{ij} \quad \forall \in N$ → unique arc leaving node i

Simply ← لازم كل node يدخل عليها arc ويطلع منها arc

← يعني دع أوصل ال location وأعاده، ماريح أزوره مرتين

• Connectivity Constraints / Subtour elimination Constraints.

↳ tour عشان يكون ال

Subtour كامل و مو

↳ S → Size of the subset (# of nodes)

• $\sum_{i \in S} \sum_{j \notin S} X_{ij} \geq 1 \quad , \forall S \subseteq N \quad |S| \geq 2$

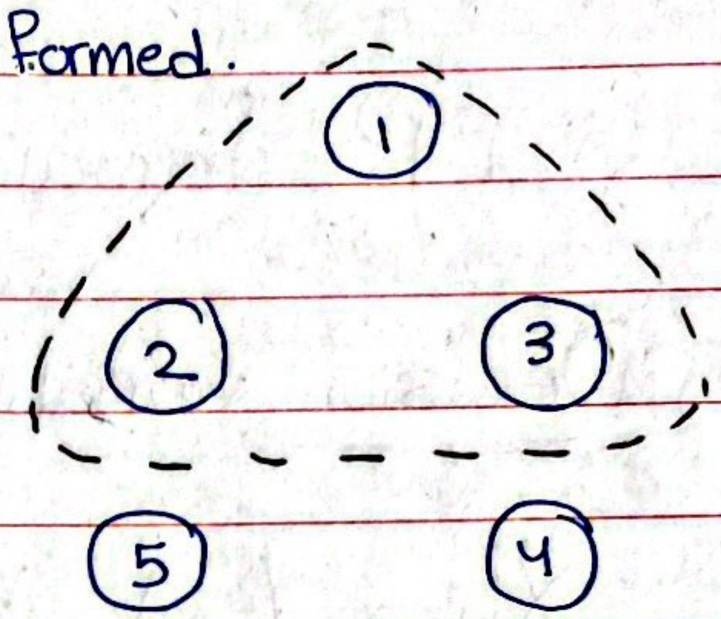
OR • $\sum_{i \in S} \sum_{j \in S} X_{ij} \leq |S| - 1 \quad , \forall S \subseteq N$

↳ ∀ = for all

↳ N → Set of all nodes

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- we cannot have more than 2 arcs $S = [1,2,3]$, $|S| = 3$ in the subset, else a subtour will be formed.



- $X_{12} + X_{13} + X_{23} \leq 2$
  ↳ 3-1
- $X_{ij} \in \{0,1\} \; \forall (i,j) \in A$
  ↳ set of arcs

↳ Because of subtour elemination Constraints we end-up with exponential # of Constraints.

↳ Conclusion : TPs is hard to solve for medium-large questions.

↳ we need to find smart heuristic to solve the problem in reasonable amount of time

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Sunday
20/11

⊛ Travel Saleman Problem :

- Goal ① : identify efficient heuristic that give good (but not necessary optimal) Solution

- Goal ② : find heuristic where worse Case quality of a Solution can be guaranteed to be within Some constant α of the true optimal Solution.

C^* : true optimal Case (unknown)

αC^* : worst heuristic Solution Cost

$\rightarrow C^* \leq C_{heuristic} \leq \underbrace{\alpha C^*}_{\hookrightarrow \text{worst Case}}$

⊛ Lower Bound for hard optimization Problem

- the LB is used to evaluate the quality of the heuristic Solution.

- Assume minimization Problem :

Suppose T^H : is a feasable tour identified by heuristic H. →

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→ $C(T^H) \geq C(TSP)^*$ Optimal

lower bound

→ $\underline{\leq}(TSP')^* \leq C(TSP)^*$

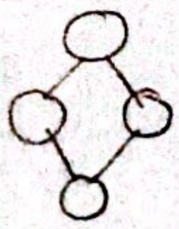
lower bound

a number ↵

→ we can't make a Comparison between heuristic Solution and optimal Solution, but if we know $\leq(TSP')$ then we know sth. about how to choose our heuristic Solution to the optimal.

⊛ Simple lower bound for TSP:

• Observe one given feasible Solution tour.

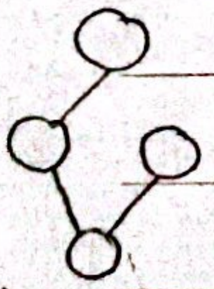


tour

$|TOUR| = n$, $n = |N|$ → # of nodes

↳ # of arcs

↳ If one arc is removed from the tour, then the remaining form a tree #



tree

↳ $TOUR = TREE + [(i,j)]$

$C(Tour) = C(Tree) + Cij$

$C(TSP^*) = MST + Cij^*$ ↘ minimization for both Sides #

→ where Cij is min. Cost arc not in the MST.

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- $C(TSP^*) \geq MST + C_{ij}^*$

$\underline{C}(TSP^*) \leq C(TSP^*) \leq C(TSP)^H$

$LB = C(MST) + C^*(i,j)$

- Steps of finding Simple LB for TSP :

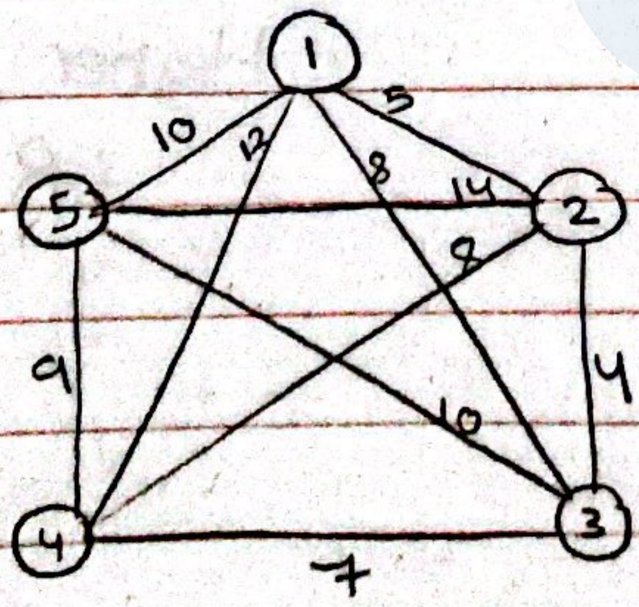
① Decompose feasible solution into 2 Pieces.
② optimize each piece
③ Combine the piece that we have broken out

- Note :

This may not be feasible tour solution to the original TSP, but the result gives LB #

↳ opt. ولو أعطتي feasible مضاعفة هول

* Example :



→ Find the LB for the TSP.

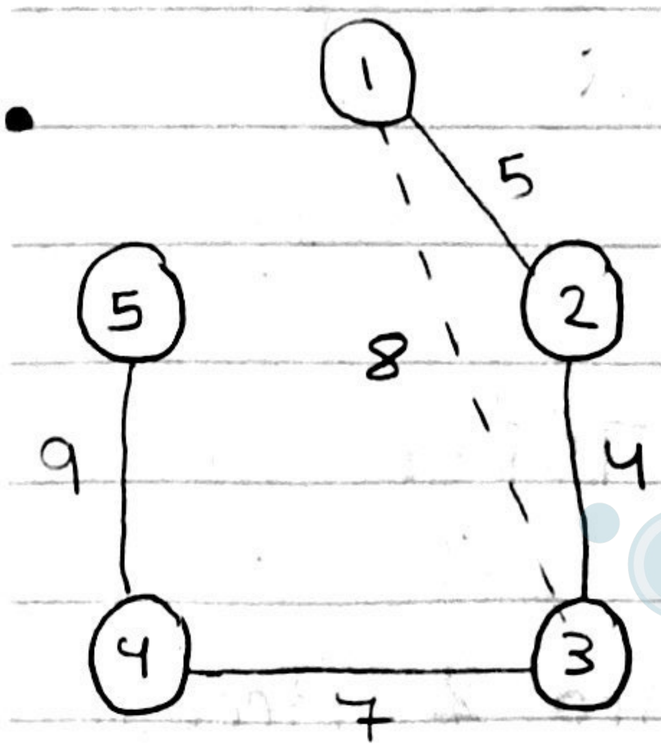
↳ LB = MST + C(i,j)*

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Sol.

Draw the MST then add min. Cost arc that is not in MST

دق لو عمل Cycle عادي بنضيفه



↳ not a feasible tour (there is subtour)

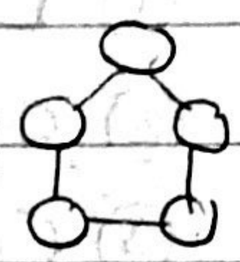
→ $LB = C(MST) + C_{ij}^*$

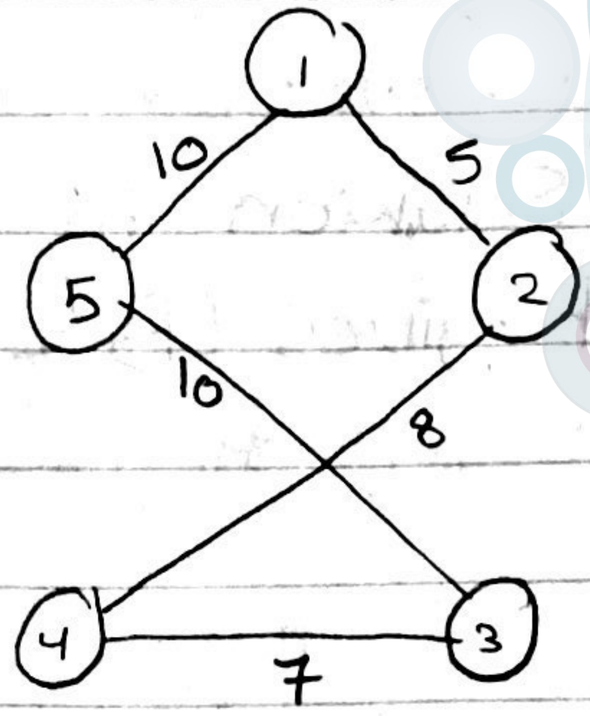
$= 25 + 8 = 33$ #

$C(TSP^*) \geq \underline{C}(TSP)$

$C(TSP^*) = 35$

$C(TSP^*) \geq 33$





→ $LB < opt. < Hueristic$

$33 < 35 < 40$

→ $40-33 = \frac{7}{33} * 100\% = 20\%$

Higher than LB

⊗ if $C^H < LB$ → wrong Sol.

⊗ if $C^H = LB$ → optimal.

⊗ if $C^H > LB$ → correct but not opt.

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Tuesday
22/11

* 2nd method for determining the lower bound for TSP

↳ 1-TREE LB for TSP.

- Definition : 1-TREE is a tree on n-1 nodes
  ↳ # of arcs in 1-TREE = (n-1)-1
  = (n-2)

⇒ now for finding MST for this graph → node اللي هو لما أشيل ال
stop solving MST before adding the last node #

- TOUR = 1-TREE$_i$ + [(i,j), (i,k)]
  ↳ commited node
  = TREE + 2 arcs from node i

- LB = MST$_i$ + (i,k) (i,j)

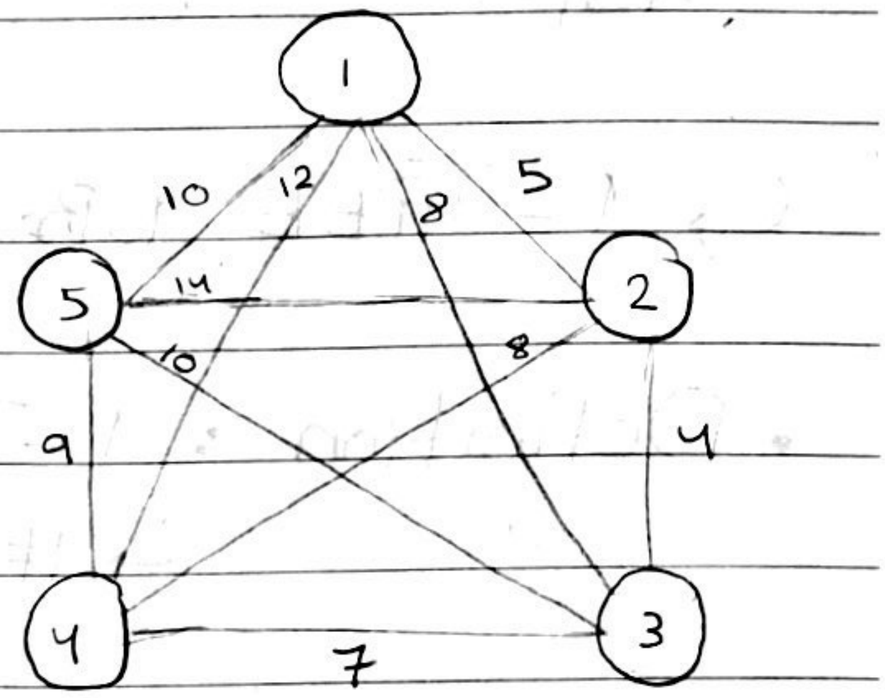
- C(TOUR) = C(1-TREE) + C_{ij} + C_{ik}

- C(TSP)* ≥ C(1-TREE) + C_{ij}^* + C_{ik}^*
  ↳ 2 smallest arc cost from (i)

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⊛ Example

↳ Complete Undirect graph that satisfies triangle inequality.

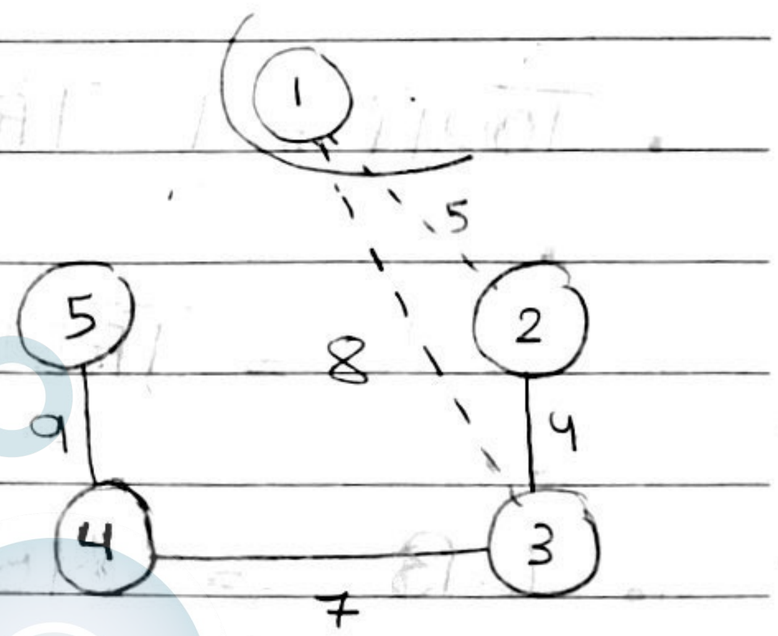


↳ UB = MST + $C(i,j)^*$ = 33

⊛ 1 - TREE,

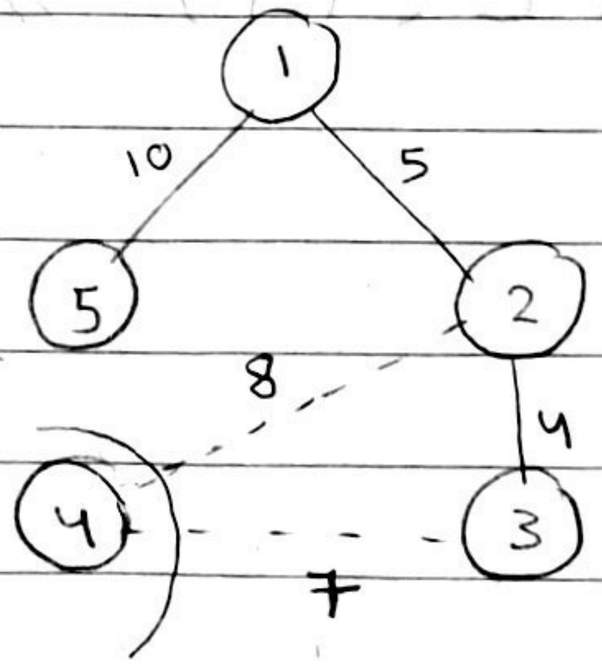
1) neglect node ①

2) take 2 arcs from the neglected node.



1 - TREE, = 33 عشوائيه node لـ ignore بنقل .

نفس الرقم ← $C(TSP^*) \geq 33$.



