

traffic_simulator

February 13, 2024

```
[228]: from datetime import datetime, timedelta
from pandas import DataFrame
import matplotlib.pyplot as plt
import networkx as nx
from networkx import Graph
from networkx.drawing.nx_agraph import write_dot, graphviz_layout
from networkx.readwrite import json_graph
import os
from random import randint
import sys
from typing import Tuple
```

```
[229]: sys.path.append("../")
tests_dir = os.path.abspath("../tests")
sys.path.append(tests_dir)
```

```
[230]: from traffic_simulator.city_map import CityMap
from traffic_simulator.model import TimeDeltaDiff
from traffic_simulator.traffic_analysis import TrafficAnalyzer
from traffic_simulator.traffic_simulation import Simulator
from confest import generate_static_city_map, generate_static_trips
```

Generate City Map

```
[231]: r2_city_map = generate_static_city_map()
r2_city_map
```

```
[231]: <networkx.classes.graph.Graph at 0x14ddee2b0>
```

```
[232]: CityMap.get_city_map_statistics(r2_city_map)
```

node degree and node clustering

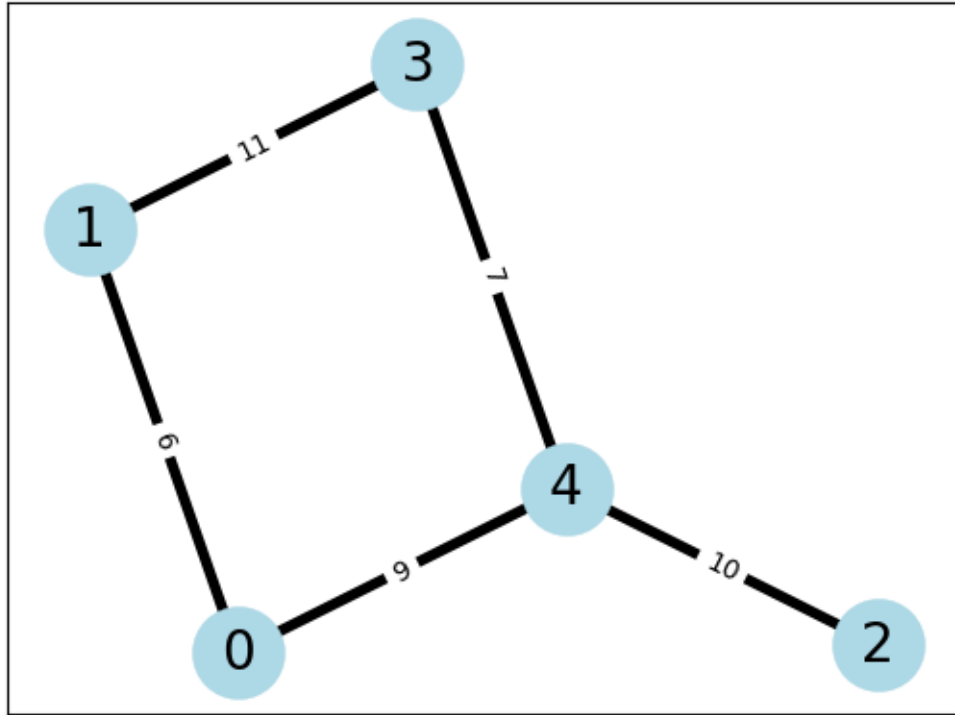
```
0 2 0
1 2 0
4 3 0
3 2 0
2 1 0
```

the adjacency list

```
0 1 4
1 3
4 2 3
3
2
```

```
[233]: CityMap.visualize_city_map(r2_city_map)
```

```
{(0, 1): 6, (0, 4): 9, (1, 3): 11, (4, 2): 10, (4, 3): 7}
```



1 Generate Static Trips

```
[234]: r2_trips = generate_static_trips()
len(r2_trips)
```

```
[234]: 20
```

```
[235]: r2_trips
```

```
[235]: {Trip(source=0, destination=2, numer_of_trips=1): Trip(source=0, destination=2,
numer_of_trips=1),
Trip(source=2, destination=0, numer_of_trips=1): Trip(source=2, destination=0,
numer_of_trips=1),
```

```

Trip(source=0, destination=3, numer_of_trips=1): Trip(source=0, destination=3,
numer_of_trips=1),
Trip(source=3, destination=0, numer_of_trips=1): Trip(source=3, destination=0,
numer_of_trips=1),
Trip(source=1, destination=2, numer_of_trips=1): Trip(source=1, destination=2,
numer_of_trips=1),
Trip(source=2, destination=1, numer_of_trips=2): Trip(source=2, destination=1,
numer_of_trips=2),
Trip(source=1, destination=4, numer_of_trips=1): Trip(source=1, destination=4,
numer_of_trips=1),
Trip(source=4, destination=1, numer_of_trips=2): Trip(source=4, destination=1,
numer_of_trips=2),
Trip(source=2, destination=3, numer_of_trips=3): Trip(source=2, destination=3,
numer_of_trips=3),
Trip(source=3, destination=2, numer_of_trips=1): Trip(source=3, destination=2,
numer_of_trips=1),
Trip(source=4, destination=0, numer_of_trips=0): Trip(source=4, destination=0,
numer_of_trips=0),
Trip(source=3, destination=4, numer_of_trips=0): Trip(source=3, destination=4,
numer_of_trips=0),
Trip(source=4, destination=3, numer_of_trips=0): Trip(source=4, destination=3,
numer_of_trips=0),
Trip(source=3, destination=1, numer_of_trips=0): Trip(source=3, destination=1,
numer_of_trips=0),
Trip(source=1, destination=0, numer_of_trips=0): Trip(source=1, destination=0,
numer_of_trips=0),
Trip(source=1, destination=3, numer_of_trips=0): Trip(source=1, destination=3,
numer_of_trips=0),
Trip(source=4, destination=2, numer_of_trips=0): Trip(source=4, destination=2,
numer_of_trips=0),
Trip(source=0, destination=1, numer_of_trips=0): Trip(source=0, destination=1,
numer_of_trips=0),
Trip(source=2, destination=4, numer_of_trips=0): Trip(source=2, destination=4,
numer_of_trips=0),
Trip(source=0, destination=4, numer_of_trips=0): Trip(source=0, destination=4,
numer_of_trips=0)}

