Introduction to Spatial Computing CSE 5ISC

Spatial Networks

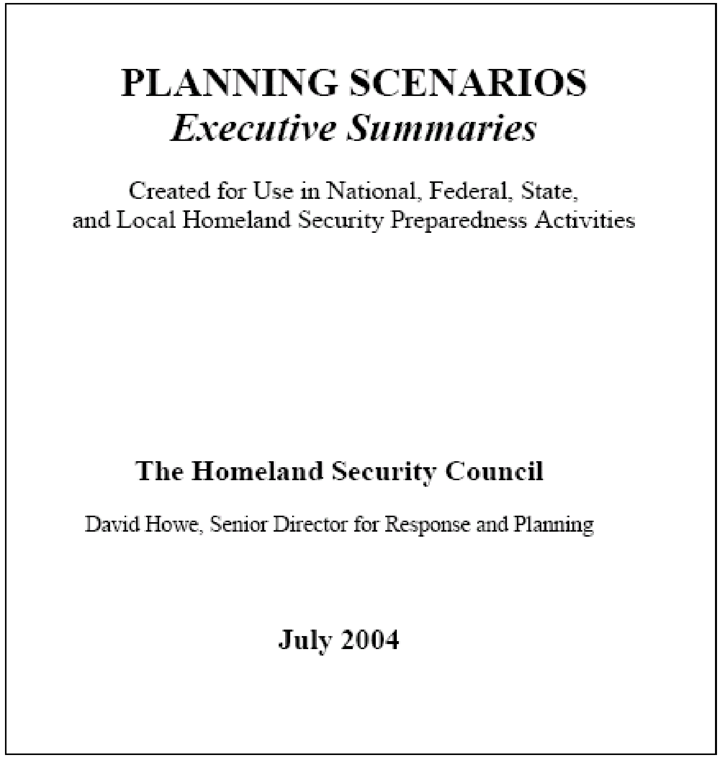
Some slides adapted from *Shashi Shekhar, University of Minnesota*

Evacuation Route Planning

Motivational Scenarios

- ***Large Scale evacuation due to Natural Events***
  - E.g., hurricane evacuations
- ***Evacuation scenarios for cities with nuclear power plants***
- ***Other scenarios***
  - E.g., Building evacuations and other places of large gatherings e.g., Hajj

Hurricane Sandy New York 2012



PLANNING SCENARIOS

Executive Summaries

Created for Use in National, Federal, State, and Local Homeland Security Preparedness Activities

The Homeland Security Council

David Howe, Senior Director for Response and Planning

July 2004

TWIN CITIES METRO EVACUATION PLAN

TECHNICAL MEMORANDUM #1

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Problem Definition

- **Given**
  - A transportation network represented as a spatial network (G= (N,E)) with
  - Capacity constraint for each edge and node
  - Travel time for each edge
  - Number of evacuees and their initial locations
  - Evacuation destinations
- **Output**
  - Evacuation plan consisting of a set of origin-destination routes
  - and a scheduling of evacuees on each route.
- **Objective**
  - Minimize evacuation egress time
  - Which is time from start of evacuation to last evacuee reaching a destination
- **Constraints**
  - Route scheduling should observe **capacity constraints** of network
  - Reasonable computation time despite limited computer memory
  - Capacity constraints and travel times are non-negative integers
  - Evacuees start from and end up at nodes

A Note on Objective Function

Why minimize evacuation time?

- Reduce exposure time to evacuees
- Since harm due to many hazards increase with exposure time!

Why minimize computation time ?

- **During Evacuation**
  - Unanticipated events
    - Bridge Failure due to Katrina, 100-mile traffic jams due to Rita
  - Plan new evacuation routes to respond to events
  - Contra-flow based plans, i.e., reverse lane directions based on needs

- **During Planning**
  - Explore a large number of scenarios Based on
  - Transportation Modes
  - Event location and time

Interpreting the notion of Capacity

- Capacity of an edge can be interpreted in two ways.
- The algorithm still holds in applicability,
- But of course the final answer (evacuation schedules) would be different.

Following are two ways to interpret capacity:

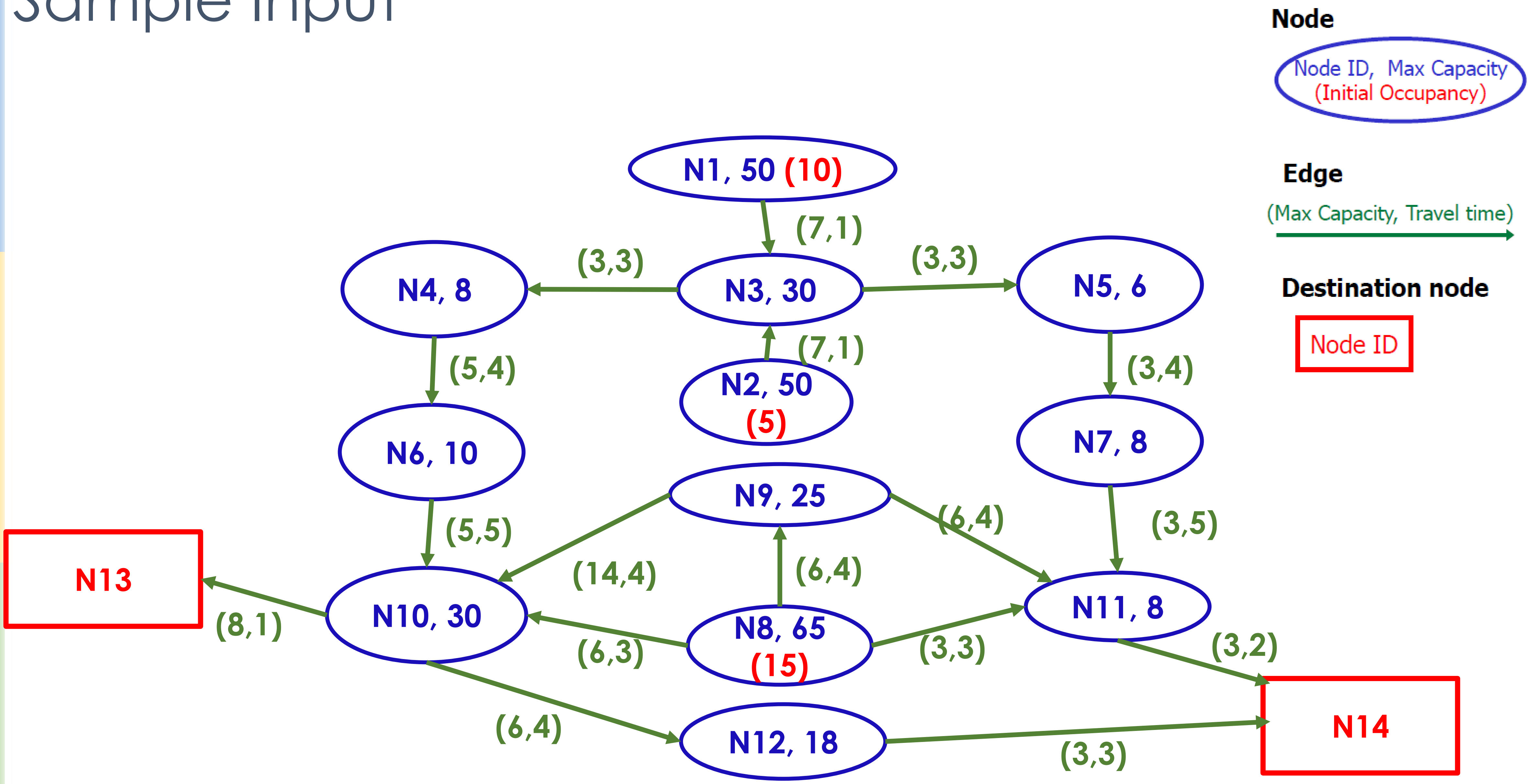
(1) Capacity as "number of lanes in the road"

- Here capacity denotes the number of people who can start off a particular point at the same time.
- You also need a "lag parameter" which denotes the lag after which next batch of people can be sent out. In these slides lag param is 1 time unit.

(2) Total number of people that are going to occupy the road for a certain duration

- If capacity is 10 and stated duration is 5 mins.
- Then it means that if we send out 10 people at t=0, we cannot send more people until t=5.
- This is interpretation can be derived from (1) though integration and some assumptions.

Sample Input



Evacuation Plan for Input on Previous Slide

Group of Evacuee			Route with Schedule	Dest. Time
ID	Source	No. of Evacuees		
A	N8	6	N8(T0)-N10(T3)-N13	4
B	N8	6	N8(T1)-N10(T4)-N13	5
C	N8	3	N8(T0)-N11(T3)-N14	5
D	N1	3	N1(T0)-N3(T1)-N4(T4)-N6(T8)-N10(T13)-N13	14
E	N1	3	N1(T0)-N3(T2)-N4(T5)-N6(T9)-N10(T14)-N13	15
F	N1	1	N1(T0)-N3(T1)-N5(T4)-N7(T8)-N11(T13)-N14	15
G	N2	2	N2(T0)-N3(T1)-N5(T4)-N7(T8)-N11(T13)-N14	15
H	N2	3	N2(T0)-N3(T3)-N4(T6)-N6(T10)-N10(T15)-N13	16
I	N1	3	N1(T1)-N3(T2)-N5(T5)-N7(T9)-N11(T14)-N14	16

Image Courtesy: Shashi Shekhar, UMN

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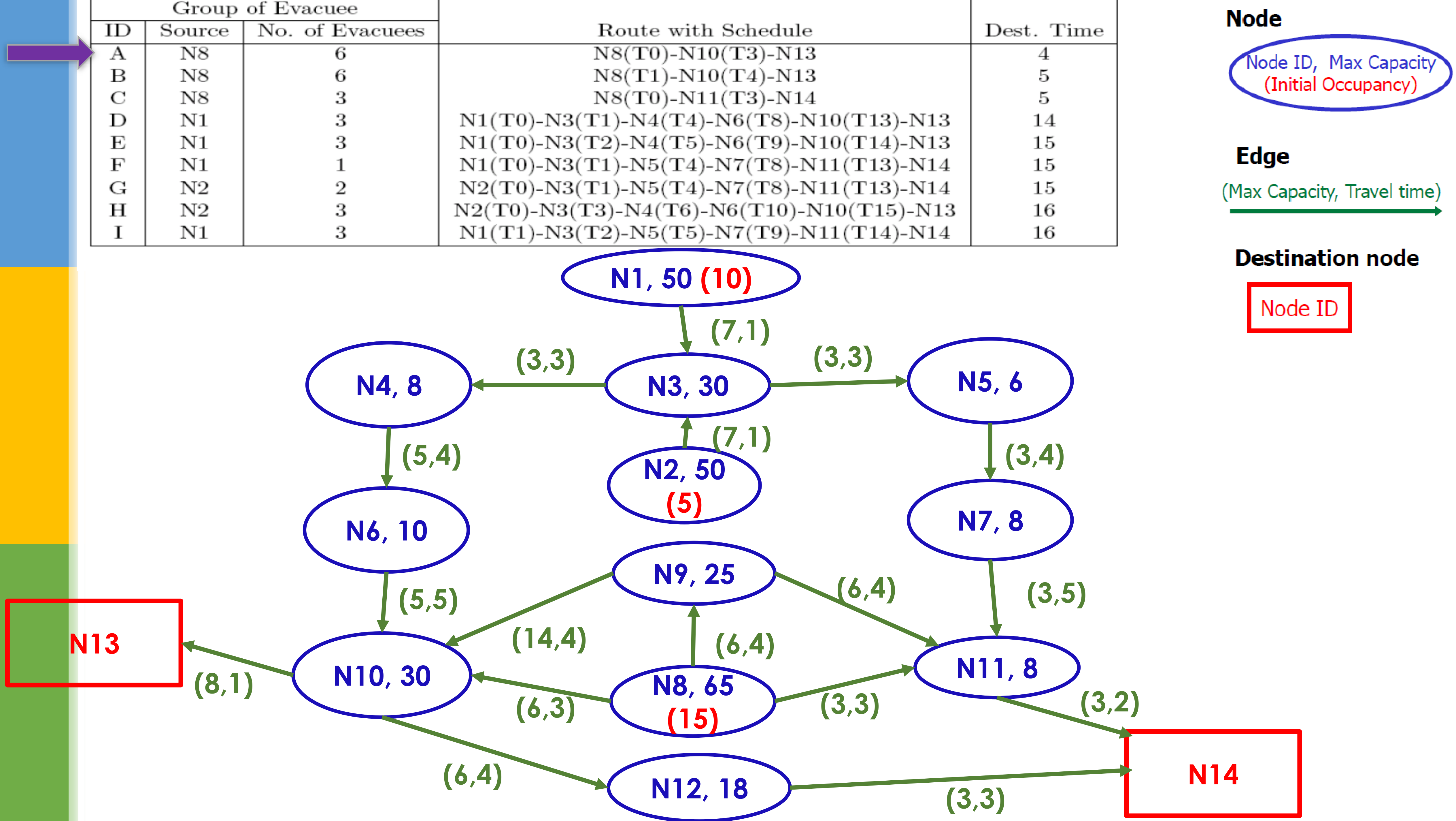