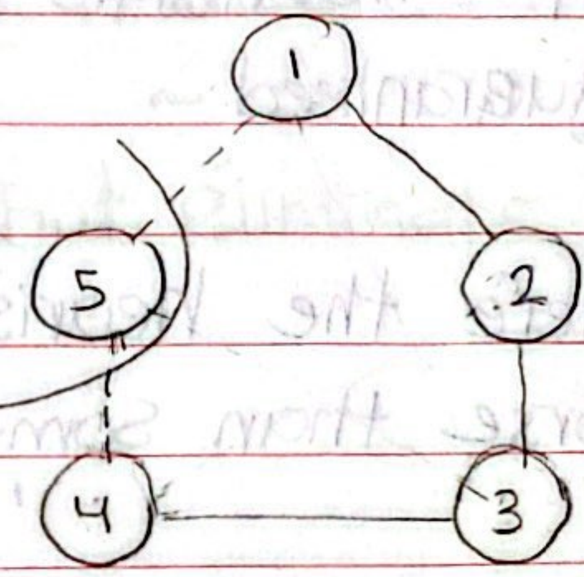
⊛ 1 - $TREE_4$ = 34

$C(TSP^*) \geq 34$

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* $1 - \overline{TREE_5} = 35$

$C(TSP^*) \geq 35$



- لـ كل ما يزيد الرقم هنا ها عم بقرّب على ال optimal.

- بختار الأعلى من ال LB لأنه هيك بكون أقرب من ال optimal ← يعني هون ال 35 هي الأحسن، كلهم valid بس ال $C(TSP^*) \geq 35$ هي ال useful

* TSP heuristic based on MST with Performance guaranteed → يعني احنا عارفين انه ال worst case يكون ضعف ال opt.

↳ here the heuristic will never give a solution worse than some particular bound

- α optimal heuristic:
  ↳ also known as α approximation heuristic.
  ↳ You will never return a solution whose cost is more than α * true optimal solution

a) 2 MST - based heuristic

1. $\alpha = 2$ → twice around MST heuristic.
2. $\alpha = 1.5$ → Christofied heuristic

→ the heuristic sol. will never be > twice opt. sol.
↳ " " " " " " > 1.5 * opt. sol.

1 ⇒ twice around MST heuristic:-

1. find MST of nodes N
2. let LIST contain 2 copies of each arc in MST
3. Create a walk of nodes in N by using arc in LIST once

Some nodes will be re-visited ← walk = $\{v_1, v_2, v_3, \dots, v_{2(n-1)}, v_1\}$

↳ →

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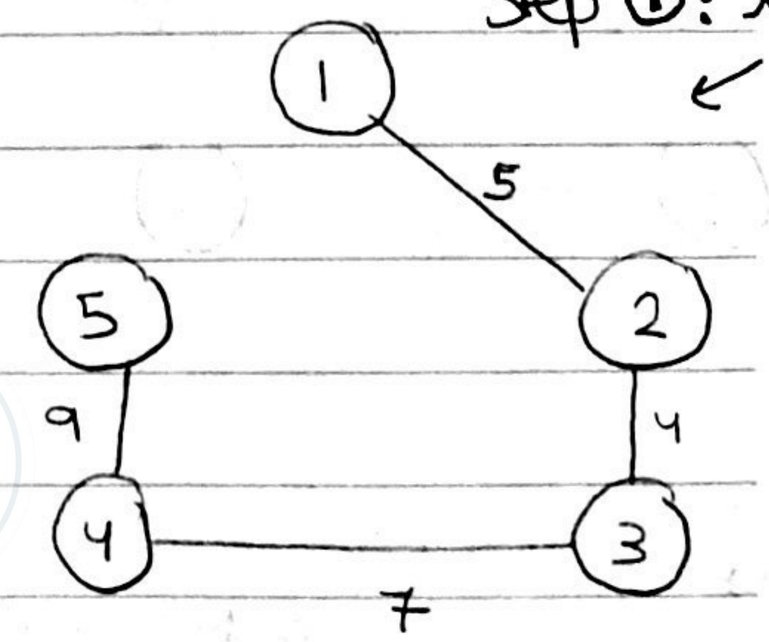
4. Create heuristic tour « T^H » from the walking by taking Shortcuts.

↳ (Follow same order as walk, but eliminate repeated visits to nodes).

---

* Example : نفس بلي قبل صفحتين

step ①: MST



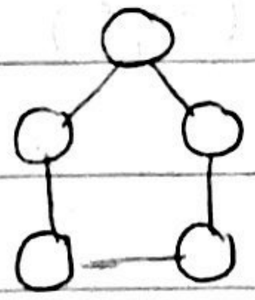
step ② LIST

(1, 2)
(1, 2)
(2, 3)
(2, 3)
(3, 4)
(3, 4)
(4, 5)
(4, 5)

بدأنا من أي node عادي

step 3 → walk = { 1, 2, 3, 4, 5, 4, 3, 2, 1 }

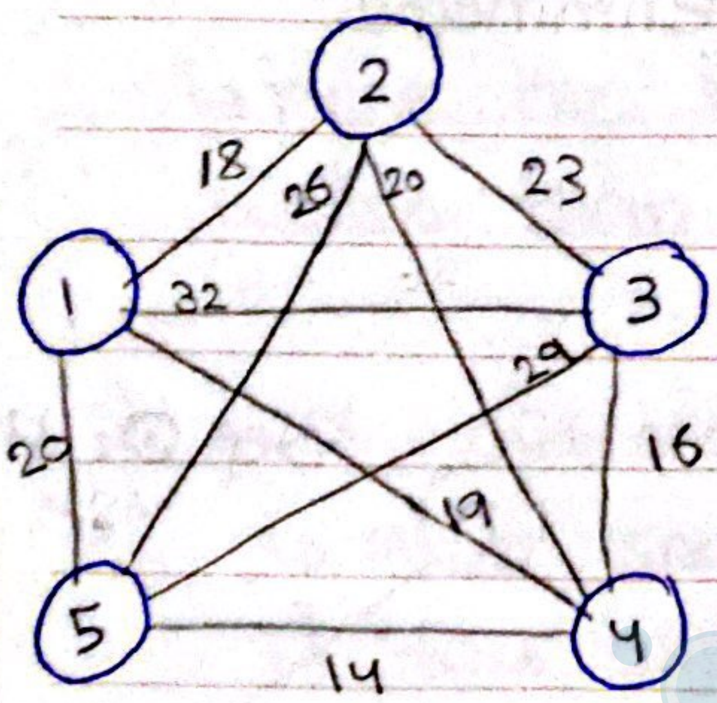
step 4 → TOUR = [1, 2, 3, 4, 5, 1] → بنشطب ال repeat لـ نرجع لنقطة البداية



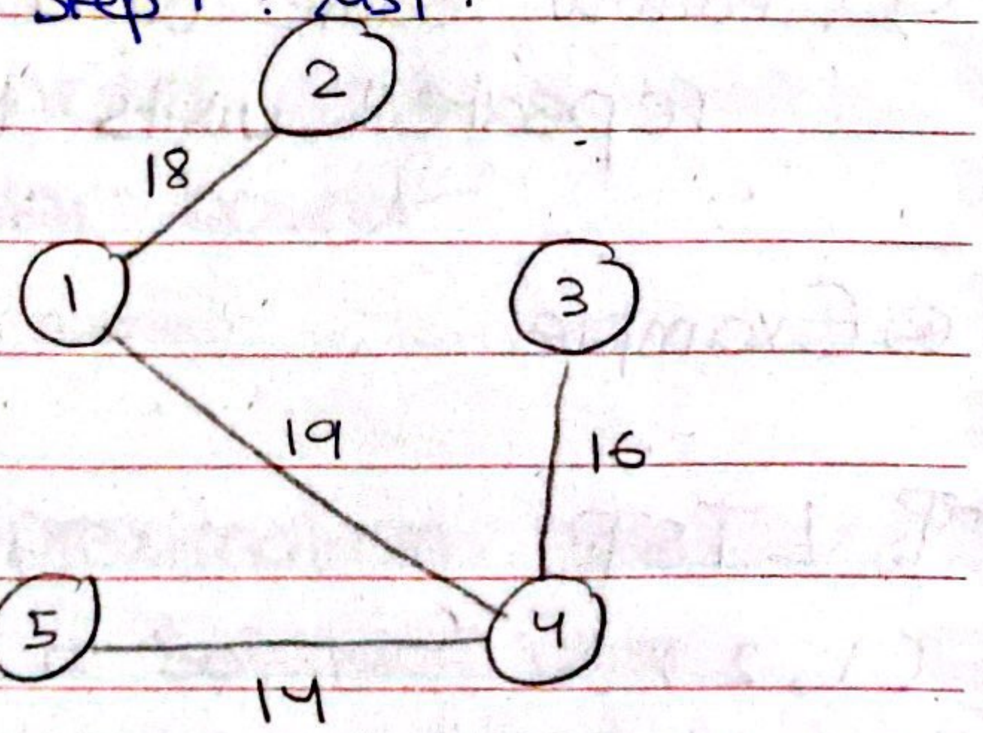
→ $C^H = 35$. #

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⊛ example 2 :



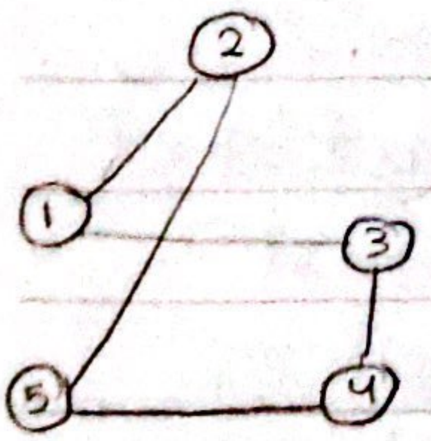
step 1 : MST :



↳ بدأنا الحل من node 4

step 3 ↳ walk = { 4, 3, 4, 1, 2, 1, 4, 5, 4 }

step 4 ↳ tour = [4, 3, 1, 2, 5, 4]



C^H = 106 ≠

↳ 14 + 16 + 32 + 26 + 18

step 2

LIST

(1, 2)
(1, 2)
(1, 4)
(1, 4)
(3, 4)
(3, 4)
(4, 5)
(4, 5)

← لو بدأنا من node تانية ممكن يطلع هذا Cost مختلف

← بس دايمًا يكون أقل من ضعف ال opt.

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Tuesday
29/11

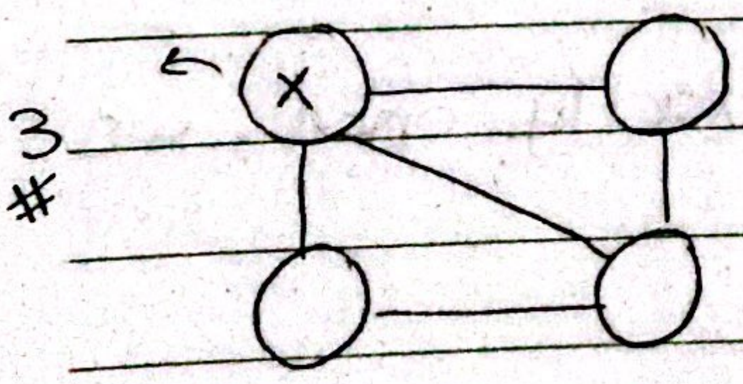
2 => Christofides heuristic
↳ the best Performance guarantee heuristic for TSP.

- TSP → OPtimal Solution ممكن ما أعرفه
  - hard to solve for med-large size Problems

→ Heuristic
- we use it to solve med-large size Prob. (instead of opt. method)

→ lower bound (LB)
- we use it to judge the heuristic evaluation
- Can be easily calculated, but usually not a Feasible tour
- but if the result LB tour is Feasible, then it's the optimal #

↳ node degree :
# of arcs adjasent to a node
↳ regadless it in or out arc.



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S → Set of nodes

↳ Perfect node Matching : Given a set of nodes (S), such that |S| is even, a Perfect node matching (w) is a set of |S|/2 node Pairings, such that each node in (S) is exactly in one Pairing

The cost of match $C(w) = \sum_{(i,j) \in w} c_{ij}$

* Christofides steps :-

[1] Find MST on the original graph

[2] let S be nodes of G with odd degree in MST.

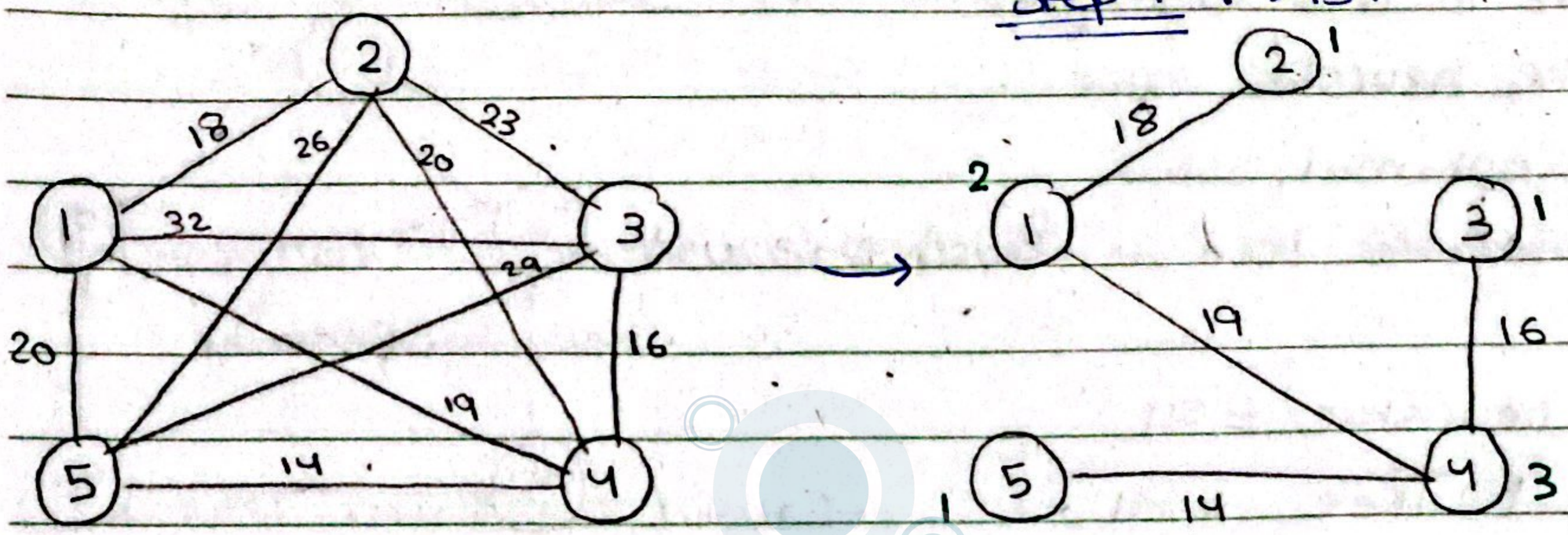
[3] Find the Perfect node matching (w^*) of nodes in (S) with min. Cost.

[4] Using arcs for MST and w^* exactly once, we generate a walk.

[5] Generate tour T^H by shortcutting the node (remove repeated nodes).

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(*) example :-



Step 2

$S = \{2, 3, 4, 5\}$ → sets of nodes with odd degree.