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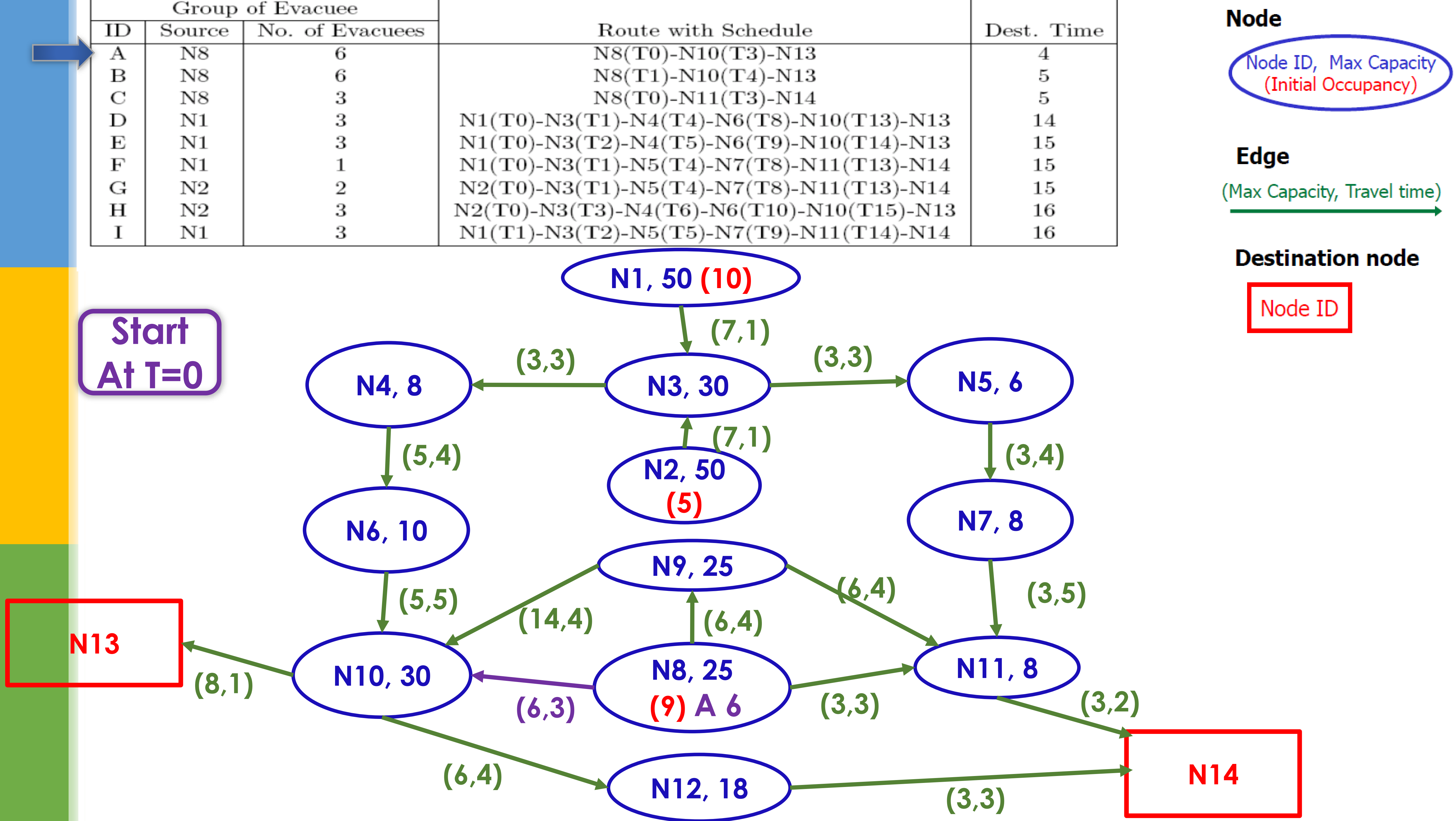

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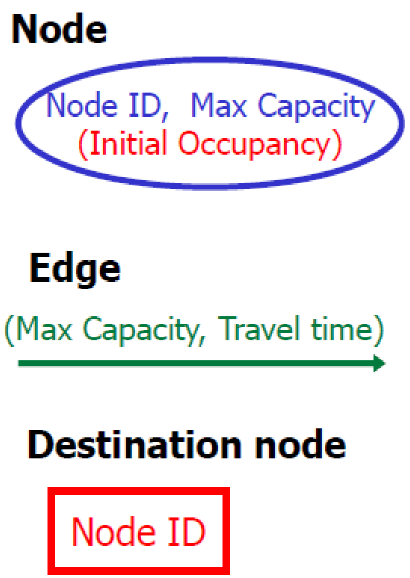

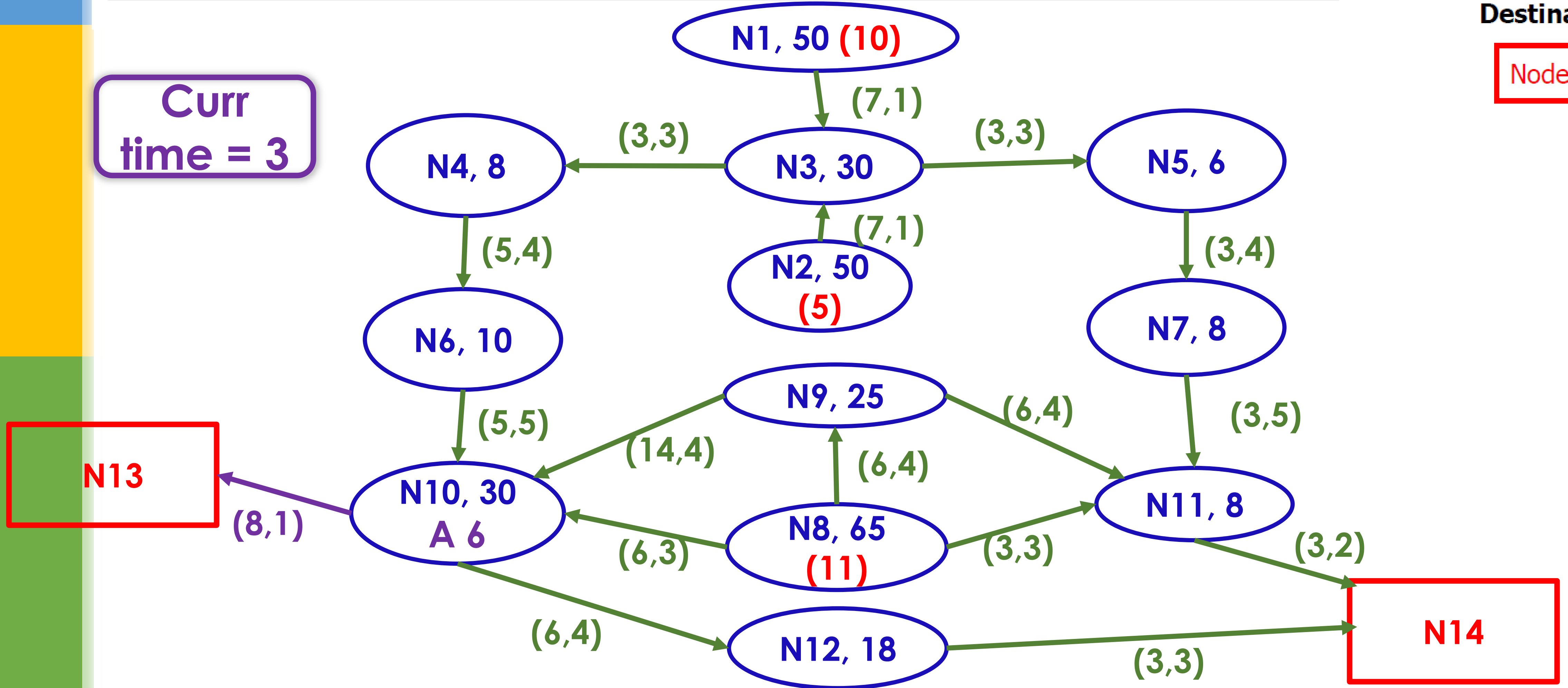

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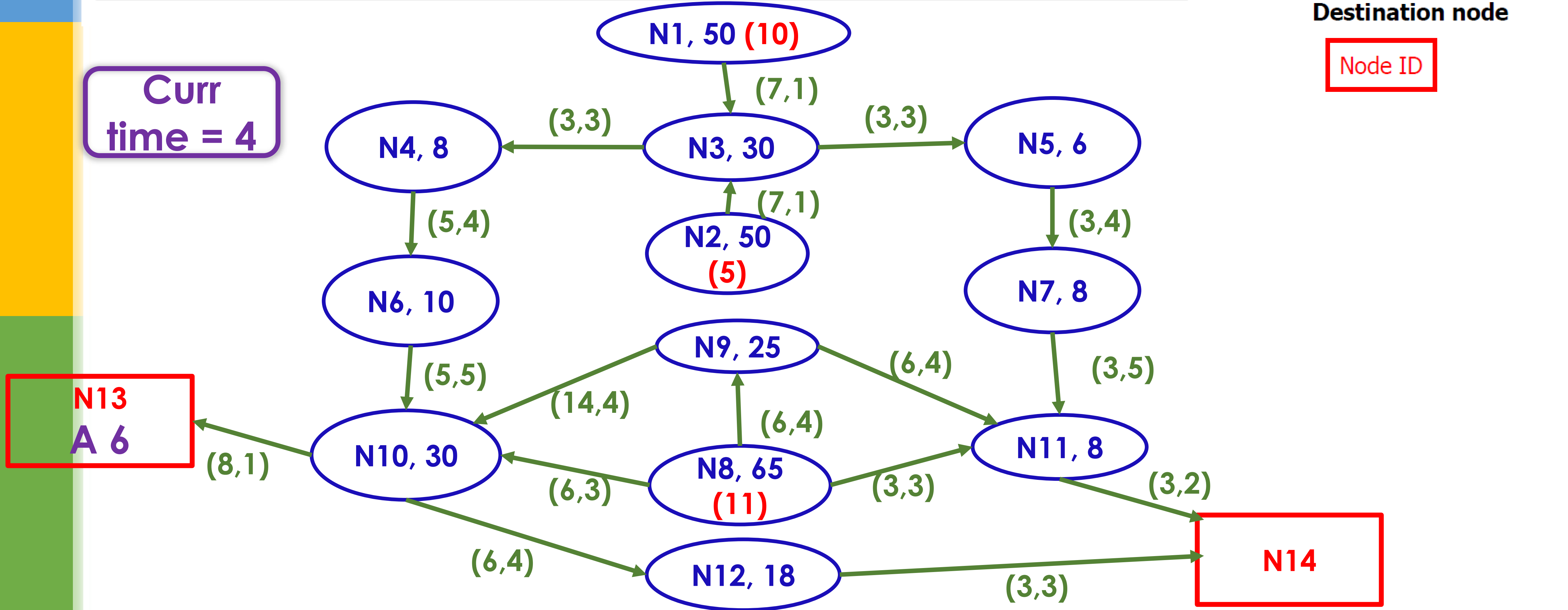


Limitations of Previous Works

A. Capacity-ignorant Approach

- Simple shortest path computation, e.g. A*, Dijktra's, etc.
- e.g. EXIT89 (National Fire Protection Association)

Limitation: Poor solution quality as evacuee population grows

B. Operations Research: Time-Expanded Graph + Linear Programming

- Optimal solution, e.g. EVACNET (U. FL), Hoppe and Tardos (Cornell U).

Limitation: - High computational complexity => Does not scale to large problems

- Users need to guess an upper bound on evacuation time

Inaccurate guess => either no solution or increased computation cost!

C. Transportation Science: Dynamic Traffic Assignment

- Game Theory: Wardrop Equilibrium, e.g. DYNASMART (FHWA), DYNAMIT(MIT)

Limitation: Extremely high compute time

- Is Evacuation an equilibrium phenomena?

Capacity Constrained Route Planer (CCRP)

Key Ideas for CCRP

Time-series attributes

Available_Node_Capacity (Ni , t)

= *#additional evacuees that can stay at* node *Ni* at time *t*

Available_Edge_Capacity (Ni -Nj , t)

= #additional evacuess that may travel via edge *Ni -Nj* at time *t*

Generalize shortest path algorithms to

- Honor capacity constraints
- Spread people over space and time

Capacity Constrained Route Planer (CCRP)

While (any source node has evacuees) do

Step 1: Find nearest pair (Source S, Destination D), based on current available capacity of nodes and edges. Note that this is the path with the earliest arrival time at a destination (starting from t=0). Also it may happen that people may have to wait at source to get the path with earliest arrival at destination.

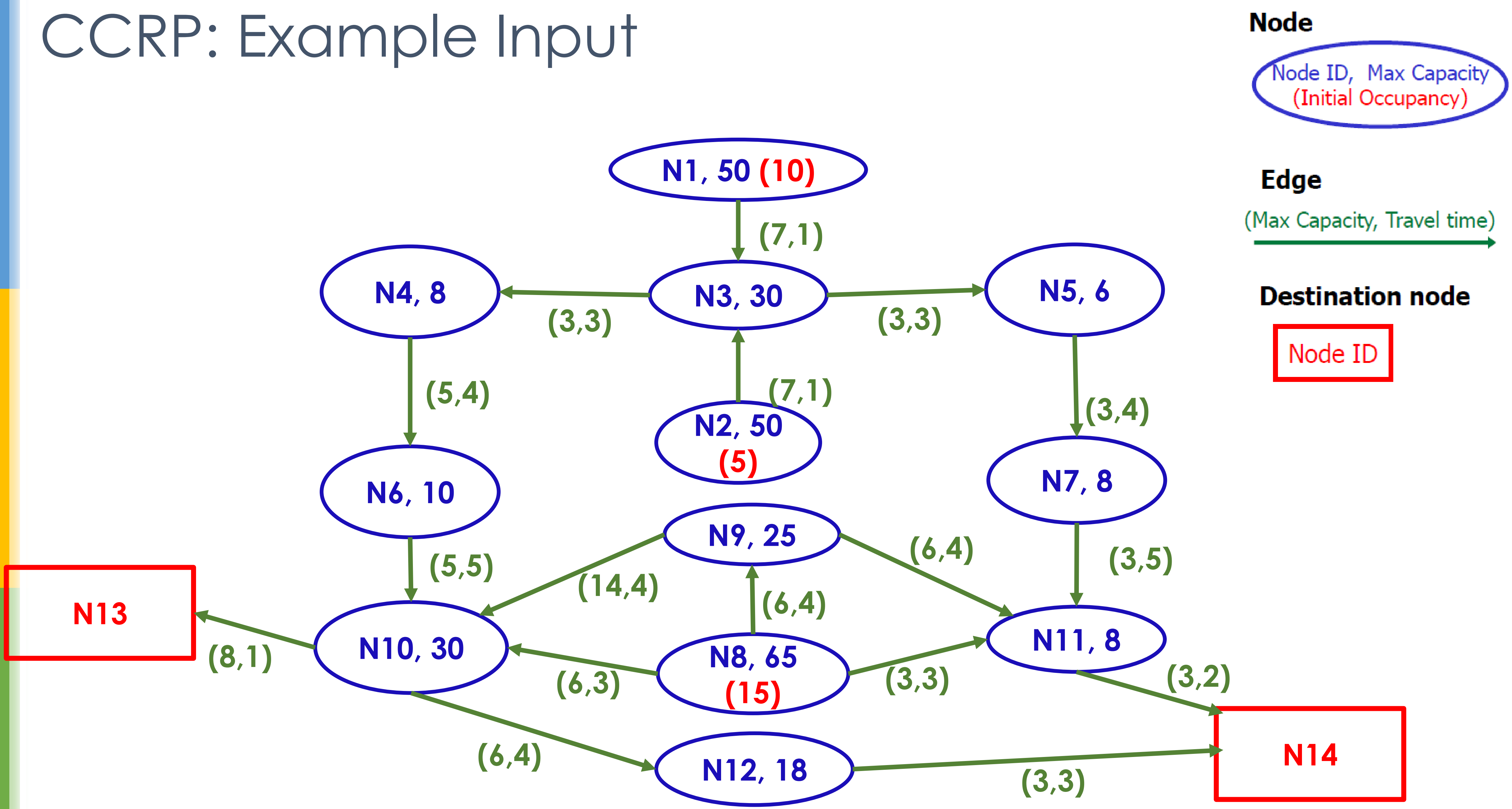
Step 2: Compute available flow on shortest route ***R (S,D)***

flow **= min { number of current evacuees at S ,**
Available_Edge_Capacity**(any edges on R),**
Available_Node_Capacity**(any nodes on R) }**

Step 3: Make reservation of capacity on route ***R***

Available capacity of each edge on *R* reduced by *flow*
Available capacity of each incoming nodes on *R* reduced by *flow*

CCRP: Example Input



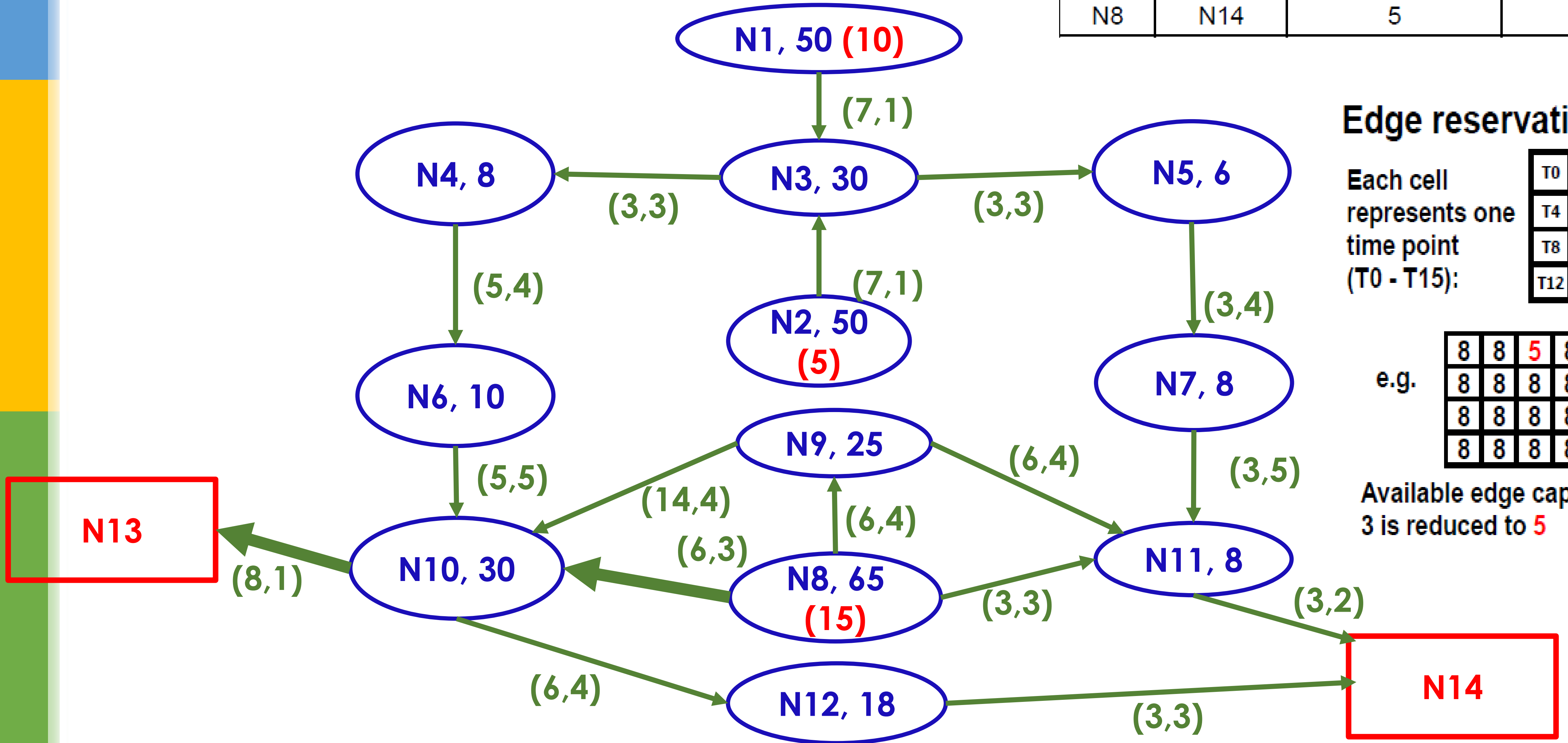
CCRP: Example Input : Iteration 1

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	4	6
N8	N14	5	3

N8 ➡ N10 ➡ N13

#Evacuees = 6

Quickest route between Source and Destination



Edge reservation table:

Each cell represents one time point (T0 - T15):

T0	T1	T2	T3
T4	T5	T6	T7
T8	T9	T10	T11
T12	T13	T14	T15

e.g.