Step 3

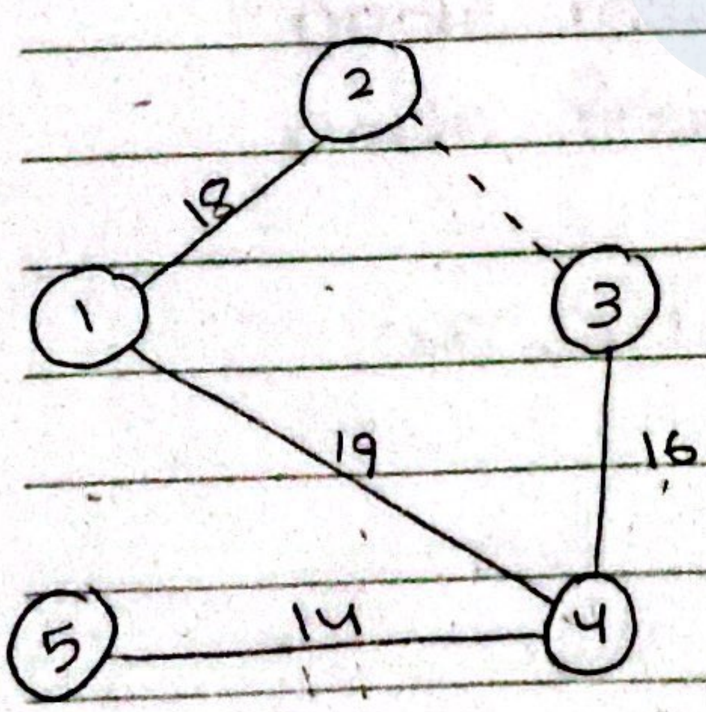
Matching : least cost. ⑤

2-3 & 4-5 → $C_{23} + C_{45} = 23 + 14 = 37$ *

2-4 & 3-5 → $C_{24} + C_{35} = 20 + 29 = 49$

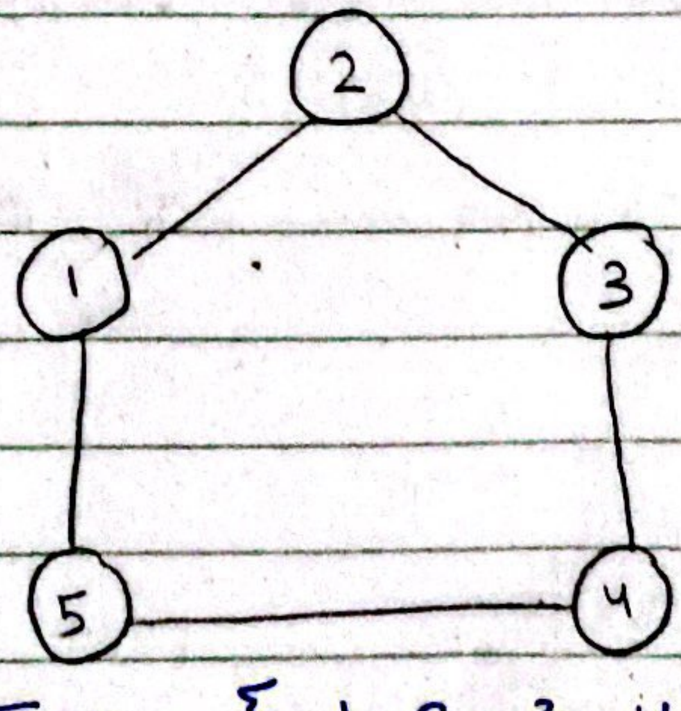
2-5 & 3-4 → $C_{25} + C_{34} = 26 + 16 = 42$

Step 4



$W = \{1, 2, 3, 4, 5, 4, 1\}$

Step 5

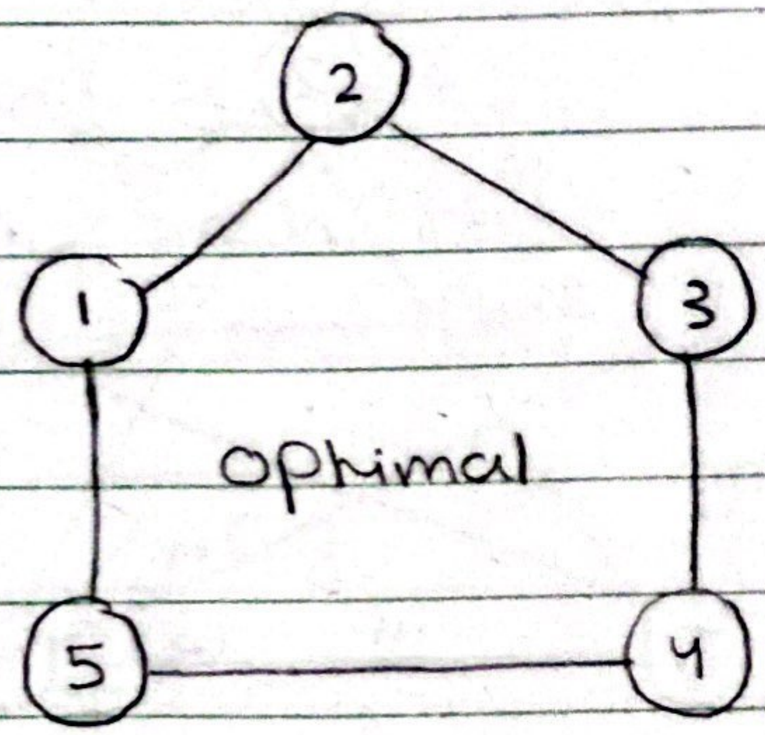


Tour = { 1, 2, 3, 4, 5, 1 }

start end.

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Tour :



→ heuristic = 91

1-TREE = 91

→ if optimal = 100 :-

Twice around ≤ 200

Christofied ≤ 150

↳ 100 * 1.5

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Sunday
4/12

⊛ α-optimal heuristic, the performance is guaranteed, (we know that the worst case for C^A is to be twice or 1.5 the opt. Cost, ((Practical heuristic)) means that there is no perfor. guaratee

⊛ Practical TSP heuristic :.

[1] Construction Approach
nearest neighbor, nearest insertion cost, furthest insertion Cost.

[2] improvement approach

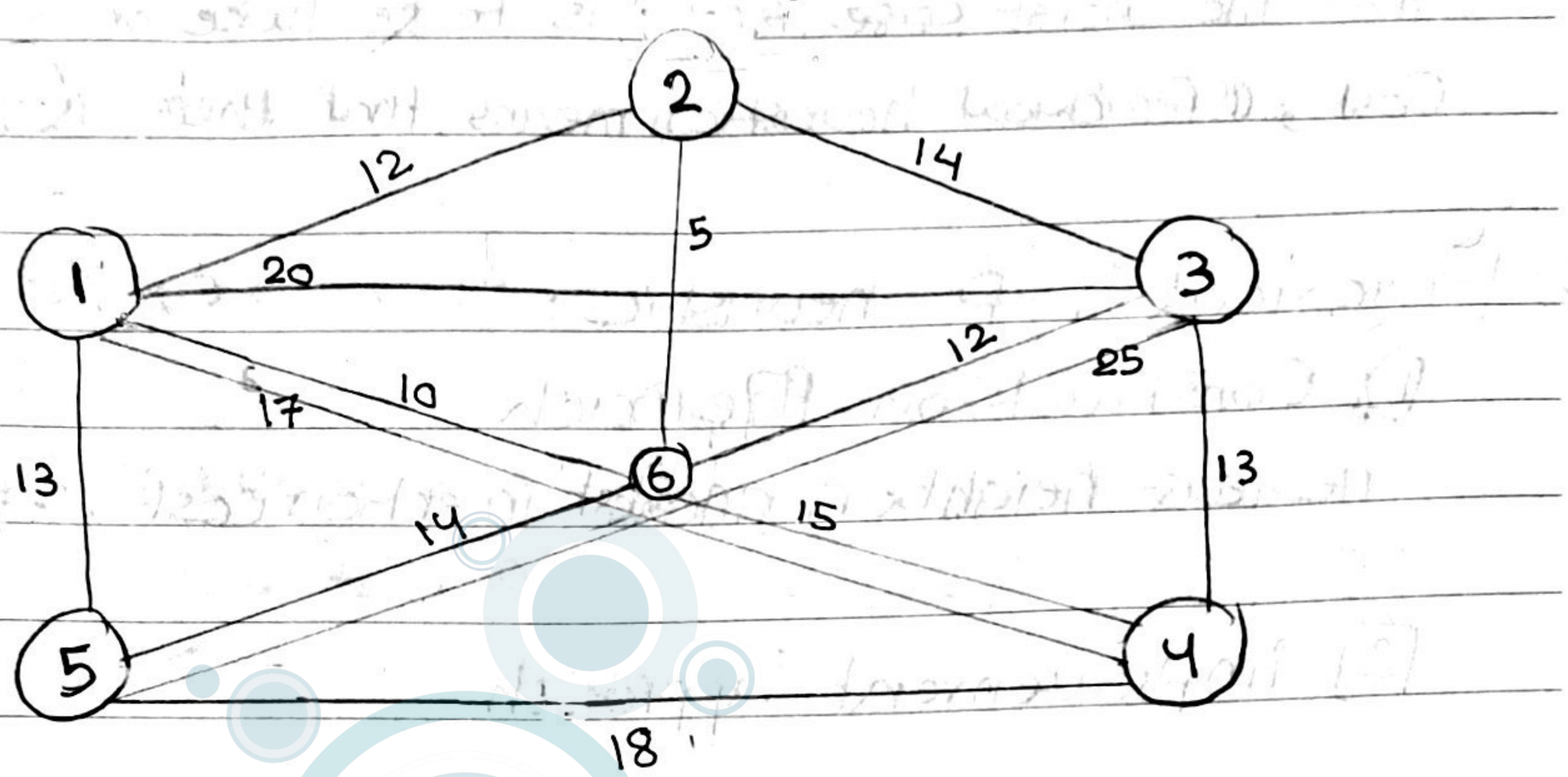
⊛ Nearest neighbor heuristic
↳ doesn't look any further than immediate move
↳ Considred to be a greedy heuristic.

• Steps :-
1. we start with the lowest Cost arc, or with arbitrary node.

2. at each node, we extend Path to nearest node reachable from either start or ending node from the Path.

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⊛ example



Sol.

⊛ Starting with the lowest

Cost arc : (2-6)

Start with arc 2,6 → end (2,6)

add arc 6,1 → end (1,2)

~~add arc 1,2~~ → Cycle X

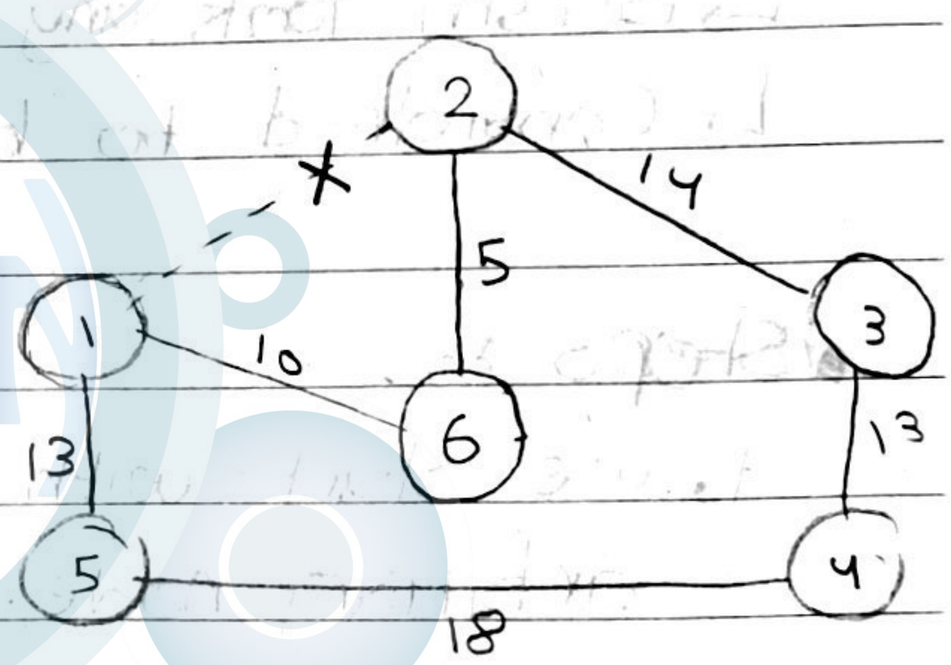
↳ = = 1,5 → = (2,5)

= = 2,3 → = (3,5)

= = 3,4 → = (4,5)

= = 4,5 → end ✱

Tour :-



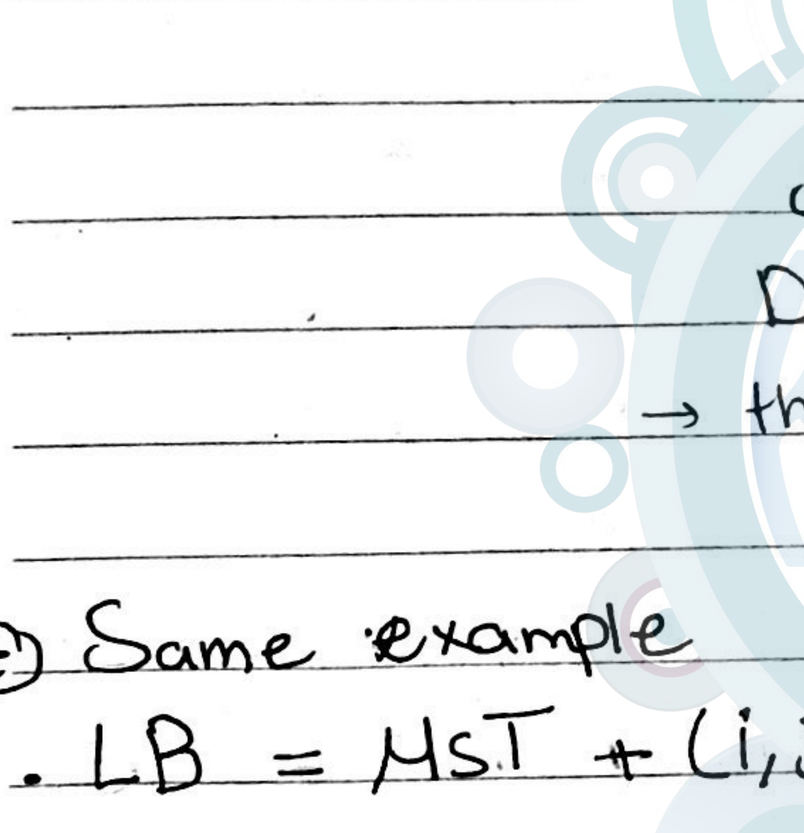
← بشوف ال arcs يلي مرتبطين بال ending & start. nodes وبختار ال lowest cost arc وبضيفه عل ال tour و هيك ...

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↳ Same example

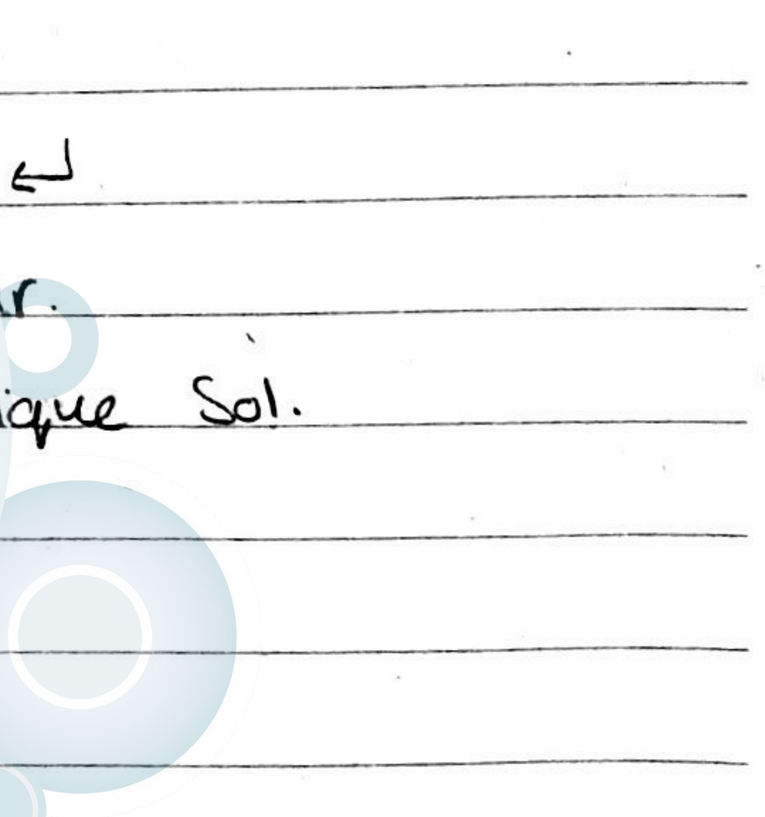
* Starting with arbitrary node:

• node (4)



↳ Cost = 73

• node (1)



↳ cost = 73

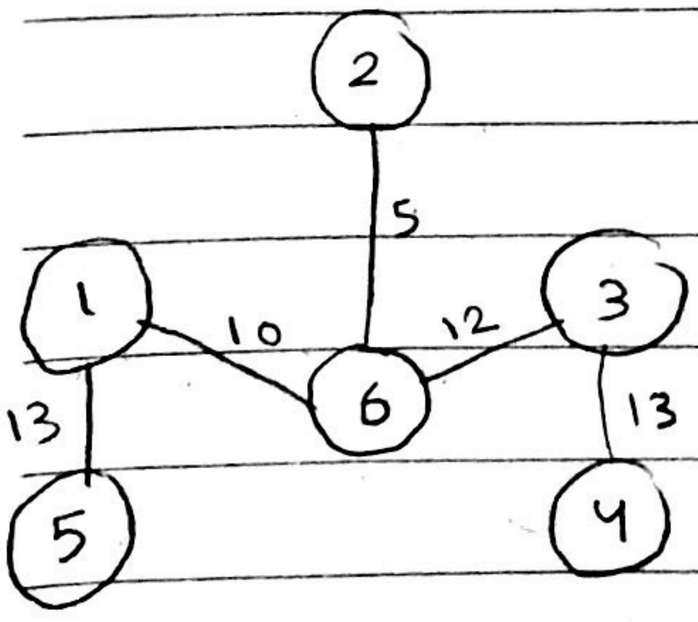
↳ ممكن بعاي الطريقه أحصّل Diff. arcs & Diff. tour.