8	8	5	8
8	8	8	8
8	8	8	8
8	8	8	8

Available edge capacity at time 3 is reduced to 5

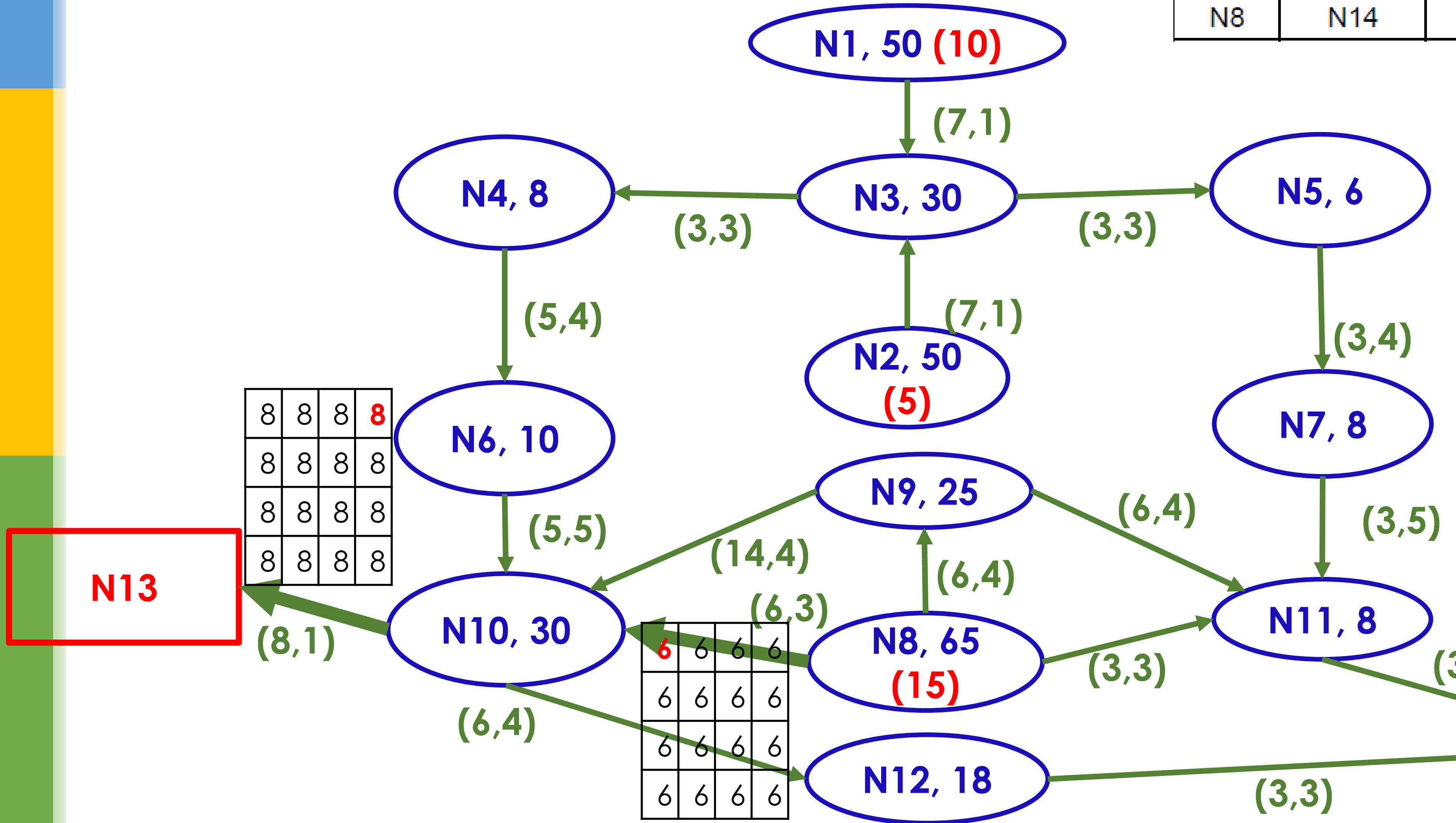
CCRP: Example Input : Iteration 1

N8 ➡ N10 ➡ N13

#Evacuees = 6

Quickest route between Source and Destination

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	4	6
N8	N14	5	3



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e.g.

8	8	5	8
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Available edge capacity at time 3 is reduced to 5

CCRP: Example Input : Iteration 1

N8 → N10 → N13

Quickest route between Source and Destination

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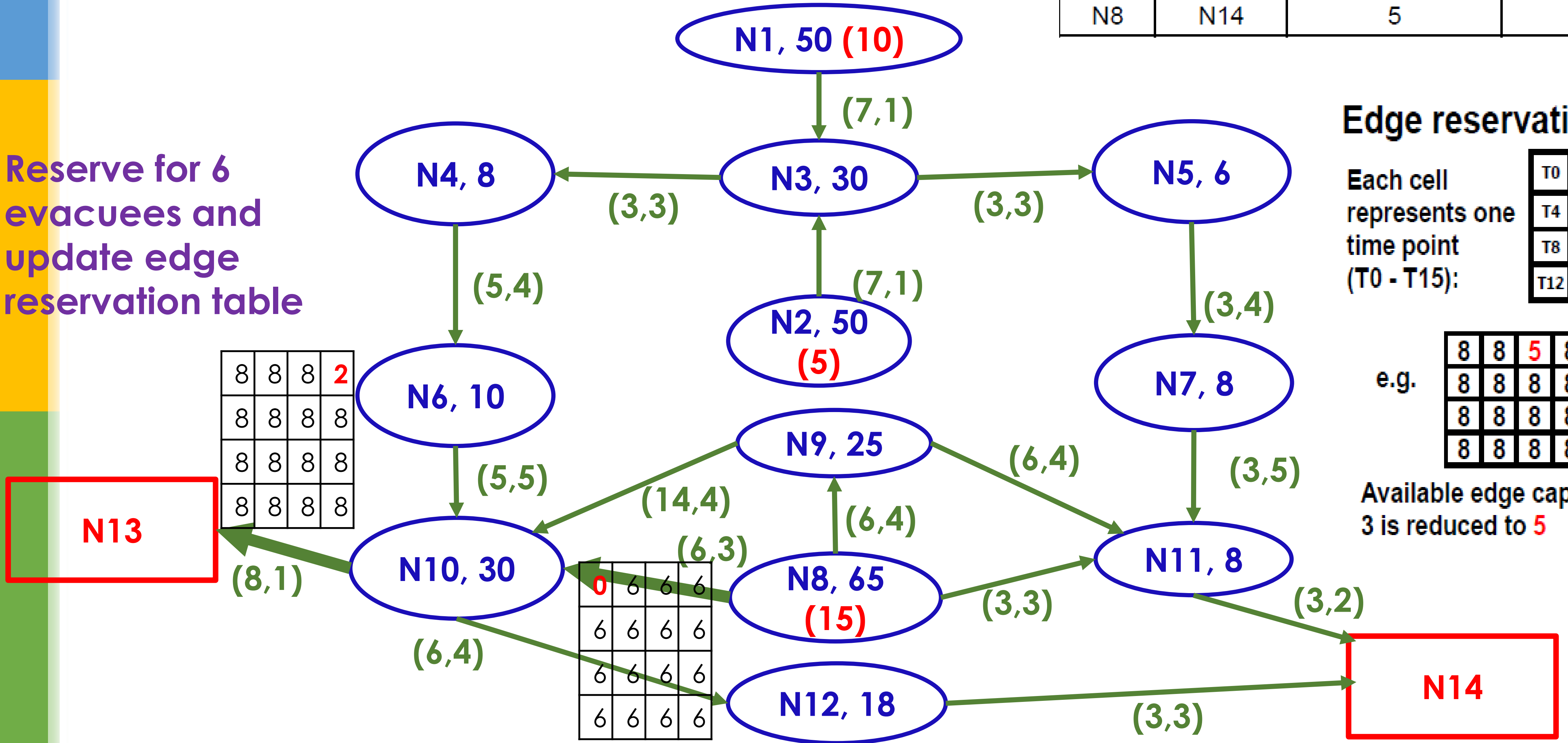
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	4	6
N8	N14	5	3

Reserve for 6 evacuees and update edge reservation table



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Each cell represents one time point (T0 - T15):

T0	T1	T2	T3
T4	T5	T6	T7
T8	T9	T10	T11
T12	T13	T14	T15

e.g.

8	8	5	8
8	8	8	8
8	8	8	8
8	8	8	8

Available edge capacity at time 3 is reduced to 5

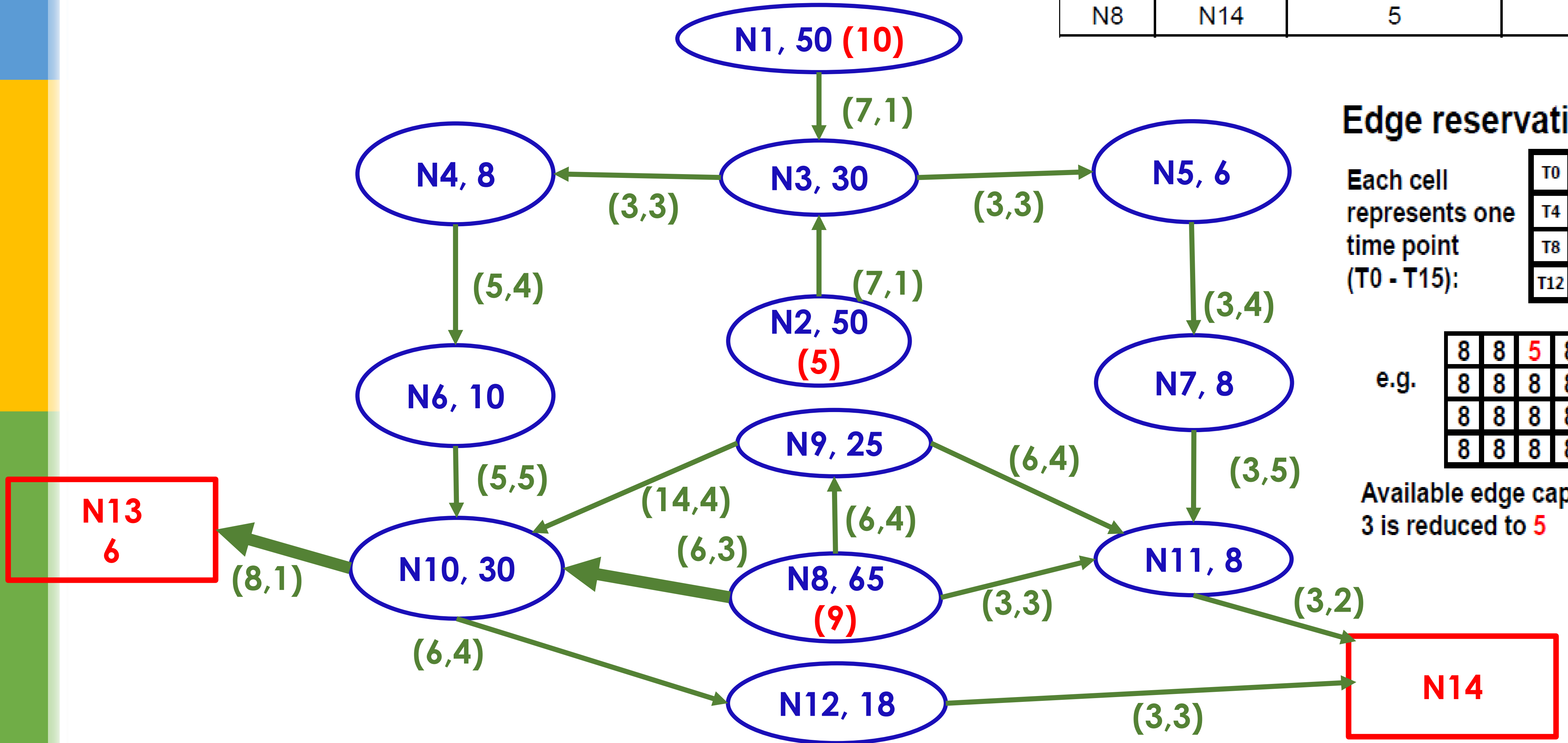
CCRP: Example Input : Iteration 1

N8 ➡ N10 ➡ N13

#Evacuees = 6

Quickest route between Source and Destination

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	4	6
N8	N14	5	3



Edge reservation table:

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T0	T1	T2	T3
T4	T5	T6	T7
T8	T9	T10	T11
T12	T13	T14	T15

e.g.