→ there is no one unique Sol.

* Same example

• LB = MST + (i,j)*

• MST:



→ MST Cost = 53

→ (i,j)* Cost = 12

→ LB = 53 + 12 = 65

→ opt. Sol. ≥ 65

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Tuesday
6/12

Nearest insertion heuristic

***Initialization*:**

→ Given an undirected network $G = (N, A)$, with costs c_{ij} associated with each $(i, j) \in A$,
→ where c_{ij} satisfies the Δ-inequality.
Initial. ← Find the arc (i, j) with minimum cost in A. Let $T = \{i, j, i\}$

***Steps*:**

while $|T| < n + 1$:

1. Find the node $j \notin T$ that is *closest* to a node currently in T. That is, find $j \notin T, i \in T$ such that c_{ij} is minimized.

2. Find the *insertion location* for node j into the existing tour. To do so, find the arc (ℓ, k) in the current tour with the minimum insertion cost: $c_{\ell j} + c_{jk} - c_{\ell k}$. Insert j between ℓ and k in T.

Farthest insertion heuristic

***Initialization*:**

Given an undirected network $G = (N, A)$, with costs c_{ij} associated with each $(i, j) \in A$, where c_{ij} satisfies the Δ-inequality.

Find the arc (i, j) with maximum cost in A. Let $T = \{i, j, i\}$

***Steps*:**

while $|T| < n + 1$:

1. Let $C_j(T)$ be $\min_{i \in T} c_{ij}$ for all nodes $j \notin T$. The node j to be inserted into the tour is one with maximum $C_j(T)$.

2. Find the *insertion location* for node j into the existing tour. To do so, find the arc (ℓ, k) in the current tour with the minimum insertion cost: $c_{\ell j} + c_{jk} - c_{\ell k}$. Insert j between ℓ and k in T.

end;

In English, Step 1 finds the node j not on the tour for which the minimum distance to a vertex on the tour is maximum, and adds that node to the current tour.

- Both nearest and farthest are ① considered to be better than nearest neighbor.

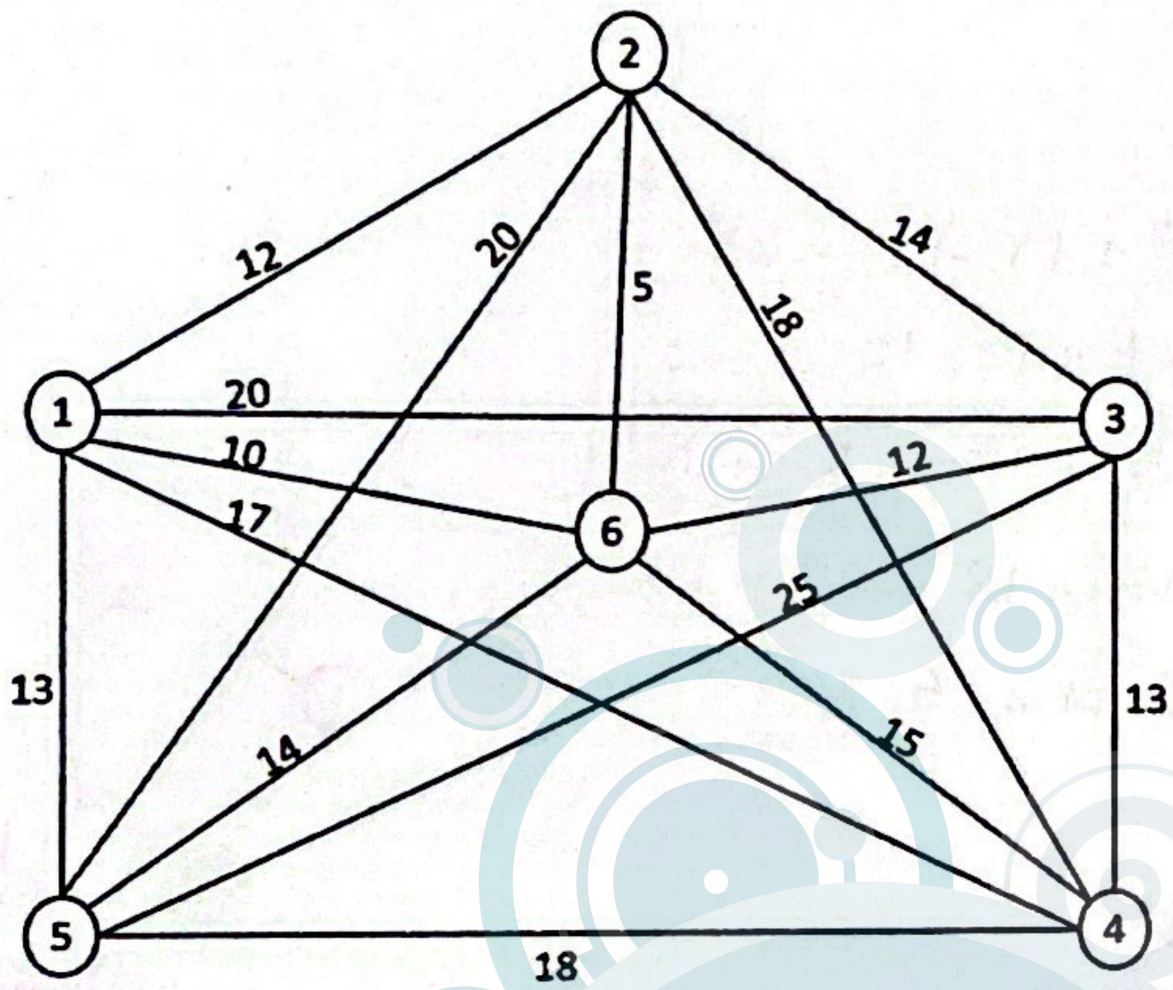
② Practical (not guaranteed Performance)
Heuristic

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Example:

Consider the following symmetric, undirected network G where the numbers next to each arc are the arc costs. Suppose that your goal is to find a good traveling salesman tour that visits all of the nodes of G.

نزور كل ال nodes ب



- Find the trave saleman tour using nearest insertion heurishic.

- **initialization:**

↳ we start with min cost arc : (2,6)

$T = [2, 6, 2]$, $C(T) = 10 \rightarrow$

tour: T, st.: 2, end.: 2

iteration ①:

- **Step 1:** [to determine which node to insert]

- iteration ① :

j ∉ tour	i ∈ tour	C_{ij}
1	6	10 ←
3	6	12
4	6	15
5	6	14

↳ we choose to insert node 1 to the tour

- **Step 2:** [to determine where to add the node]

Node 1 will be inserted

btw node 2 & 6 $T = \{2, 1, 6, 2\}$

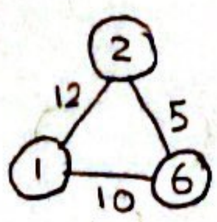
insertion cost $= C_{21} + C_{16} - C_{26}$

$= 12 + 10 - 5 = 17$

$T = [2, 1, 6, 2]$,

$C(T) = C(T)_{\text{Previous}} + \text{insertion Cost}$

$= 10 + 17 = 27$ #



Iteration ②:

Step 1

j ∉ T	i ∈ T	C_{ij}
3	6	12 ←
4	6	15
5	1	13

↳ we choose node ③ to insert.

Step 2

insert node 3 either:

btw 2,1 $= C_{23} + C_{31} - C_{21} = 14 + 20 - 12 = 22$

" 1,6 $= C_{13} + C_{36} - C_{16} = 20 + 12 - 10 = 22$

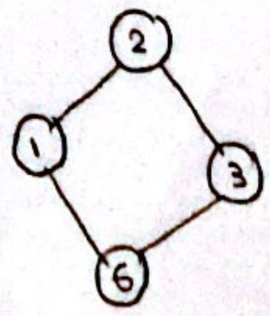
" 6,2 $= C_{63} + C_{32} - C_{62} = 12 + 14 - 5 = \boxed{21}$

↳ we will insert it btw 6 & 2.

$T = \{2, 1, 6, 3, 2\}$.

$C(T) = C(T)_{\text{Prev.}} + \text{insertion Cost}$

$= 27 + 21 = 48$ #



Cont'd. →

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Iteration (3):

Step 1

J∈T	i∈T	C_{ij}
4	3	13
5	1	13

↳ we choose node 4 to insert

Step 2

Insert node 4 either

btw 2,1 = $C_{24} + C_{41} - C_{21}$ = 18 + 17 - 12 = 23

btw 1,6 = $C_{14} + C_{46} - C_{16}$ = 17 + 15 - 10 = 22

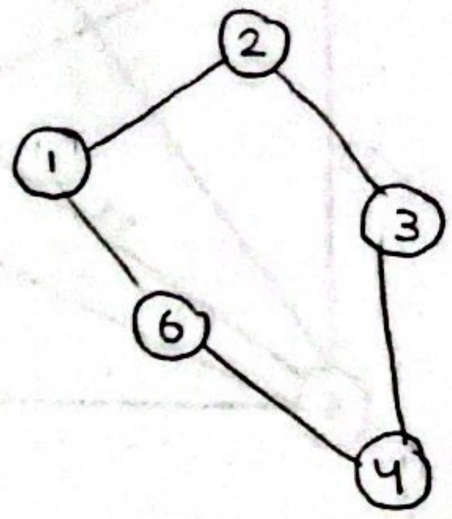
btw 6,3 = $C_{64} + C_{43} - C_{63}$ = 15 + 13 - 12 = **16**

btw 3,2 = $C_{34} + C_{42} - C_{32}$ = 13 + 18 - 14 = 17

↳ we choose to insert node 4 btw 6 & 3

$T = \{2, 1, 6, 4, 3, 2\}$

$C(T) = 48 + 16 = 64$ #



Iteration (4):

Step 1

node 5

$T = \{2, 1, 6, 4, 3, 2\}$

Step 2

inserting node 5 either:

btw 2,1 = $C_{25} + C_{51} - C_{21}$ = 21

≈ 1,6 = $C_{15} + C_{56} - C_{16}$ = 17 ✓

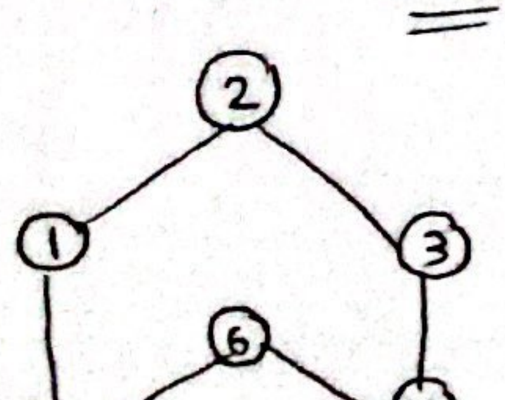
≈ 6,4 = $C_{65} + C_{54} - C_{64}$ = 17 ✓

≈ 4,3 = $C_{45} + C_{53} - C_{43}$ = 30

≈ 3,2 = $C_{35} + C_{52} - C_{32}$ = 31

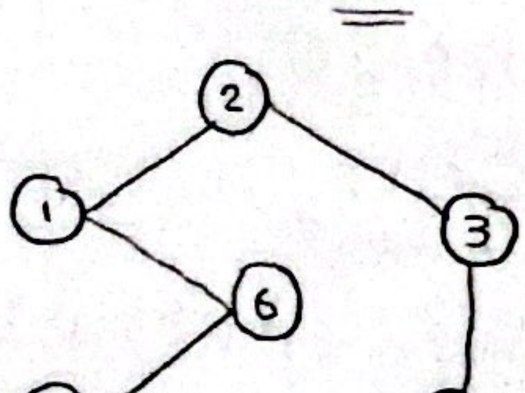
(*) btw 1 & 6 → $T = \{2, 1, 5, 6, 4, 3, 2\}$

$C(T) = 64 + 17 = 81$



(*) btw 6 & 4 → $T = \{2, 1, 6, 5, 4, 3, 2\}$

$C(T) = 64 + 17 = 81$

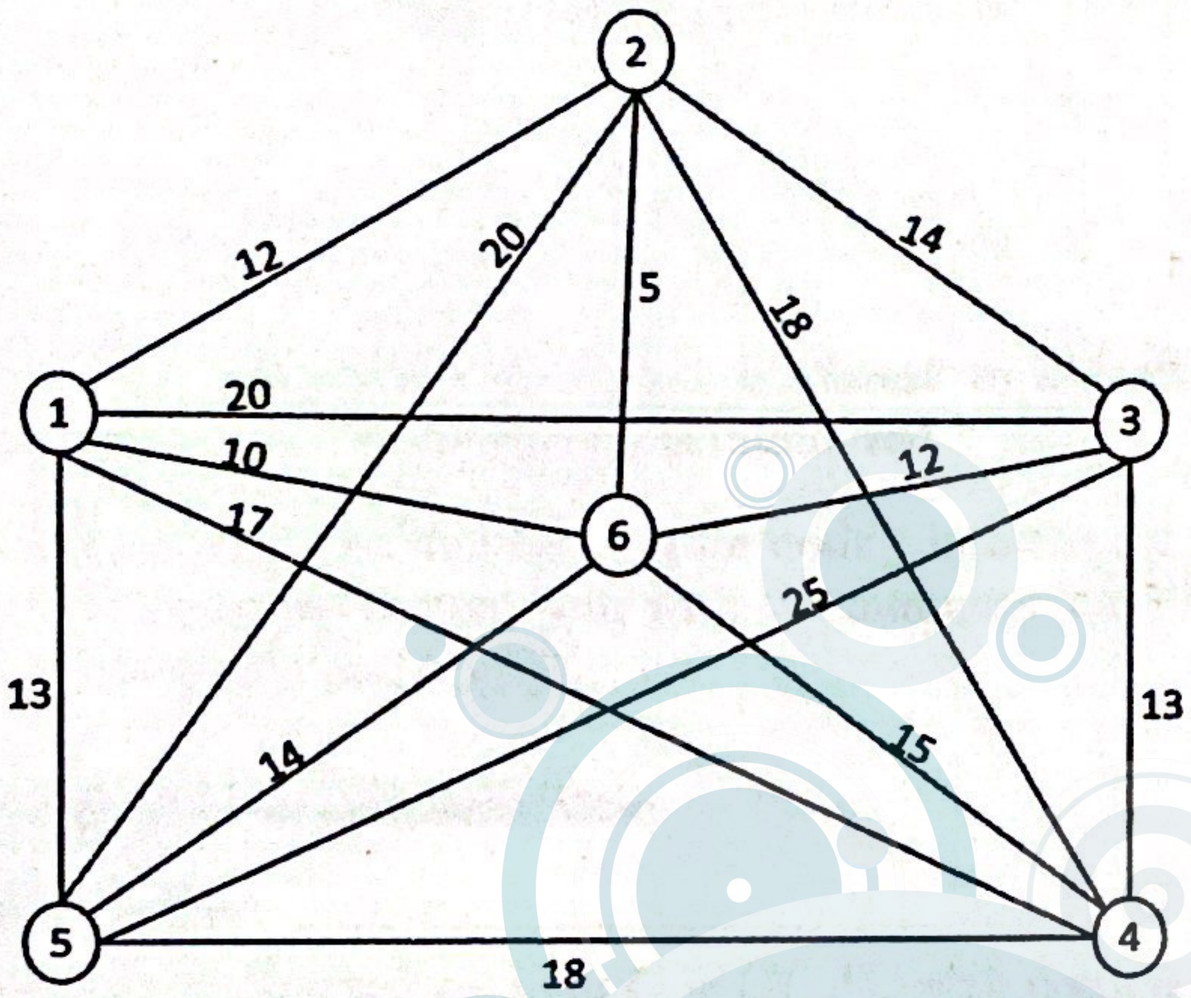


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Thursday
8/12.

Example:

Consider the following symmetric, undirected network G where the numbers next to each arc are the arc costs. Suppose that your goal is to find a good traveling salesman tour that visits all of the nodes of G.



ال min هـون
باخدها بس عند ال
insertion
← الباقي كلّه max.

Initialization : (3,5)
↳ max cost arc.

$T = \{3, 5, 3\}$, $C(T) = 50$

Iteration 1 : $T = \{3, 5, 3\}$

step1

j∉T	i∈T	C_{ij}
1	5	13
→ 2	3	14
4	3	13
6	3	12

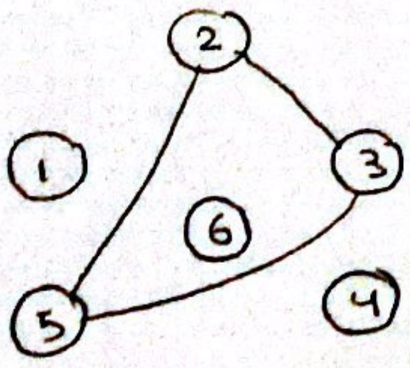
we choose to insert node 2 → max. cost

step2

insertion cost = $C_{32} + C_{25} - C_{35}$

$= 14 + 20 - 25 = \underline{9}$

$C(T) = 50 + 9 = 59$ #



Iteration 2:

step1

j∉T	i∈T	C_{ij}
1	2	12
4	3	13
6	2	5

↳ we choose to insert node (4)

step2 → $T = \{3, 2, 5, 3\}$

btw 3,2 = $C_{34} + C_{42} - C_{32} = 17$
= 2,5 = $C_{24} + C_{45} - C_{25} = 16$
= 5,3 = $C_{54} + C_{43} - C_{53} = \boxed{6}$ ←

$T = \{3, 2, 5, 4, 3\}$

$C(T) = C(T)_{\text{Prev.}} + \text{insertion}$

$= 59 + 6 = 65$ #

→

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Iteration [3] :-

Step 1

J ∉ T	i ∈ T	C_{ij}
1	2	12 ←
6	2	5

↳ we choose node ① to insert

Step 2 $T = \{3, 2, 5, 4, 3\}$

btw 3,2 $= C_{31} + C_{12} - C_{32} = 18$

= 2,5 $= C_{21} + C_{15} - C_{25} = 5$ ←

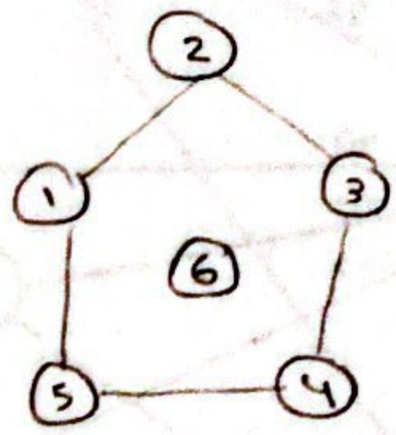
= 5,4 $= C_{51} + 5_{14} - C_{54} = 12$

= 4,3 $= C_{41} + C_{13} - C_{43} = 24$

↳ we will insert it btw 2 & 5

$T = \{3, 2, 1, 5, 4, 3\}$

$C(T) = 65 + 5 = 70$ #



Iteration [4] :-

Step 1

node ⑥ will enter the tour.

Step 2

btw 3,2 $= C_{36} + C_{62} - C_{32} = 3$ ←

2,1 $= C_{26} + C_{61} - C_{21} = 3$ ←

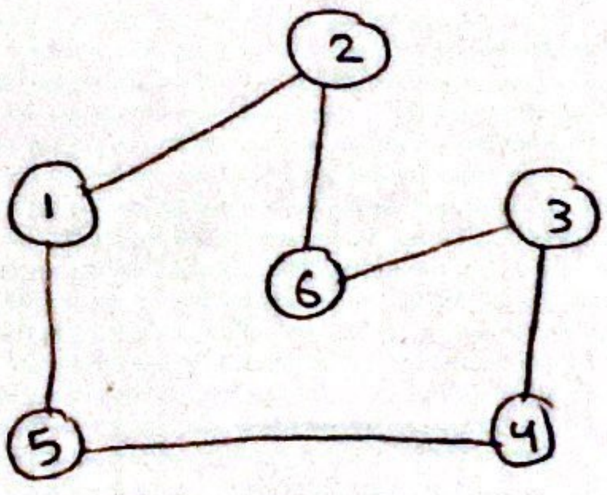
1,5 $= C_{16} + C_{65} - C_{15} = 11$

5,4 $= C_{56} + C_{64} - C_{54} = 11$

4,3 $= C_{46} + C_{63} - C_{43} = 14$

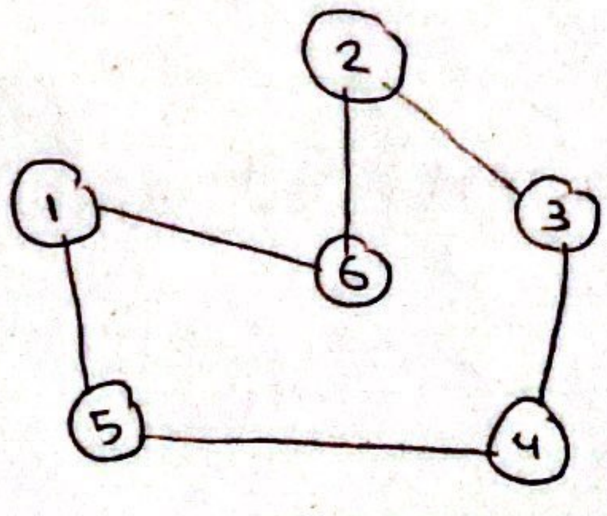
btw 3,2 → $T = \{3, 6, 2, 1, 5, 4, 3\}$

$C(T) = 70 + 3 = 73$



btw 2,1 → $T = \{3, 2, 6, 1, 5, 4, 3\}$

$C(T) = 70 + 3 = 73$ #



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Sunday
11/12

⊛ Revision

- Recall TSP → Optimal Sol.
  → Heuristic
  → LB

- Heuristic

① Performance guaranteed.:

- α optimal heuristic

1 → $\alpha = 1.5$ (Christofides) → best Performance guarantee

2 → $\alpha = 2$ (twice around).

② Performance not guaranteed: (Practical heuristic)

[1] Construction approach

- nearest neighbor heuristic
- nearest insertion heuristic
- farthest insertion heuristic

[2] improvement approach

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⊛ improvement heuristic

- idea : given an existing tour, Consider small, local changes to decrease tot. Cost.

Current Sol. لـ لأنها تعتمد على ال

- the existing tour could by one of the Previous heurishic Solutions mentioned.

- Common approach: λ- exchange

↳ Choose Some λ (integer #) arcs to remove, and then choose λ arcs to add to create Feasible Solution.

لـ يعني tour مو Subtour أو ...

- λ optimal

a tour is λ-optimal if there is noway to replace λ arcs Currently in the tour with λ arcs not in the tour to Create a feasible Solution.

improvement ← لازم كل tour يكونه عنده
exchange كل ← tour جديد يطلع

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- given a complete undirected network $G_1 = (N, A)$ and tour T_i, $A(T_i)$ be .. set of arcs in T_i

such that $\Rightarrow$ $A(T_i) = \{(v_1, v_2), (v_2, v_3), \dots, (v_{n-1}, v_1)\}$

- then T_i is $\exists$ optimal if there do not exist two set of arcs

Set of arcs removed ← $\therefore X \in A(T_i)$

Set of arcs added ← $Y \in A / A(T_i)$ ↳ except.

$\exists$ opt. ② Conditions

1. $|X| = |Y| = \lambda$

2. $\sum_{(i,j) \in X} C_{ij} - \sum_{(i,j) \in Y} C_{ij} > 0$ → يعني لـ م أكون حلت Saving أو Cost الـ min.

3. the set $A(T_i) + Y \setminus X$ allows a new feasible tour. T_{i+1}

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⑭ Steps : ٢ optimal heuristic (exchange heu.)

- initialization : given some initial feasibal tour

$(T_0) \rightarrow \underline{\underline{K=0}}$

iteration ل عـنّاد ال

- Iteration :

[1] identify a feasible λ-exchange with positive saving, That is, find two sets :-

$X \in A(T_i)$

$Y \in A / A(T_i)$

↳ such that Conditions 1-3 mentioned before are met.

. if no sets can be found, stop.

because → T_K is λ-optimal #

[2] let T_{K+1} be new tour generated by removing (X) and adding (Y)

[3] K++, Repeat from 1

قيمـة ال λ الدكتورة بتحددها باكمتدان ؛"

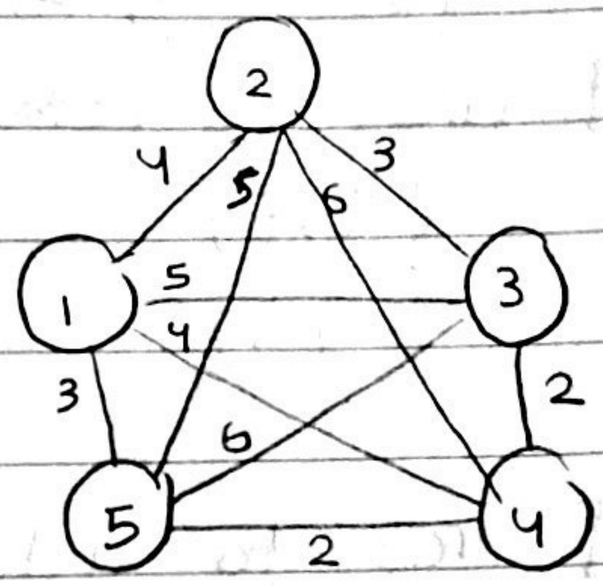
لأنّه ما بتعدر نشوف كل ال Possibilities

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⊛ example

Suppose we have Complete Undirect graph G

G



$T_o = [1, 2, 4, 5, 3, 1]$

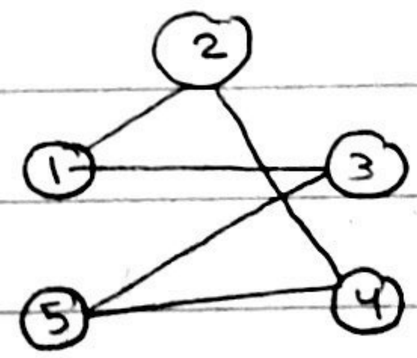
→ Perform 2 exchange heuristic on this tour T_o, to try to improve cost.

Sol.

1] identify arcs to remove:

(3,1)
(2,4)] → يلي بنعاطعوا

T_o ↘

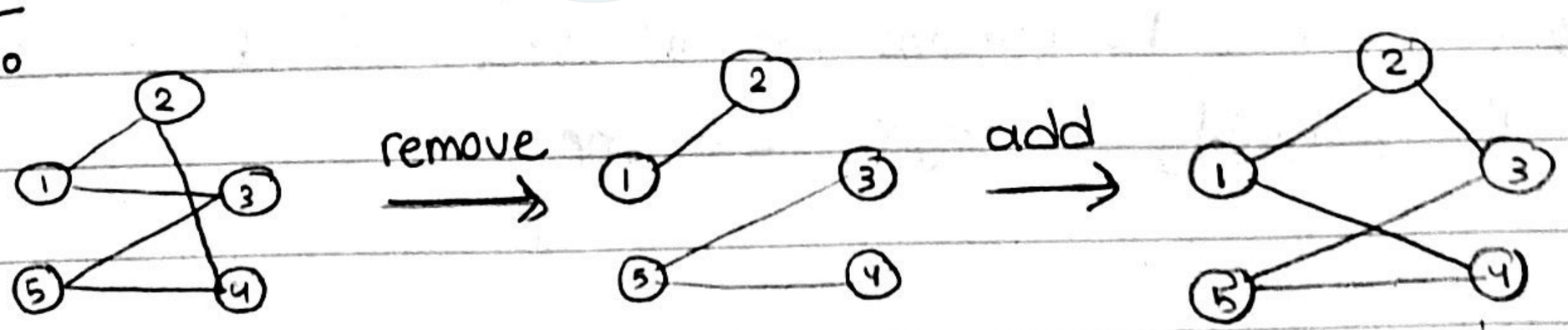


2] identify arcs to add

(2,3)
(1,4)

3] Check for improvement.

T_o



• $(C_{31} + C_{24}) - (C_{23} + C_{41}) \overset{!?}{>} 0$

$11 - 7 > 0$ ✓

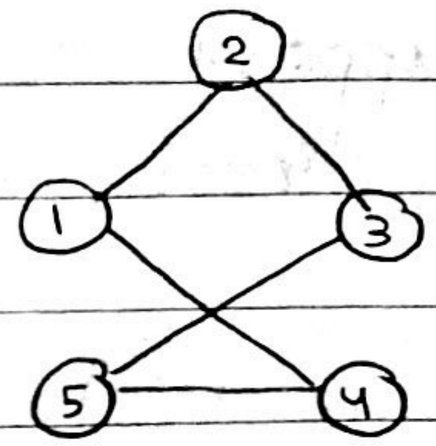
↳ Since improvement is checked, this will become T_o for next iteration

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Iteration [2]

$T_0 = \{1, 2, 3, 5, 4, 1\}$

To V



1] arcs to remove :

(3,5)

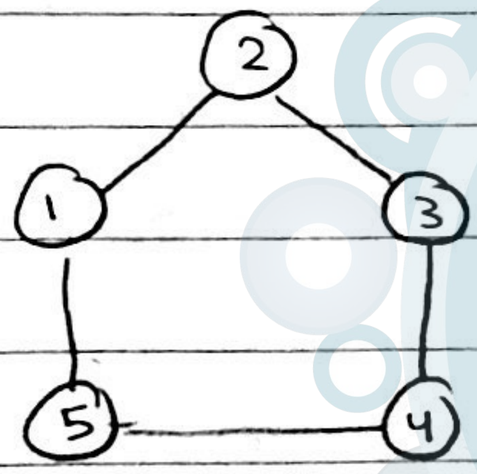
(1,4)

2] arcs to add :

(1,5)

(3,4)

3] Check for improvement :-



$(C_{14} + C_{35}) - (C_{15} + C_{34}) > 0$

$4 + 6 - 3 + 2 > 0$

$5 > 0 \rightarrow$ exchange accepted. #

↳ tour after removing & adding arcs.

$C(T) = 14$ #

☹ we choose to remove the intersect arcs because of the possibility of high cost there.

مادة الكويز #

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Tuesday
13/12

⊛Bin Packing Problem : « BPP »

- Description of the Problem :

↳ we have some # of identical bins (or truck, container, ...) each with Capacity Q

↳ we have some # of items that need to be Packed into bins, item i has size q_i

- $q_i \in [0, Q]$ → q_i قيمة ال

↳ also we cannot split items (order) between bins.

↳ let's assume we are given items & sizes in a list :-

$$L = \{q_1, q_2, \dots, q_n\}$$

- Problem : assign each item to a bin such that :

[1] Capacity is observed, total weight / volume of all items in a bin $\leq Q$

[2] Smallest # of bins is used

- Example :

11 groups of People of Sizes : 2,2,3,3,3,4,4,4,5,5,5 need to fit to mini buses with Capacity of 10 but must stay together in their groups,

→ Find Smallest # of buses need to transport them.

→

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Sol.

↳ bin 1 = [5, 5]

↳ bin 2 = [3, 3, 4]

↳ bin 3 = [5, 3, 2]

↳ bin 4 = [4, 4, 2]

⊛ IP Formulation

- Decision variables :

$$Y_j = \begin{cases} 1 \rightarrow & \text{if bin is Utilized} \\ 0 \rightarrow & \text{otherwise} \end{cases}$$

$$X_{ij} = \begin{cases} 1 \rightarrow & \text{if item is assigned to bin (j)} \\ 0 \rightarrow & \text{otherwise} \end{cases}$$

- Objective :

$$\text{Min} \sum_{j=1}^{m} Y_j$$

- Such that (Constraints) :

Capacity Constraint [1] $\sum_{i=1}^{n} q_i X_{ij} \leq Q \rightarrow \forall_j$ ↳ for all j

each order should be served in 1 bin [2] $\sum_{j=1} X_{ij} = 1 \rightarrow \forall_i$

Connects btw X_{ij} & y_j [3] $X_{ij} \leq Y_j \rightarrow \forall_j, \forall_i$

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- example
  - if $X_{13} = 1$ $\xrightarrow{\text{then must}}$ $Y_3 = 1$
  - $=$ $X_{13} = 0$
    - $Y_3 = 1$ or $Y_3 = 0$

- BPP, in theory : easy to understand
  + hard to solve] just like TSP
  ← heuristic لحلها نلجأ ع فَ

⊛ Approaches to Solve BPP :

[1] Online methods :

→ Data are received overtime

→ Irrcoverable decisions are made based on known data with Some time limit

→ Short load visibility

[2] Offline methods :

→ Data about all items are available before any decision need to be finalized.

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Sunday
18/12

Heuristic for BPP :

* Online heuristic

[1] Next fit heuristic (NF) → Performance $\alpha = 2$

- NF :

→ only one open bin at each step of the heuristic
→ Given list L of items each with size q_i
→ each bin has a Capacity of Q.

- Steps :

① Take item from the top of the list.