8	8	5	8
8	8	8	8
8	8	8	8
8	8	8	8

Available edge capacity at time 3 is reduced to 5

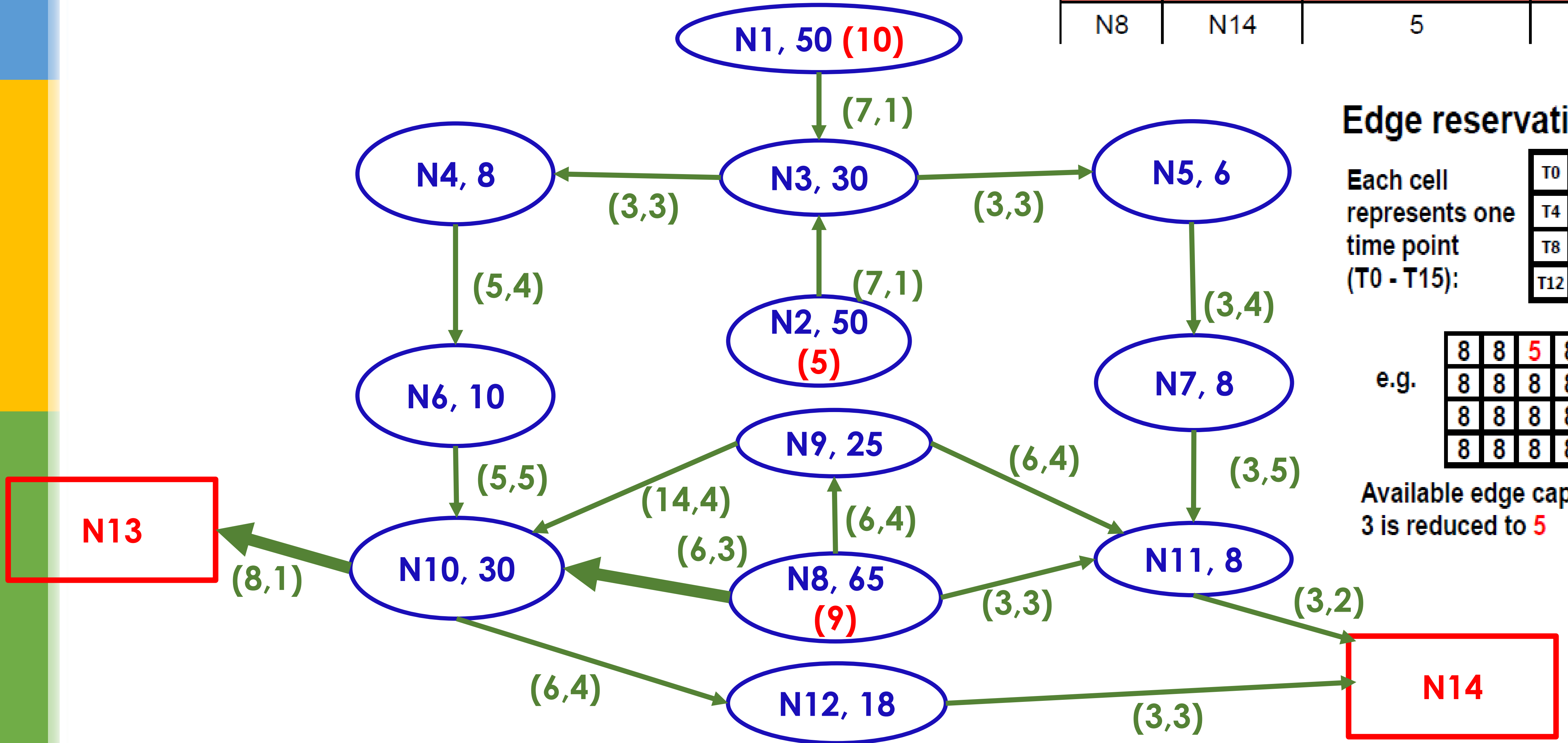
CCRP: Example Input : Iteration 2

N8 ➡ N10 ➡ N13

#Evacuees = 6

Quickest route between Source and Destination

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	5	6
N8	N14	5	3



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T0	T1	T2	T3
T4	T5	T6	T7
T8	T9	T10	T11
T12	T13	T14	T15

e.g.

8	8	5	8
8	8	8	8
8	8	8	8
8	8	8	8

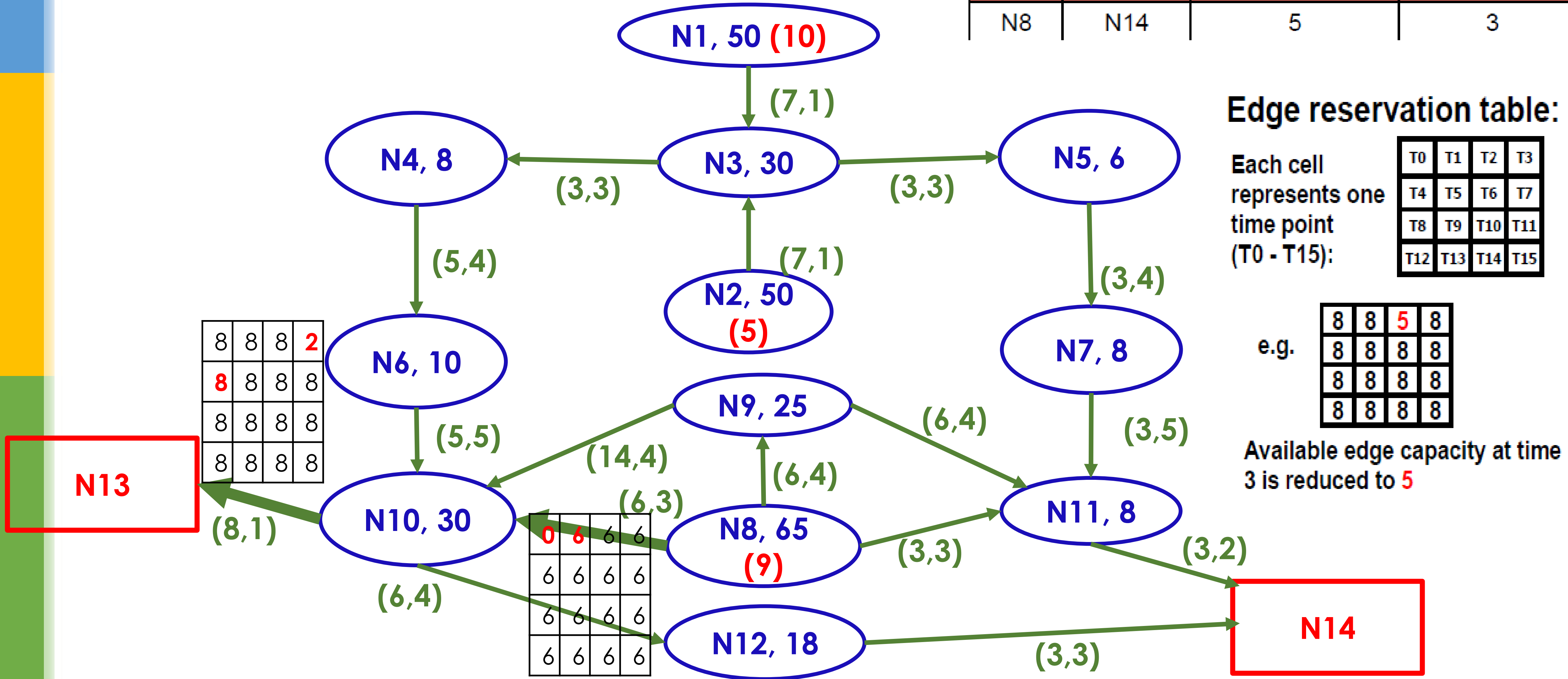
Available edge capacity at time 3 is reduced to 5