② If it fits in the current open bin, Place it & remove item from the list (then go back to step 1)

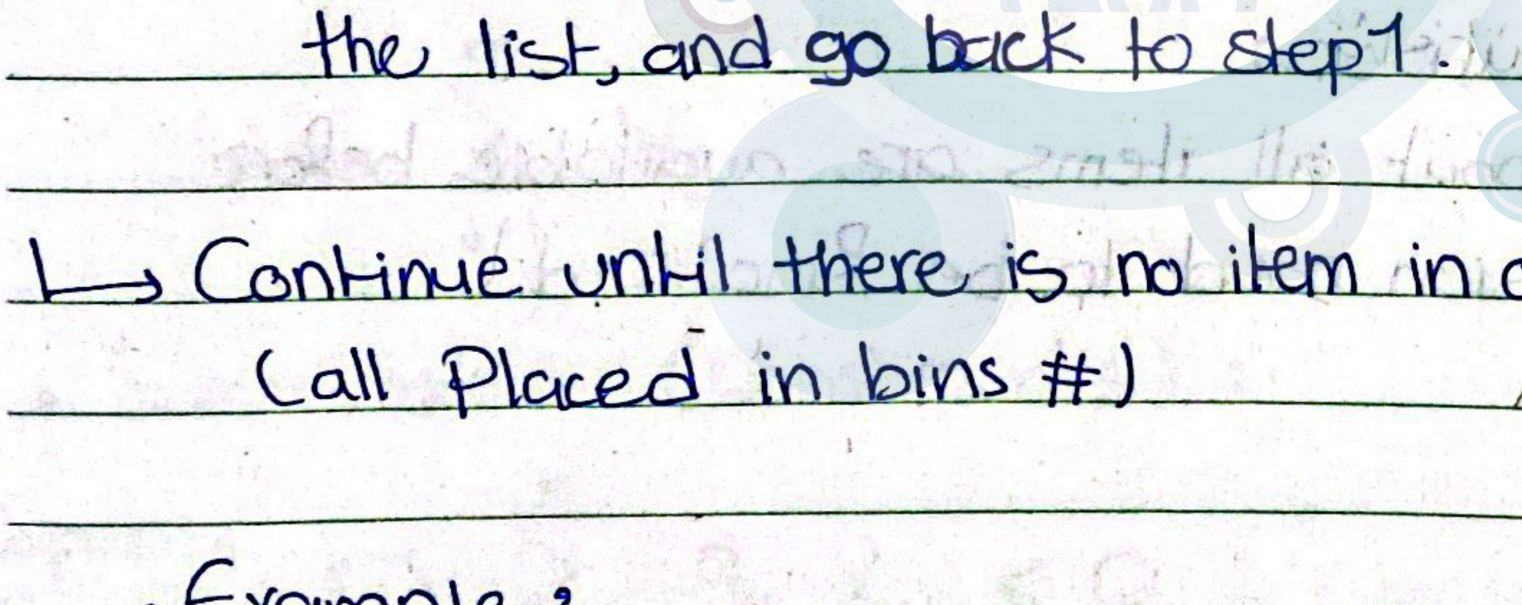
③ If it doesn't fit, Close the Current bin, open a new bin and Place item there, then remove item from the list, and go back to step 1.

↳ Continue until there is no item in our LIST (all Placed in bins #)

- Example :

L = [16, 10, 14, 12, 4, 8, 3, 12, 7, 14, 9, 6, 3], Q = 20

Sol.



⇒ So # of bins needed using NF heuristic is 8 bins #

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2 First-Fit heuristic (FF) $1.7 \leq \alpha \leq 1.75$

- idea : Keep all bins open until Completely Full or entire list has been processed.

- Steps :

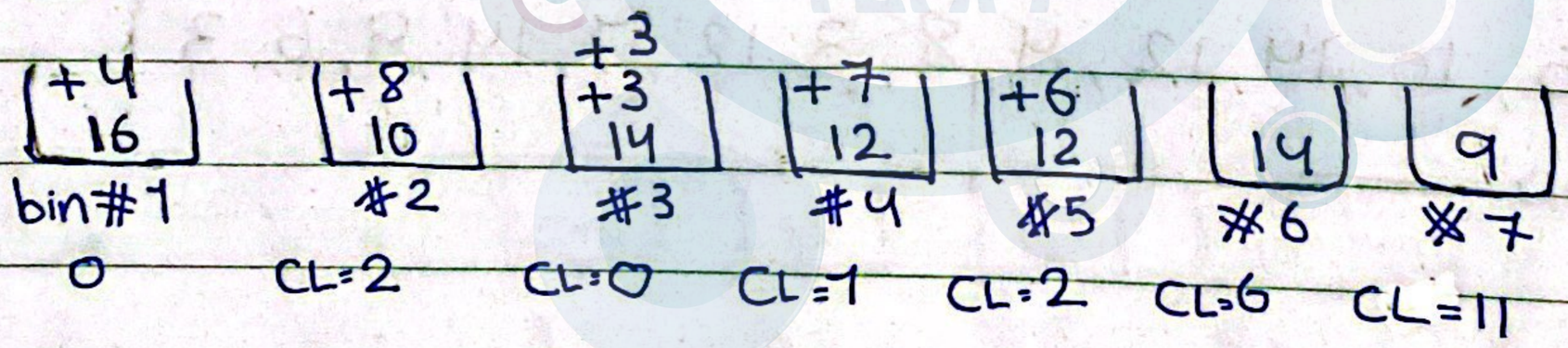
① Place next unplaced item in the lowest numbered bin, in which it fit, if no such bin exists, open new bin bin & place it there

② move to the next item & repeat.

- Example

$L = [16, 10, 14, 12, 4, 8, 3, 12, 7, 14, 9, 6, 3]$ $Q = 20$

Sol.



⇒ So # of bins needed using FF heuristic is 7 bins#

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[3] Best Fit heuristic $1.7 \leq \alpha \leq 1.75$

- idea: Keep all bins open until Completely full or entire list has been processed.

- Steps

① Place next unplaced item in bin such that:
   a) item fit
   b) residual Capacity at Choosen bin is minimized.
   c) if ties, Choose lower numbered bin.

② if no such bin exists, open new bin & place it there.

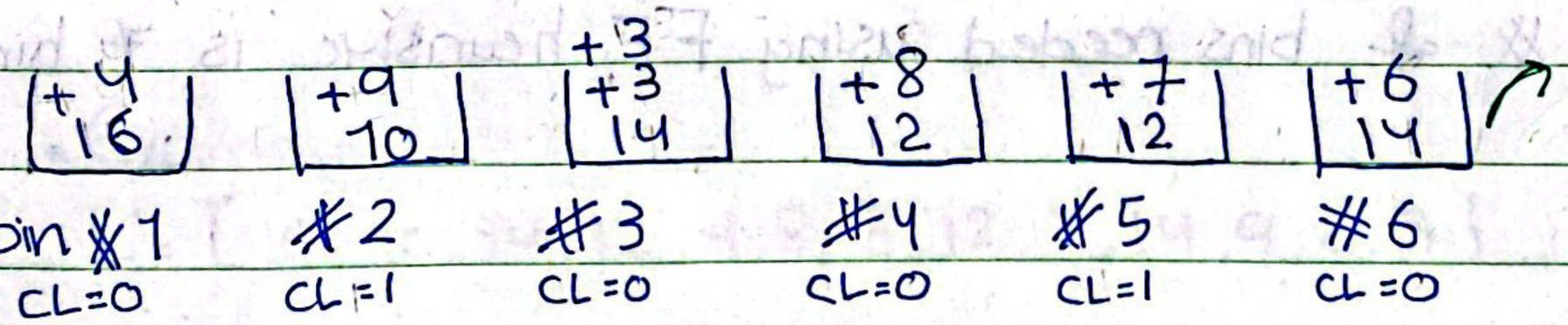
③ move to the next item and repeat.

- Example

$L = \{16, 10, 14, 12, 4, 8, 3, 12, 7, 14, 9, 6, 3\}$

$Q = 20$

Sol.



6 bins are needed using BF heuristic

- $LB = \left\lceil \frac{\sum q_i}{Q} \right\rceil$ ← أكبر عدد صحيح.

→ Not feasible

→* order might be Split.

(in BPP we assumed that orders (items) Cannot be Split)

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Tuesday
20/12

⊛ BPP offline heuristic

↳ assume the list of items is completely known in advance:

1. Sort L (LIST) in non-increasing order of item size
   ↳ Size نفسها بس انه مسموح يكون عندي ٢ نفس ال decreasing

2. Run NF, BF, FF heuristic:

↳ offline heu. الكل دي (data is already available)

↳ NF — Sorted data → Next Fit - decreasing
↳ BF — Sorted data → Best Fit - decreasing
↳ FF — Sorted data → First Fit - decreasing

$\alpha = 1.5$ (worst case)

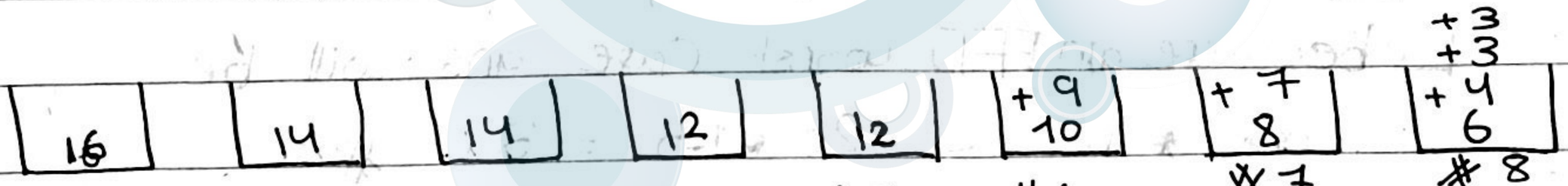
- Example:

a) apply NF - decreasing on the following items

$L = [16, 10, 14, 12, 4, 8, 3, 12, 7, 14, 9, 6, 3]$, $Q = 20$.

Sol. 1- Sorted → $L = [16, 14, 14, 12, 12, 10, 9, 8, 7, 6, 4, 3, 3]$

2- NF:



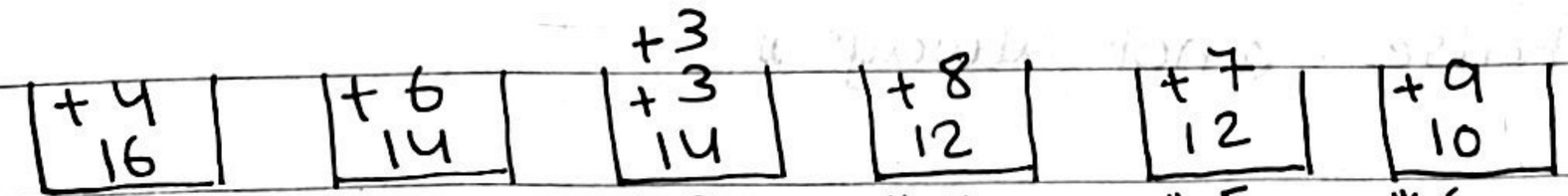
bin #1 #2 #3 #4 #5 #6 #7 #8

Capacity Left = 4, C.L=6, C.L=6, C.L=8, C.L=8, CL=1, CL=5, CL=4

↳ 8 bins needed

b) apply FF - decreasing on the same list.

Sol.



bin #1 CL=0, #2 CL=0, #3 CL=0, #4 CL=0, #5 CL=1, #6 CL=1

↳ 6 bins needed.

c)

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c) apply BFD → (best fit decreasing)

Sol.



6 bins needed using BFD #

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note

- Performance for BF & FF decreasing is $\alpha = 1.5$
  ↳ this means that there is an adv. if having data already

- Bonus Question :- (Bin Packing Problem)

⇒ assume you solve BPP for optimality and your solution was 20 bins required, your friend applied FF-decreasing and solution was 35 bins required then :-

a) your friend is wrong
b) your friend is right
c) you don't have enough info. to judge.

Ans. [a] → your friend is wrong.
↳ because at FFD worst case ans will be

opt * 1.5 → 20 * 1.5 = 30 #

لـ يعني مستحيل الـ FFD تطلع رقم أكبر من 30 .

- True or False ?!

⇒ BF-heuristic always yeilds a Sol. better than FF.
Ans. False. «not always»

Remember : • BF → Best Fit → online heuristic
• BFD → Best Fit-decreasing → offline heuristic
⇒ and so for NF, FF.

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⊛ Vehicle Routing Problem « VRP »

- Description :
  - we have fleet vehicles, each with Capacity Q, these vehicles station at a depot.

  - Customers (n), where Customer i has demand q_i

⊛ demand → Delivery demand : order توصل ال
→ Pickup demand order تاخد ال

⊛ VRP « Basic » :
→ all orders are either delivered orders or Pickup orders.

→ All vehicles have homogenous Capacity Q. (Same Capacity)

- Goal of VRP :
  To Find set of routes to serve all Customers with minimum distance or cost or time without violating vehicle Capacity

- Basic VRP is a combo between TSP & BPP
  « Travel Saleman Problem & Bin Packing Problem »

- Every TSP is a vehicle routing Problem #
- TSP → 1 vehicle
- VRP → fleet of vehicles.

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Thursday
22/12.

⊛ • TSP is Special Case of VRP:

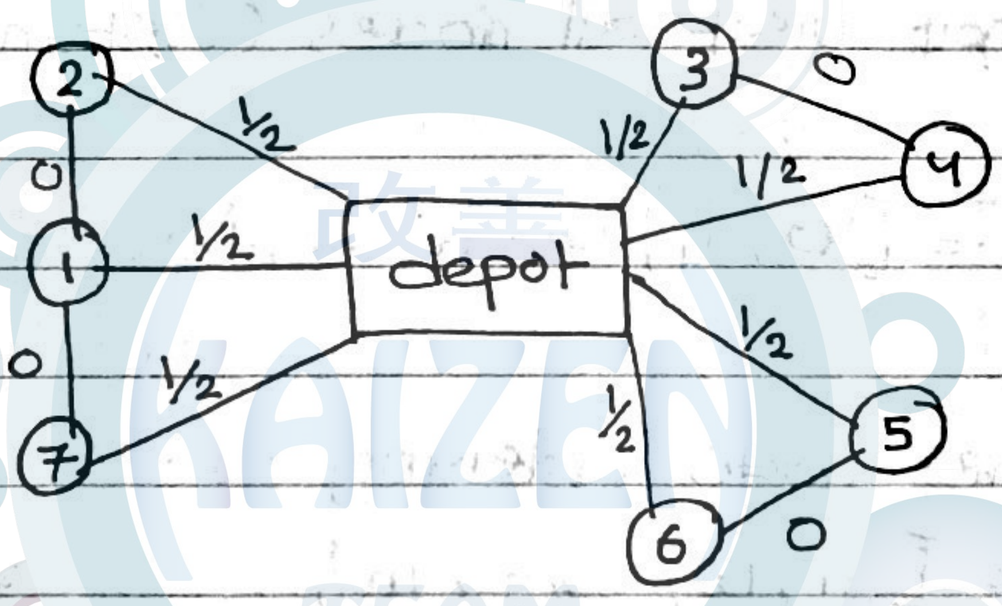
↝ when Capacity is ∞ or large enough to have all orders served in one vehicle → 1 tour → 1 tour = TSP #

⊛ • BPP is Special Case of VRP:

↝ BPP → min. # of bins utilized.
VRP = ↳ min distance / cost / time / ...

↳ From VRP to BPP:

هيك لو حليت VRP ال ↳ distances btw Customers = 0
↳ distance btw Customers & the depot = 1/2
زي كأني حليت BPP



• VRP [just like TSP & BPP] is a Hard-to-Solve Problem which means it Cannot be solved by optimality
So we will use heuristic algorithms to solve it.

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* VRP heuristics

⇒ 3 - heuristic algorithms.

[1] TSP Partitioning heu. (route 1st cluster 2nd)

steps

1) let « T » be an optimal or near-optimal TSP tour that visit all nodes (customers) & the depot.

↳ $T = \{0, i_1, i_2, i_3, \cdots, i_n, 0\}$

2) Define the node ordering

$T_0 = [i_1, i_2, i_3, \cdots, i_n]$ → Depot بس شلنا ال

3) Create Customer Clusters by running the NF bin Packing heuristic with Customer order (demand) q_i and vehicle Capacity Q on the Customer order defined by T_0.

4) Suppose the generated Clusters are

$[i_1, i_2, \cdots, i_K]$, $[i_{K+1}, \cdots, i_L]$, $[i_{L+1}, \cdots, i_n]$

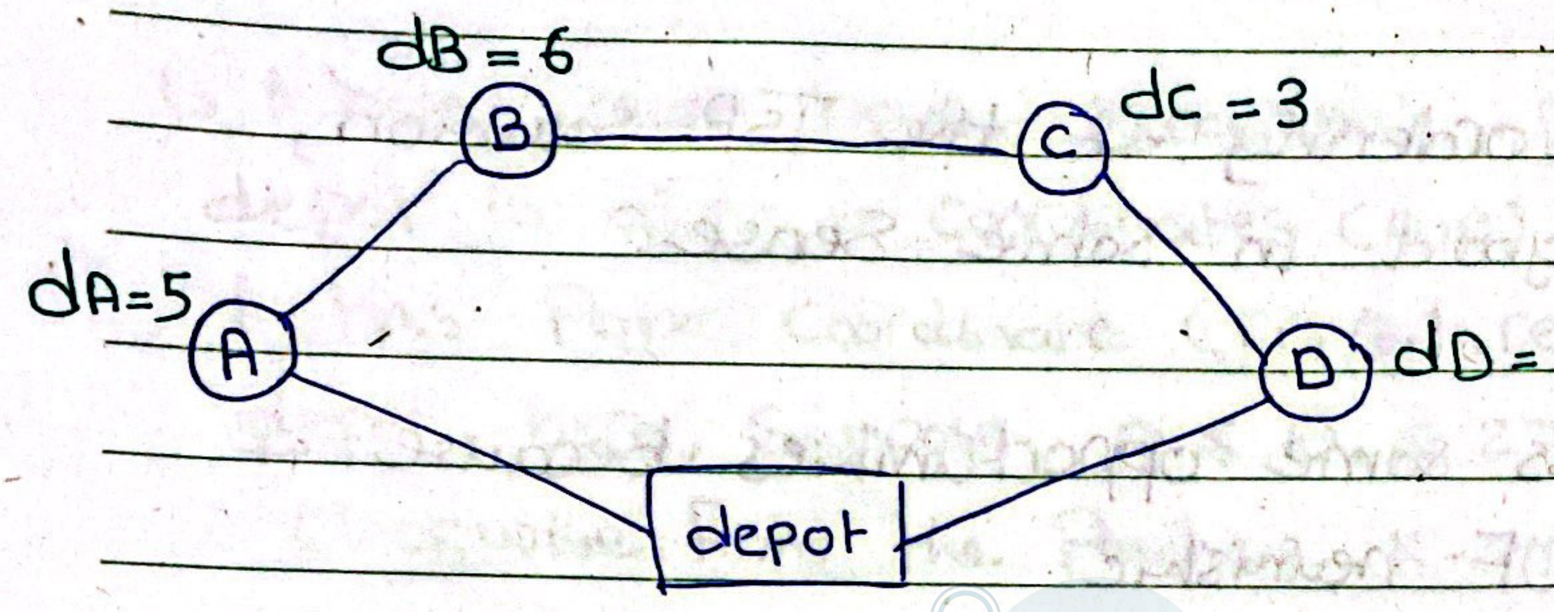
So the final VRP tours are given as :

$\{0, i_1, i_2, \cdots, i_K, 0\}$, $\{0, i_{K+1}, \cdots, i_L, 0\}$, etc...

↳ the order of Customers in the VRP tours is identical to the order in the original TSP tour #.

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example



, Q = 10 units

Sol.

step 1 : $\overline{T}$ = [depot, A, B, C, D, depot]

step 2 : $\overline{T_0}$ = [A, B, C, D]

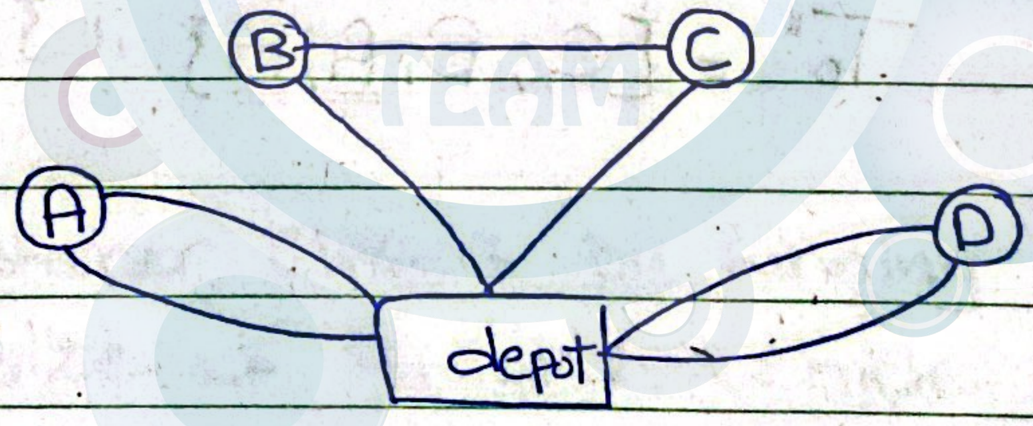
step 3 : NF

Cluster 1 = [A] ↳ $\overline{T_1}$ = [0, A, 0]

Cluster 2 = [B, C] ↳ T_2 = [0, B, C, 0]

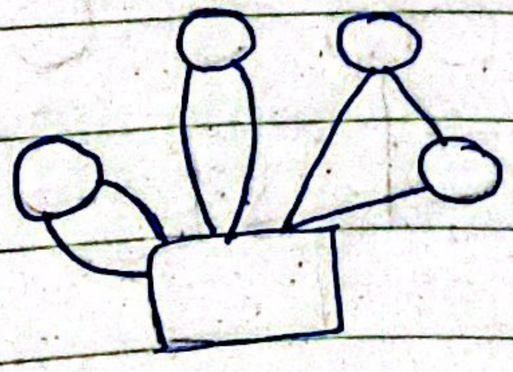
Cluster 3 = [D] ↳ T_3 = [0, D, 0]

step 4:

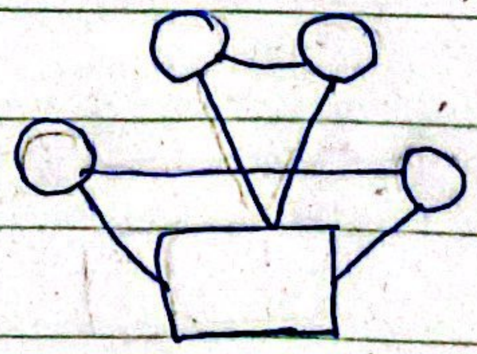


↳ 3 vehicles

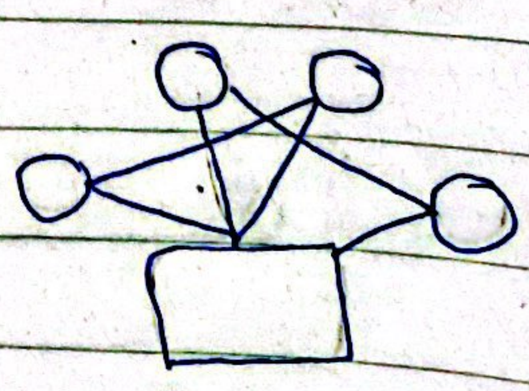
↳ other Possibilities if we didn't apply NF:



3 vehicles



2 vehicles



2 vehicles.

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* Properties of (route 1st cluster 2nd) heu. :-

① It Preserve ordering of the TSP solution, which is good in some sense

② It may miss some opportunities because of using the NF heuristic

③ It can be good as starting point for improvement heuristic

④ It Can be easily modified
↳ by changing the order of To

ex. ↳ $T_o = [A, B, C, D]$
$T_o' = [B, C, D, A]$
$T_o'' = [C, D, A, B]$

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Tuesday
3/1

[2] Sweep heuristic : Cluster 1st, Route 2nd

↳ Nodes must have geographic positions., Suppose depot is given a Coordinates (0,0) & each Customer i has Polar Coordinate (r_i, θ_i) relative to the depot. here, Suppose $0 \leq \theta_i \leq 2\pi$ is measured clockwise from the Positive x-axis.

Steps

[1] Choose a start ray, with Polar angle θ

[2] For each Customer, Calculate Δ_i as a relative angle between ray and Customer location, measured C.W.

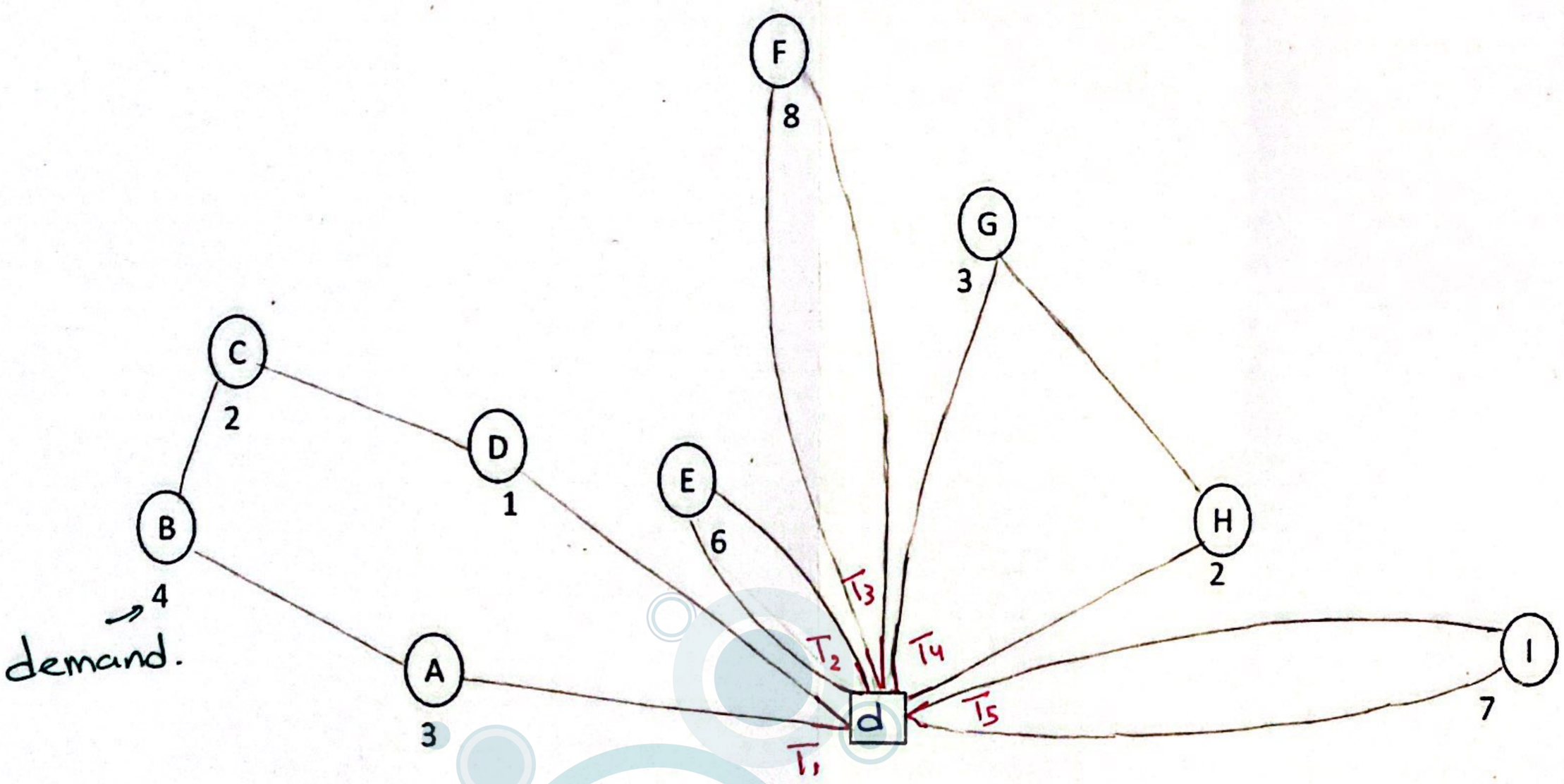
[3] Sort the Customers in order of non-decreasing Δ_i, Suppose the order created is
$T_o = \{i_1, i_2, i_3, \ldots, i_n\}$.

[4] Create Customer Clusters by running NF heuristic with lot size of q_i and vehicle Capacity of Q on the customer order defined by T_o.

[5] Create Final VRP by generating a Separate TSP tour For each Cluster and the depot.

⊕ 2 examples.

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• Prob.: Using the Sweep heu., generate Clusters of Customers each to be served by a Single vehicle. Begin with ray through Customer A, and rotate your ray clockwise. ($Q = 10$).

• Sol.

$T_0 = \{A, B, C, D, E, F, G, H, I\}$

NF Cluster 1 = {A, B, C, D} ↪ $T_1 = \{0, A, B, C, D, 0\}$

↙ = 2 = {E} ↪ $T_2 = \{0, E, 0\}$

Next = 3 = {F} ↪ $T_3 = \{0, F, 0\}$

Fit = 4 = {G, H} ↪ $T_4 = \{0, G, H, 0\}$

heu. = 5 = {I} ↪ $T_5 = \{0, I, 0\}$

application.

#

• لو أعطانا السؤال Distances بنحل TSP.

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2

Suppose you are the dispatcher for an LTL trucking firm, and you need to dispatch small delivery trucks for the local delivery of freight. Suppose you have many trucks available, each with the capacity to haul 10 tons of freight. Suppose that the polar angle (relative to the x-axis, and measured clockwise in degrees) of the seven customers are {45, 105, 220, 135, 60, 85, 300}. Suppose that the demands of the seven customers in tons are {7, 3, 4, 5, 2, 4, 6}.

Using the Sweep Heuristic, generate clusters of customers each to be served by a single vehicle. Begin with a ray through customer 1, and rotate your ray clockwise

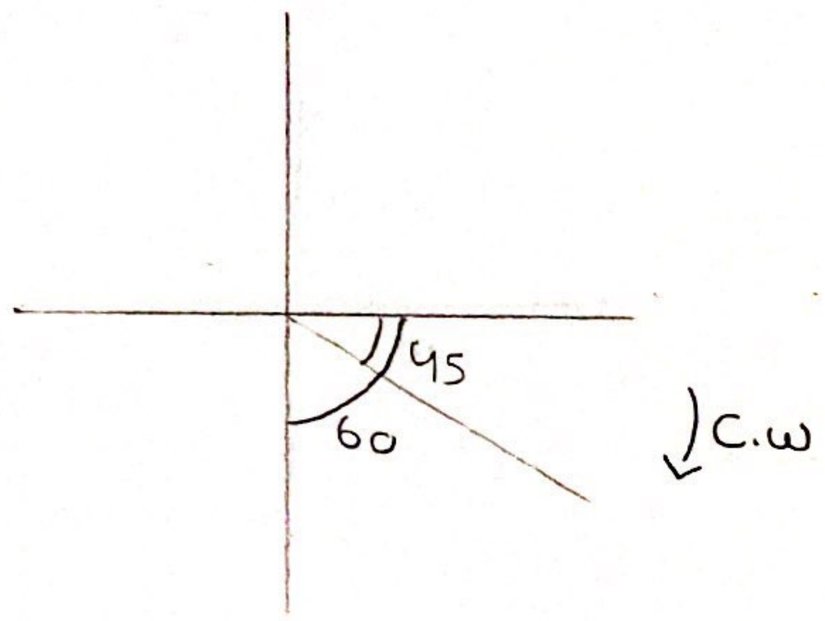
↳ given:

- Polar angles of the 7 customers

  {45 , 105 , 220 , 135 , 60 , 85 , 300}
  C_1 C_2 C_3 C_4 C_5 C_6 C_7

- Customers demands

  {7 , 3 , 4 , 5 , 2 , 4 , 6}
  C_1 C_2 C_3 C_4 C_5 C_6 C_7



Sol.

$T_0 = \{C_1, C_5, C_6, C_2, C_4, C_3, C_7\}$

NF Cluster 1 = $\{C_1, C_5\}$ → $T_1 = [0, C_1, C_5, 0]$

= 2 = $[C_6, C_2]$ → $T_2 = [0, C_6, C_2, 0]$

= 3 = $[C_4, C_3]$ → $T_3 = [0, C_4, C_3, 0]$

= 4 = $[C_7]$ → $T_4 = \{0, C_7, 0\}$.