CCRP: Example Input : Iteration 2

N8 ➡ N10 ➡ N13

Quickest route between Source and Destination

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	5	6
N8	N14	5	3



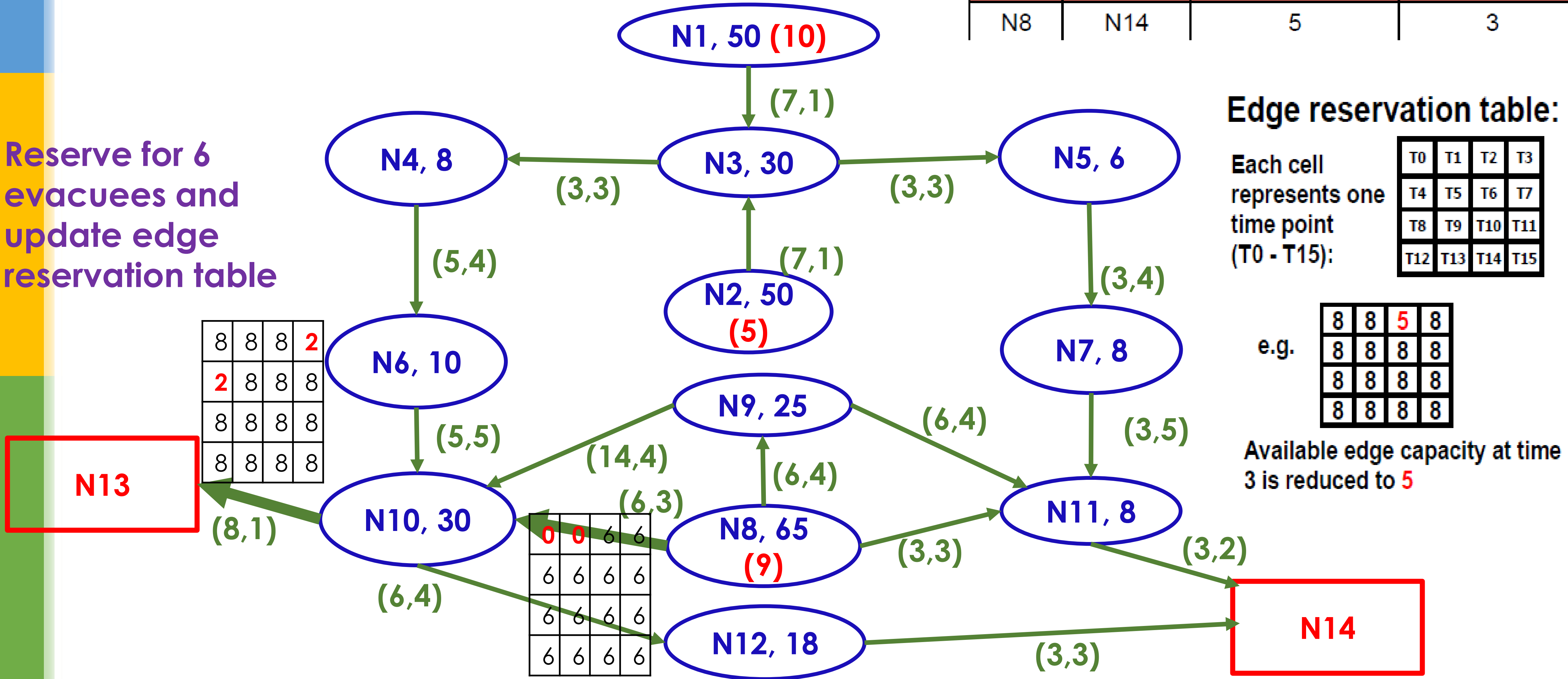
CCRP: Example Input : Iteration 2

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	5	6
N8	N14	5	3

N8 → N10 → N13

#Evacuees = 6

Quickest route between Source and Destination



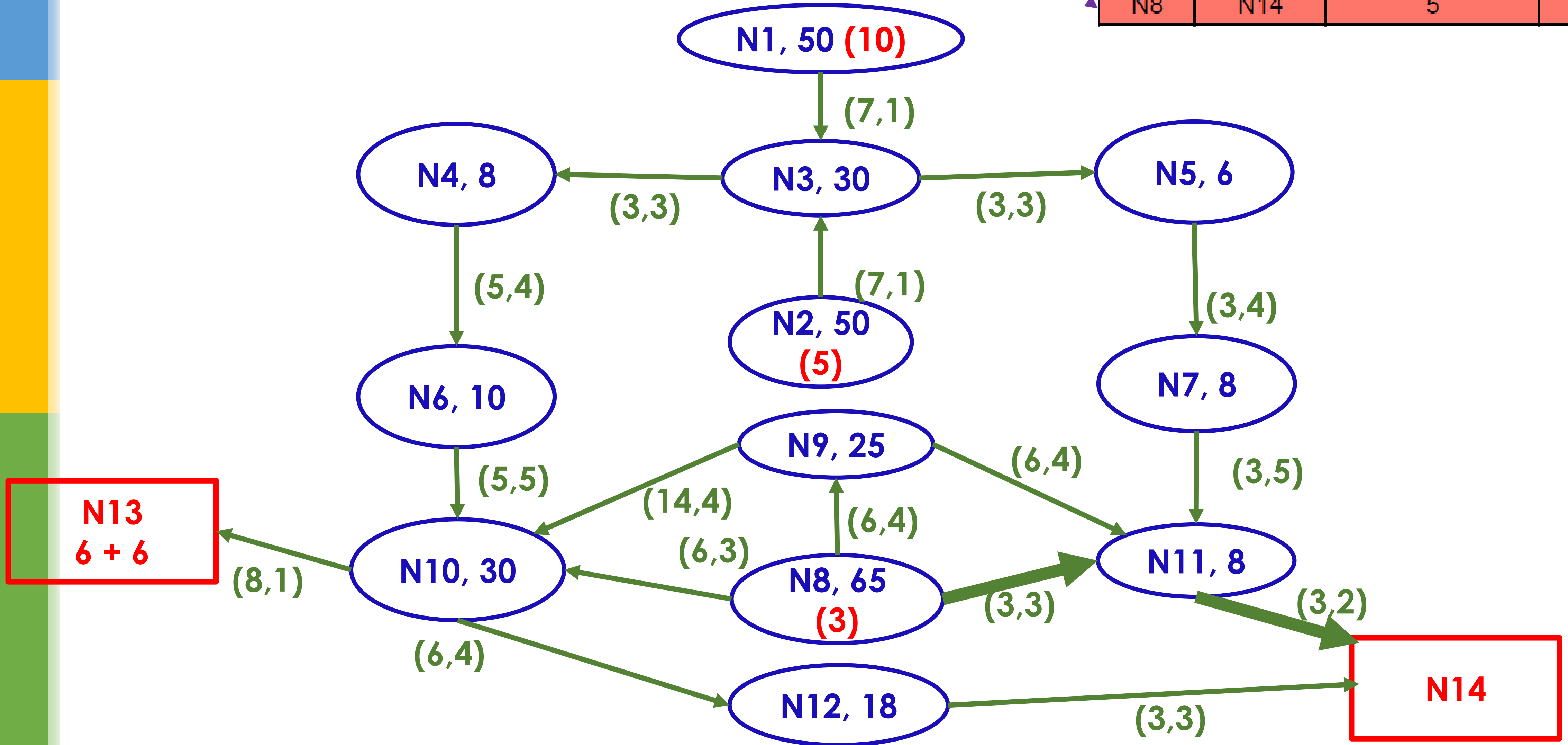
CCRP: Example Input : Iteration 3

N8 ➡ N11 ➡ N14

#Evacuees = 3

Quickest route between Source and Destination

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3
N8	N13	6	3
N8	N14	5	3



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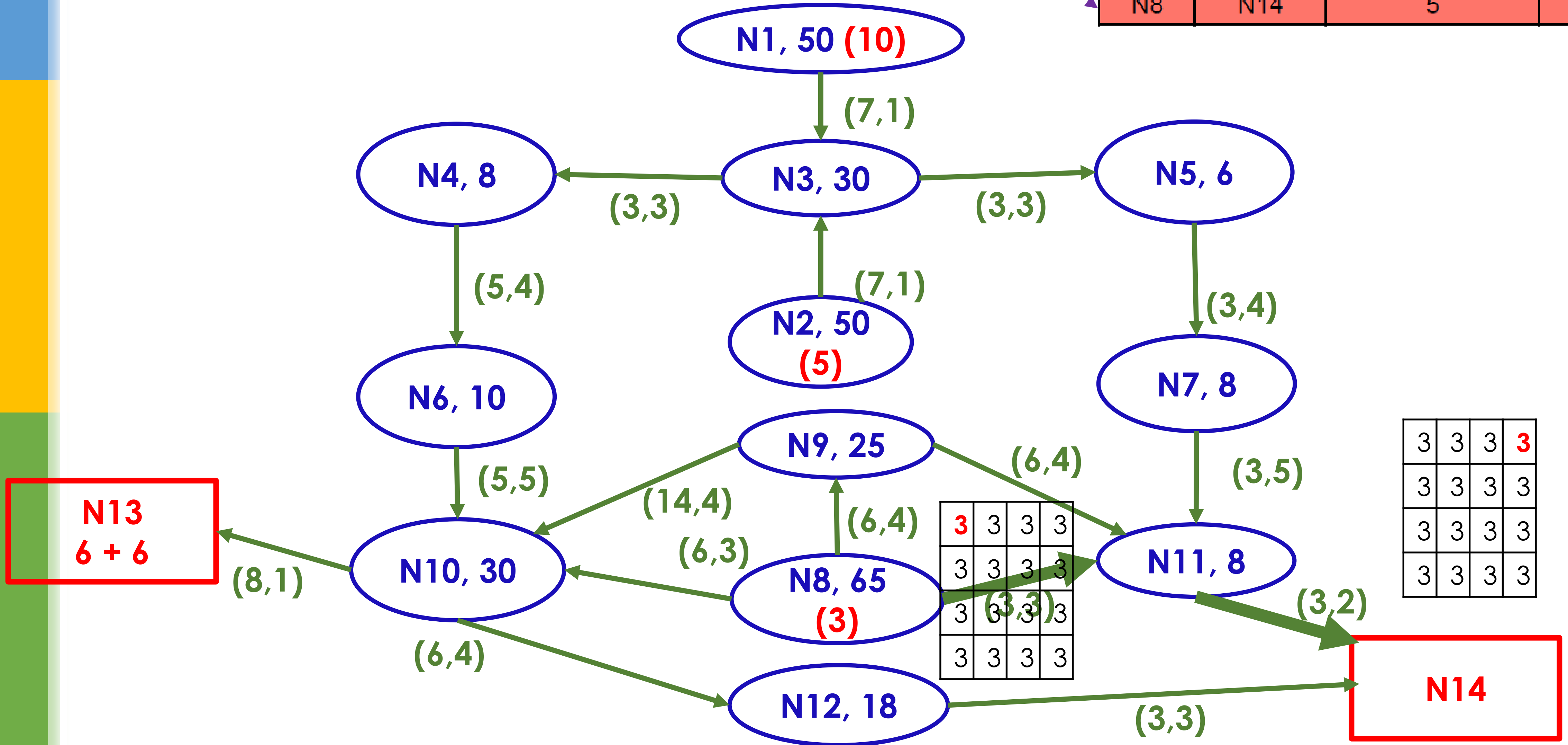

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Quickest route between Source and Destination

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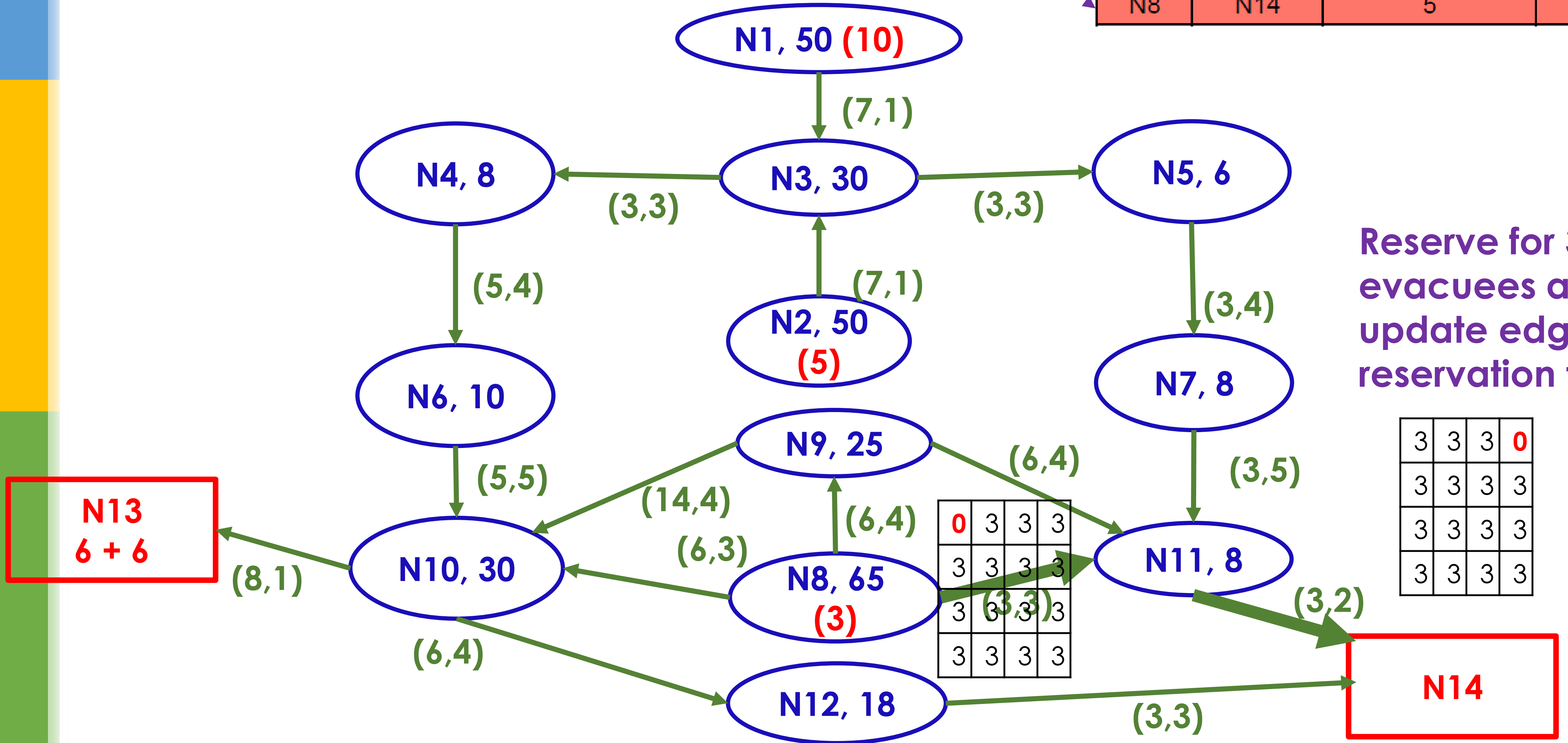
Reserve for 3 evacuees and update edge reservation table