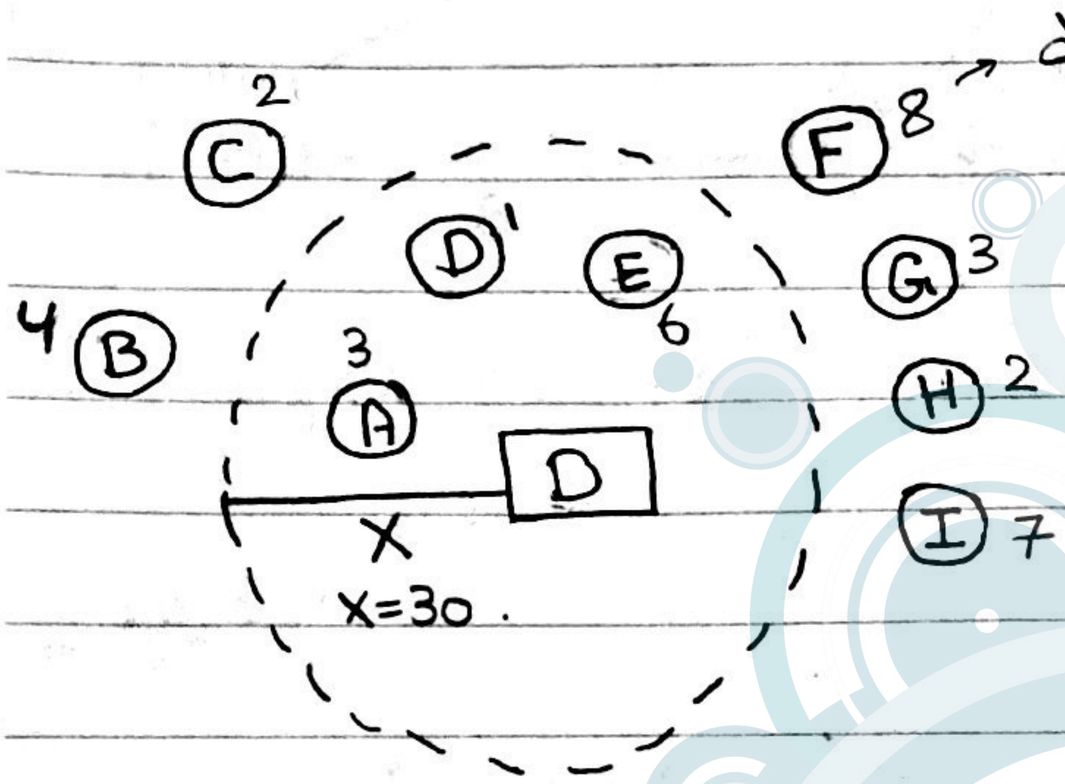
#

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⊛ Modification layered sweep.

- idea : Setup regions based on radius from depot to Customer.

then ↳ Run sweep in each region.



↳ radius « X »

لـ بنرسم دائرة من عند الـ depot بـ radius بـ given وبعدد بجرها مين الـ Customers يلي جوّا الـ region ومين برّاها.

↳ {A, D, E} → Close to the depot → region 1

↳ {B, C, F, G, H, I} → far from the depot. → region 2

↘ region كـ

NF Cluster 1 = {A, D, E}

" 2 = {B, C}

" 3 = {F}

" 4 = {G, H}

" 5 = {I}

Clustering Letters لـ

- # of Clusters = # of vehicles = # of tours.

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Sunday
8/1

↗ 3rd VRP heu.

[3] Clarke-Wright Savings Heuristic

idea : The Clarke-Wright method begins with a poor initial solution in which each vehicle visits a single customer. Tours are then combined as long as total cost savings are produced. Suppose the depot is node 0.

steps :

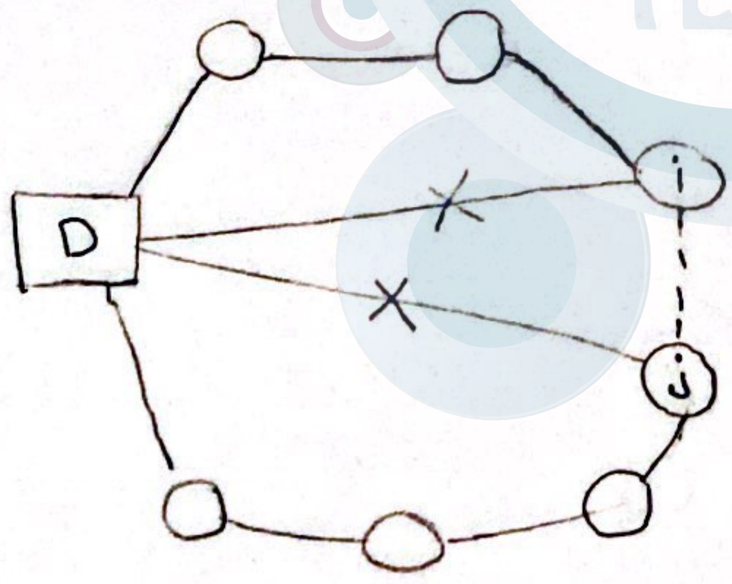
1. For each node $i \in N$, construct a tour $T_i = \{i\}$ beginning at the depot, traveling to node i, and returning to the depot. Let S be the set of tours.
2. Calculate the savings $S_{ij} = c_{0i} + c_{j0} - c_{ij}$ for all pairs of nodes i, j.
3. Sort the savings in nonincreasing order.
4. Walk down the savings combination list, and find the next feasible combination pair (i, j) such that:
   (a) i and j are on different tours, and i is the last node on its tour T_k and j is the first node on its tour T_ℓ.
   Capacity ← (b) $\sum_{k \in T_i \cup T_j} q_k \leq Q$.
   Saving , LP ← (c) $S_{ij} \geq 0$

⇒ Add the combined tour $T_i + T_j$ to S, and remove T_i and T_j. Repeat this step as long as feasible combinations remain in the savings list.

arcs removed arc added

- Savings → $S_{ij} = C_{0i} + C_{j0} - C_{ij}$

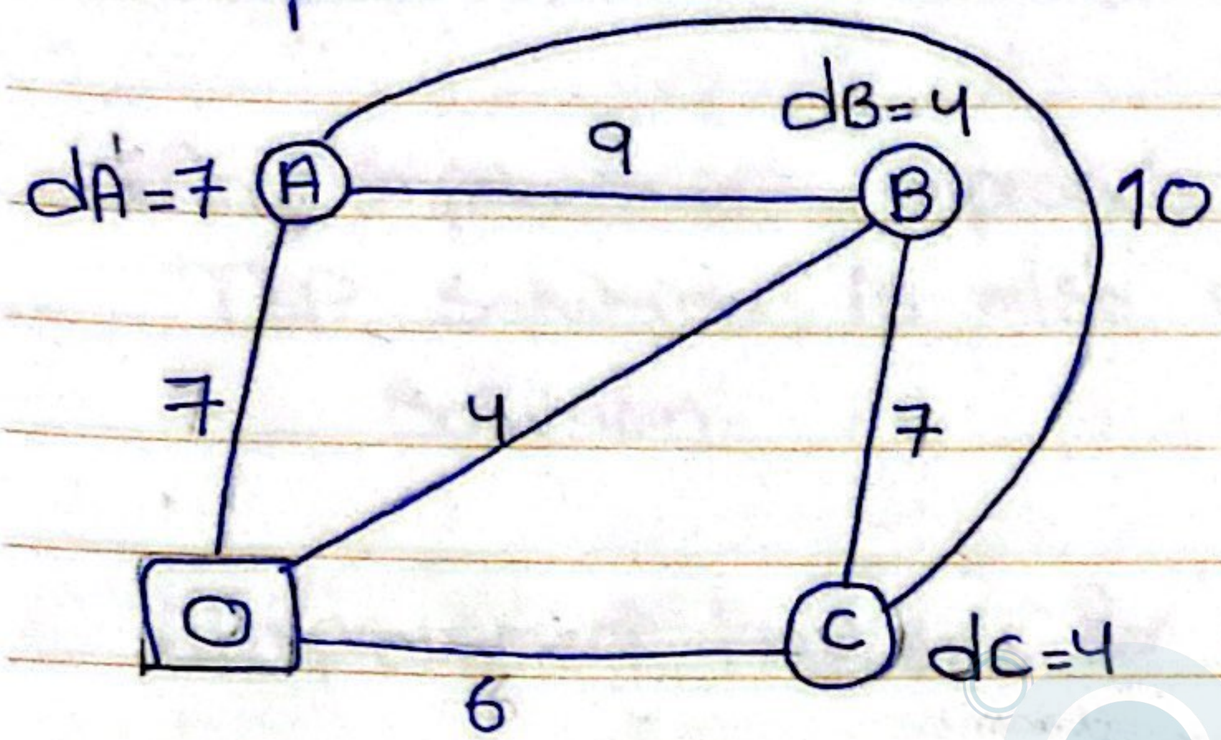
⇒



+ example

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example 2-



Q = 70 (truck Capacity)
d = demand
node = Customer.

↳ apply clarke - wright heuristic

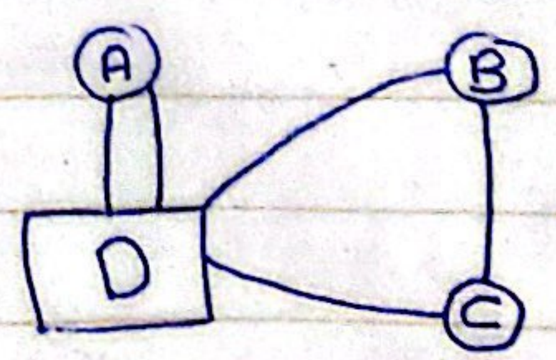
Sol :-

- $T_A = [O, A, O]$
  $T_B = [O, B, O]$
  $T_C = [O, C, O]$
  ] ↳ our initial Poor Solution.
  ↳ يعني هو انه بكل Tour بنطلع من ال depot لعند Customer واحد بس ونرجع.

- $S_{AB} = C_{OA} + C_{OB} - C_{AB} = 2$
  $S_{AC} = C_{OA} + C_{OC} - C_{AC} = 3$
  $S_{BC} = C_{OB} + C_{OC} - C_{BC} = 3$
  ] Savings for all Combinations.

- we will choose either BC or AC, depending on Capacity
  → we can't Combine A&C because $d_A + d_C > 70$
  → // Can only Combine B&C → $d_B + d_C < 70$

- $T_A = [O, A, O]$
  $T_{BC} = [O, B, C, O]$ →
  ↳ Cost = 31 #



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⊛ other improvements approaches for VRP

- Any improvement approach that we apply for Tsp Solution is also applicable for VRP Solution.

- Improvement heuristics for VRP :-

[1] Insert (i, j)

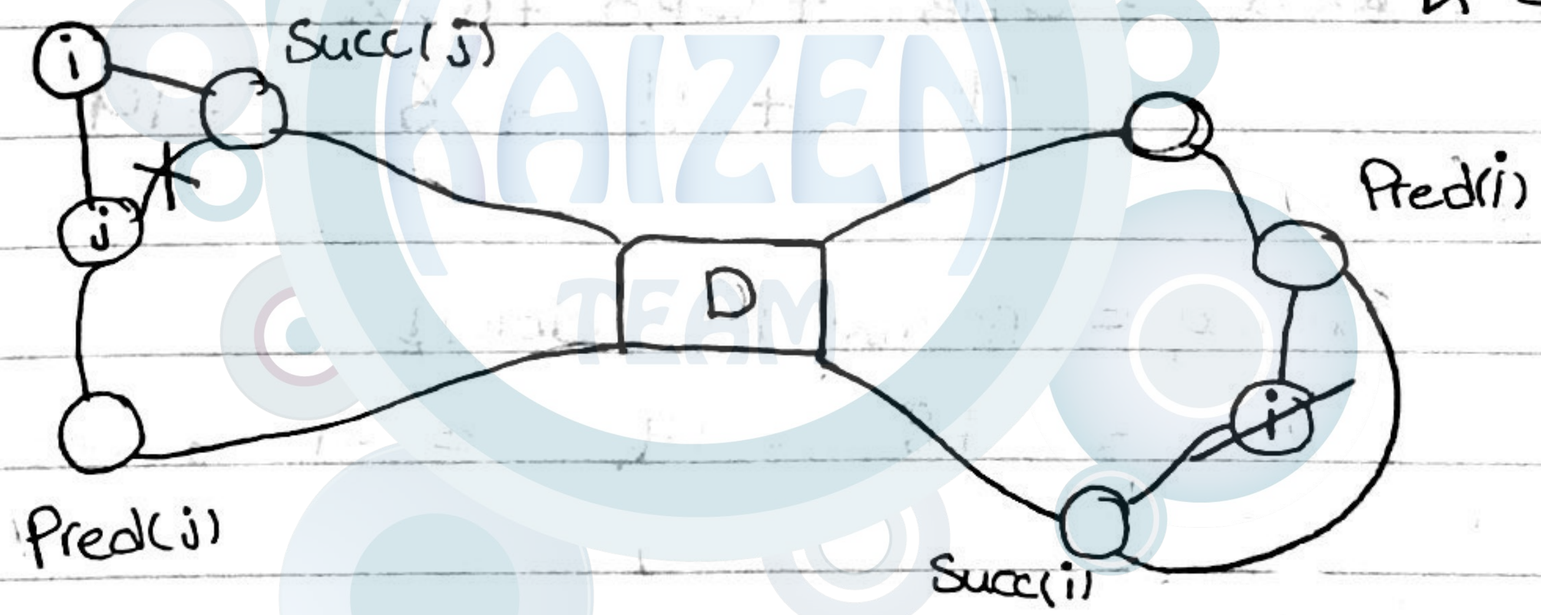
Steps 1) Remove customer (i) from the current tour.

2) Insert customer (i) between j and succ(j)

↳ Successor

↳ only applicable if satisfies Capacity Constraint.

& Saving



$$\text{Cost Removed} = C_{pred(i),i} + C_{i,succ(i)} + C_{j,succ(j)}$$

$$\text{Cost Added} = C_{pred(i),succ(i)} + C_{ji} + C_{i,succ(j)}$$

$$\text{Saving} = \text{Cost removed} - \text{Cost added.}$$

- Pred = Predecessor
  Succ = Successor

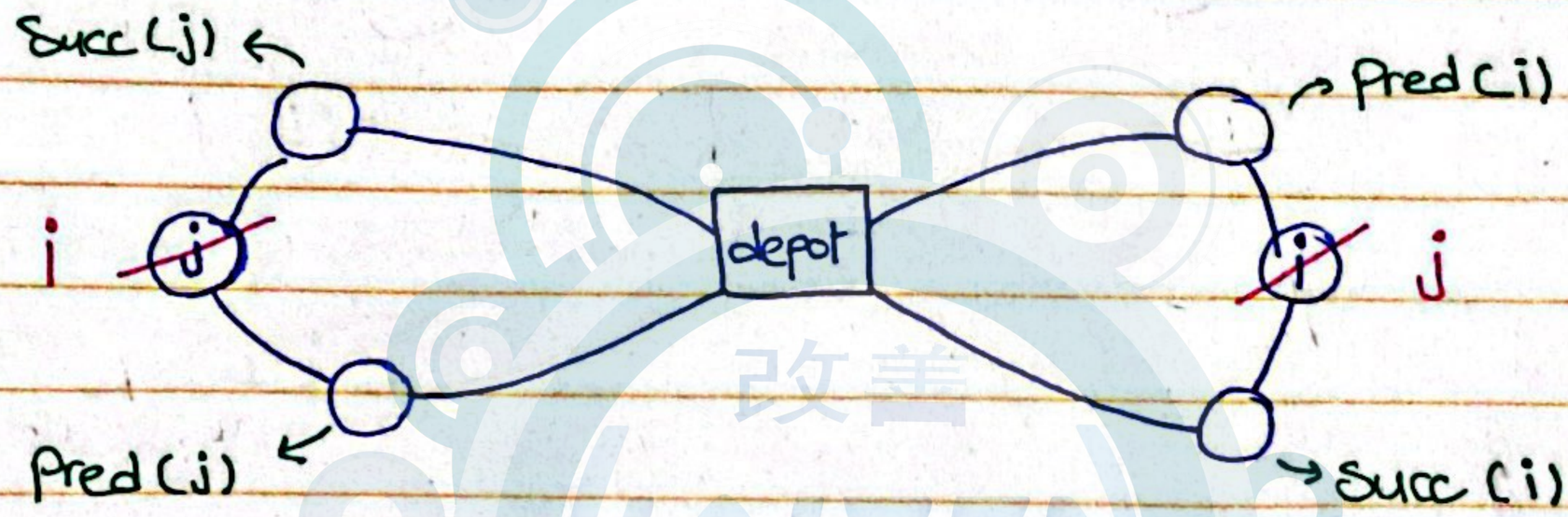
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[2] Swap (i, j)

↳ Move customer i to customer j's position, and
j to customer i's position

↳ must satisfy Capacity Constraint

↳ Saving :-



Cost Removed = $C_{pred(i),i} + C_{i,succ(i)} + C_{pred(j),j} + C_{j,succ(j)}$

Cost Added = $C_{pred(i),j} + C_{j,succ(i)} + C_{pred(j),i} + C_{i,succ(j)}$

Saving = Cost Removed − Cost Added.

##

Done.

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