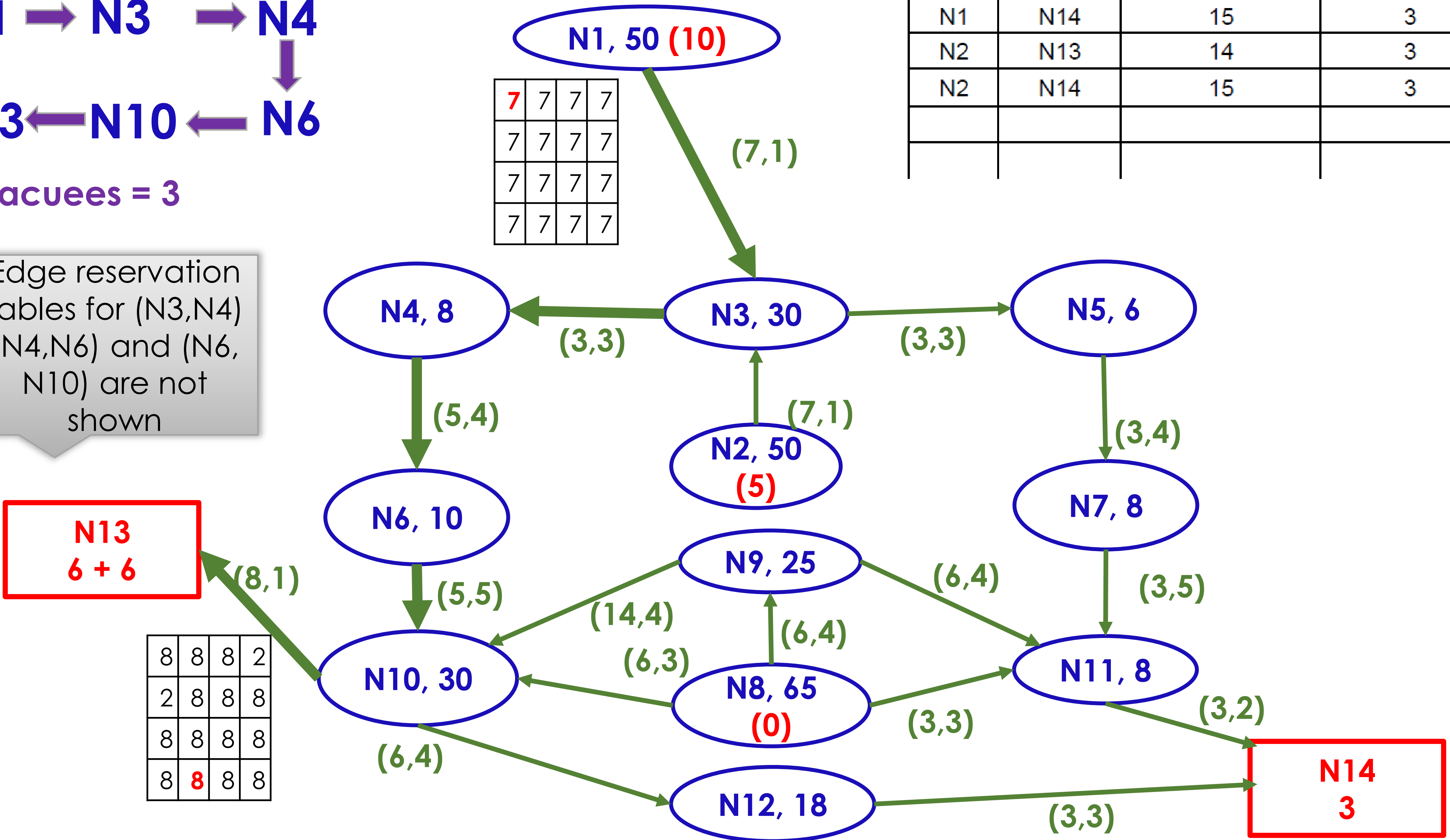
CCRP: Example Input : Iteration 4

N1 → N3 → N4 → N6 → N10 → N13

#Evacuees = 3

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3

Edge reservation tables for (N3,N4) (N4,N6) and (N6, N10) are not shown



CCRP: Example Input : Iteration 4

Source	Destination	Dest. Arrival Time	No. of Evacuees
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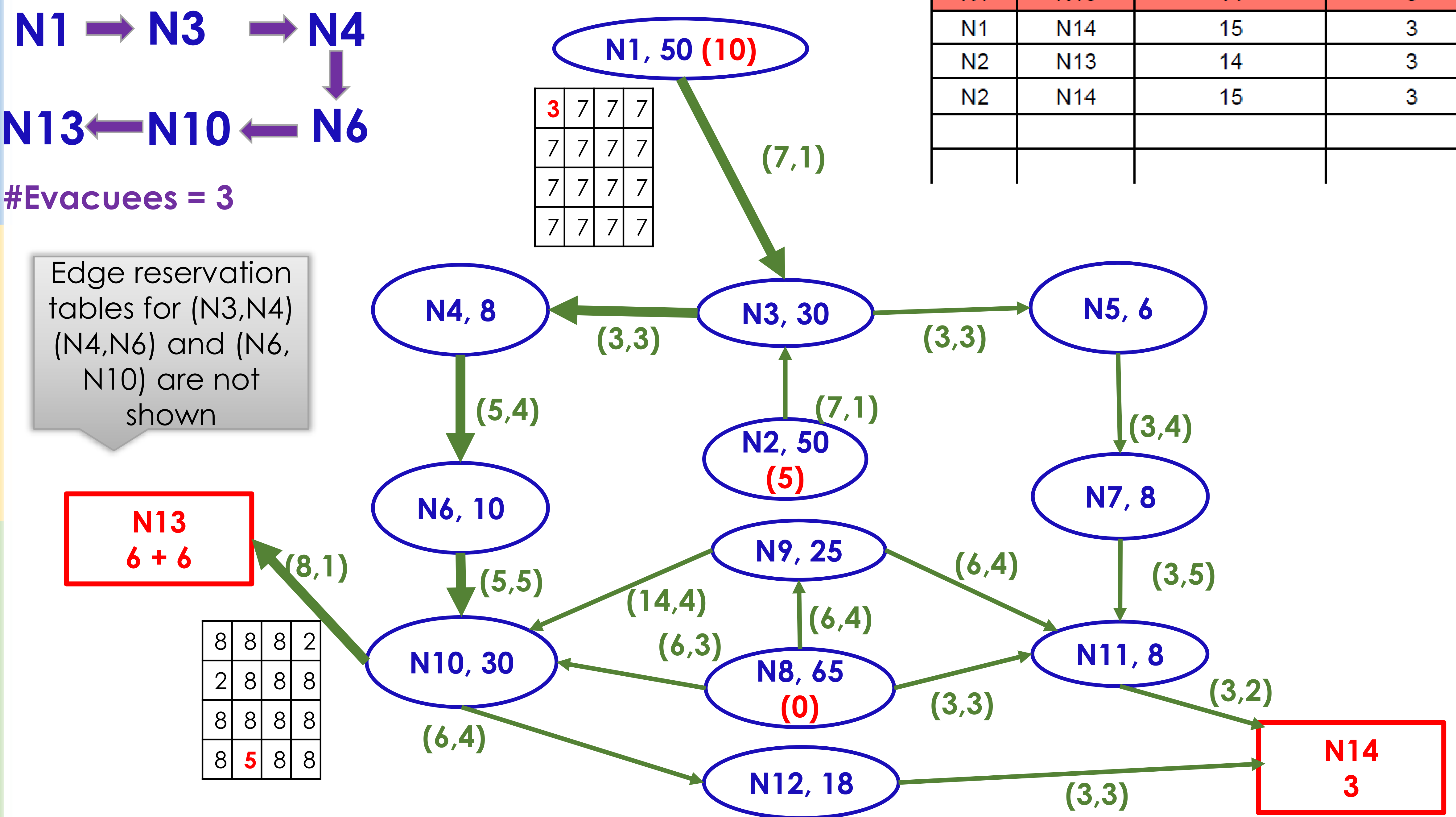
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3



CCRP: Example Input : Iteration 4

Source	Destination	Dest. Arrival Time	No. of Evacuees
N1	N13	14	3
N1	N14	15	3
N2	N13	14	3
N2	N14	15	3

N1 → N3 → N4 → N6 → N10 → N13

#Evacuees = 3

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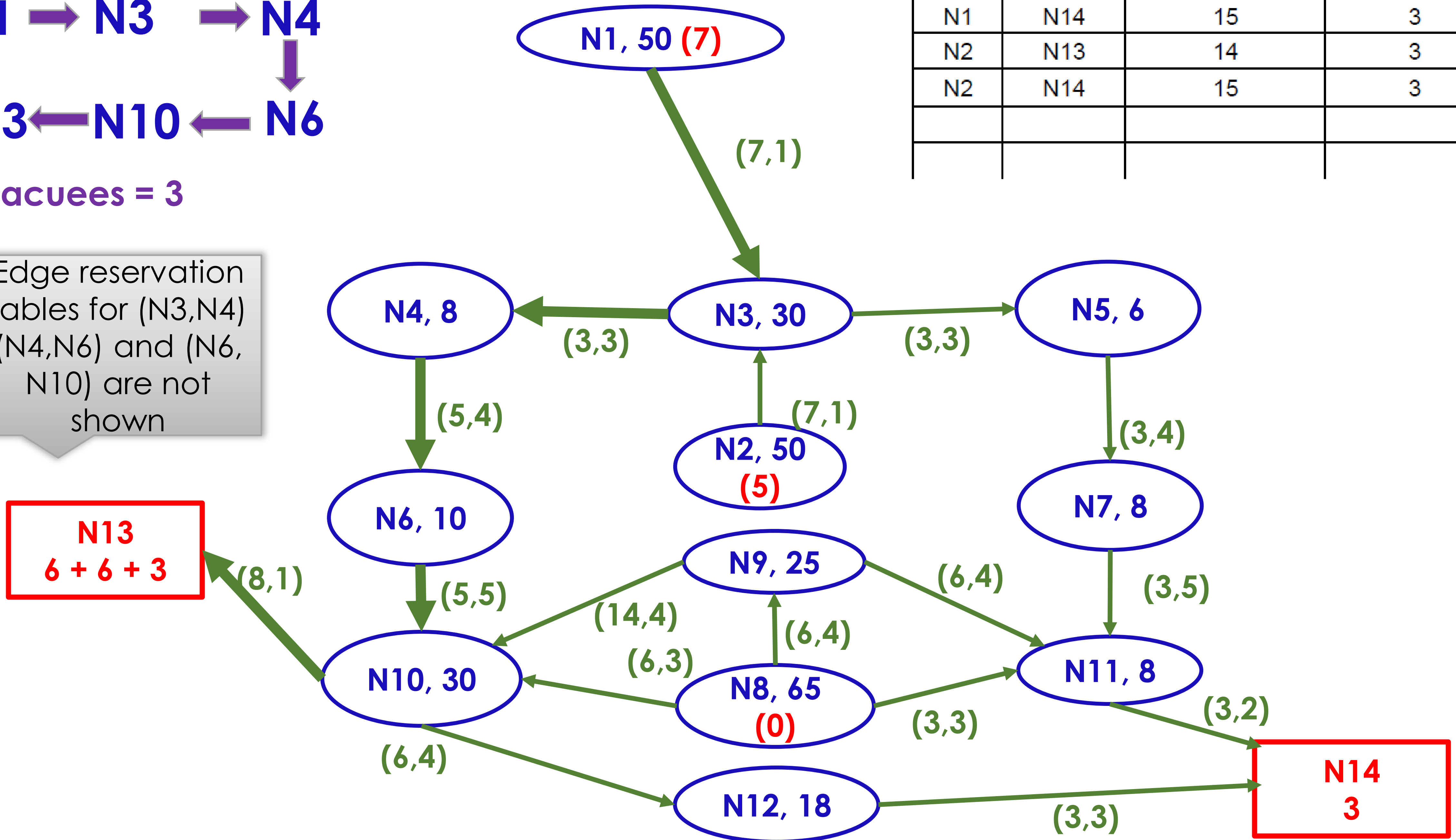
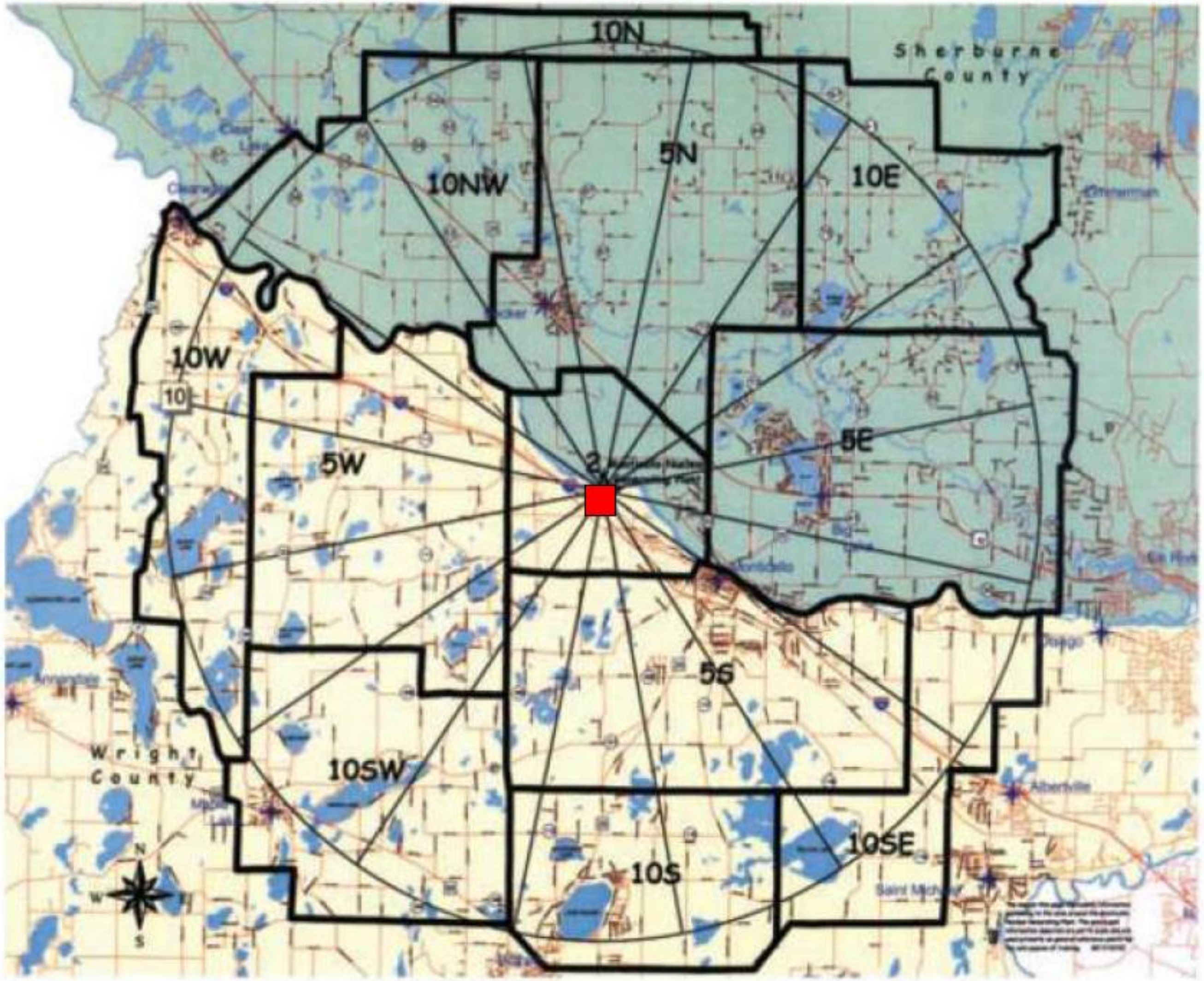


Sample Evacuation Scenarios

Emergency Planning Zone (EPZ) is a 10-mile radius around the plant divided into sub areas.



Monticello EPZ

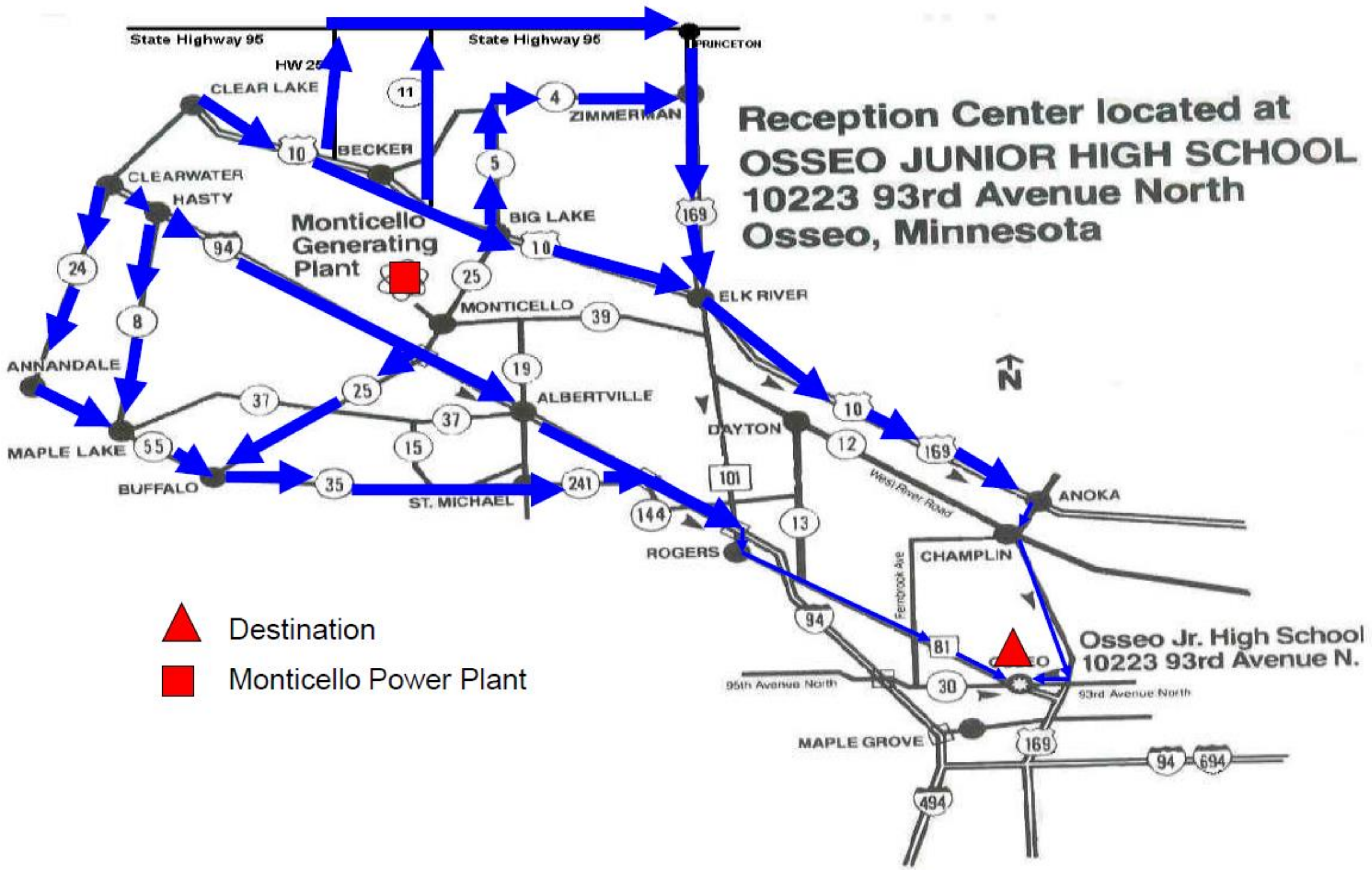
Subarea	Population
2	4,675
5N	3,994
5E	9,645
5S	6,749
5W	2,236
10N	391
10E	1,785
10SE	1,390
10S	4,616
10SW	3,408
10W	2,354
10NW	707
Total	**41,950**

Estimate EPZ evacuation time:
Summer/Winter (good weather):
3 hours, 30 minutes
Winter (adverse weather):
5 hours, 40 minutes

Data source: Minnesota DPS & DHS
Web site: http://www.dps.state.mn.us
http://www.dhs.state.mn.us

Evacuation Zone for Montecello, MN, USA

Old Evacuation Plan

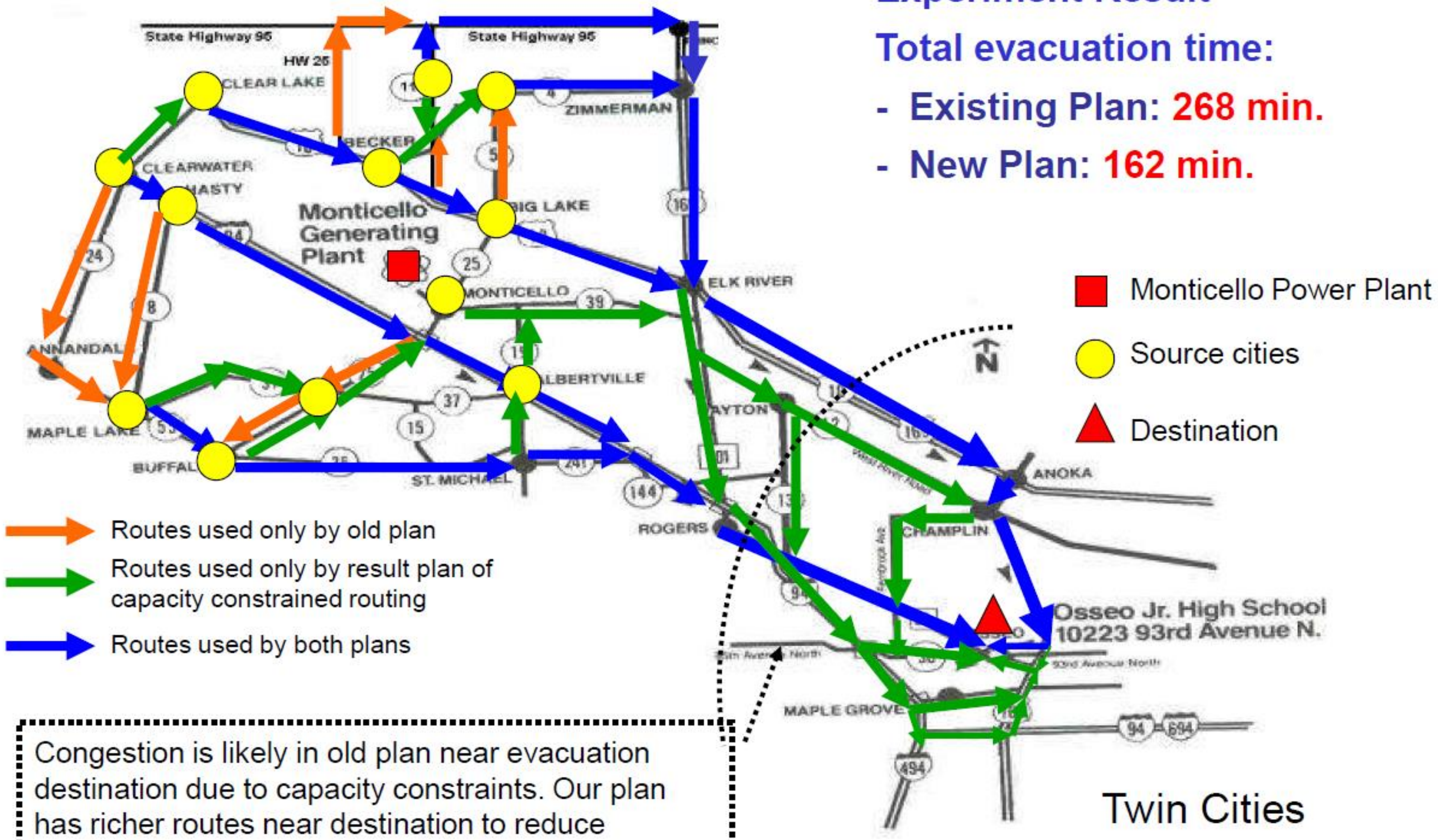


Plan Generated by CCRP

Experiment Result

Total evacuation time:

- **Existing Plan: 268 min.**
- **New Plan: 162 min.**



Congestion is likely in old plan near evacuation destination due to capacity constraints. Our plan has richer routes near destination to reduce congestion and total evacuation time.

Capacity Constrained Route Planer (CCRP)

Summary of CCRP:

- Each iteration generate route and schedule for one group of evacuee.
- Destination capacity constrains can be accommodated if needed
- Solution evacuation plan observes capacity constraints of network
- Wait at intermediate nodes not considered in this algorithm.

References:

- Shekhar et. al.: Experiences with evacuation route planning algorithms. International Journal of Geographical Information Science 26(12): 2253-2265 (2012)
- Lu et. al.: Evacuation Route Planning: a Case Study in Semantic Computing. Int. J. Semantic Computing 1(2): 249-303 (2007)
- Lu et. al.: Capacity Constrained Routing Algorithms for Evacuation Planning: A Summary of Results. SSTD 2005: 291-307