```

2 R2

The benefit values of constructing the following new roads:

(0,2), (0,3), (1,2), (1,4), (2,3)

Use a k value (budget) of 2, which two of the above roads would you recommend for construction? Remember that once the first road is

constructed, benefits that you initially computed for the other 4 will now change and these will need to be recomputed.

Generate Benefit Matrix $k = 0$ # Initial Benefit Matrix

```
[236]: def get_max_benefit_road_segment(max_benefit_matrix: DataFrame) -> Tuple[int, int]:
        max_benefit = max_benefit_matrix.iloc[0].values
        source = int(max_benefit[0])
        destination = int(max_benefit[1])

        return source, destination
```

```
[237]: r2_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r2_city_map, r2_trips)
        r2_benefit_matrix
```

```
[237]:
```

	source	destination	benefit
3	2	3	38.6
4	0	2	38.0
2	1	4	36.0
0	1	2	30.0
1	0	3	12.8

```
[238]: ##### k = 1 # Recommended road to build first is the road segment (2,3)
        r2_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r2_benefit_matrix)
        r2_max_benefit_matrix
```

```
[238]:
```

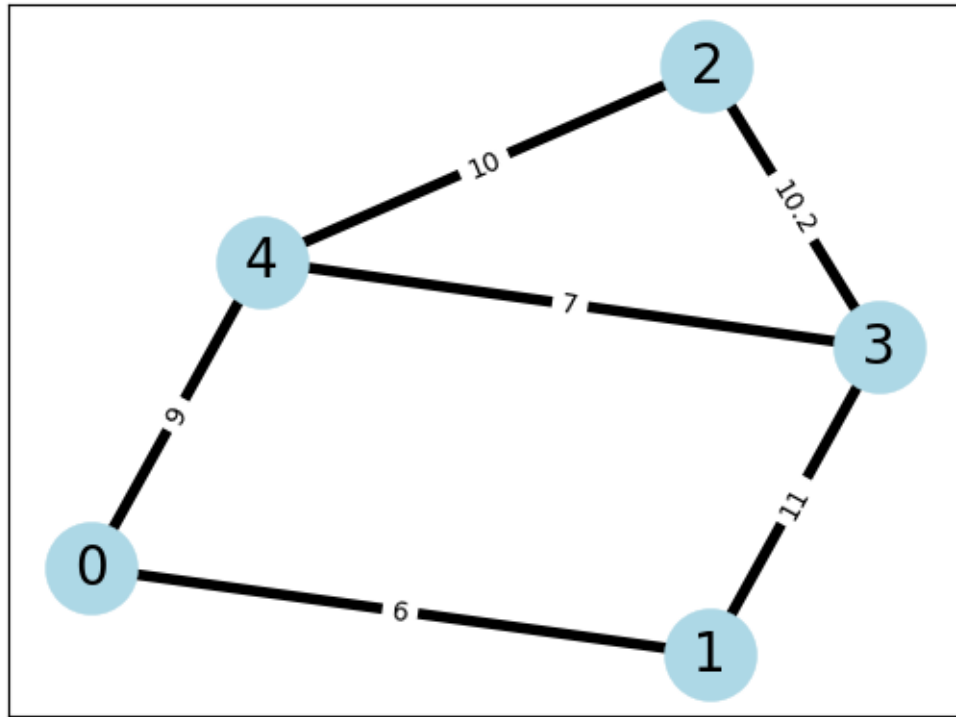
	source	destination	benefit
3	2	3	38.6

```
[239]: source, destination = get_max_benefit_road_segment(r2_max_benefit_matrix)
        print(f"({source}, {destination})")
```

(2, 3)

```
[240]: CityMap.add_road_segment(r2_city_map, source, destination)
        CityMap.visualize_city_map(r2_city_map)
```

```
{(0, 1): 6, (0, 4): 9, (1, 3): 11, (4, 2): 10, (4, 3): 7, (3, 2): 10.2}
```



```
[241]: r2_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r2_city_map,
    ↪r2_trips)
r2_benefit_matrix
```

```
[241]:
```

	source	destination	benefit
1	0	2	26.6
0	1	2	26.0
3	1	4	24.6
2	0	3	12.8

```
[242]: ##### k = 2 # Next recommended road to be built is the road segment (0,2)
max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r2_benefit_matrix)
max_benefit_matrix
```

```
[242]:
```

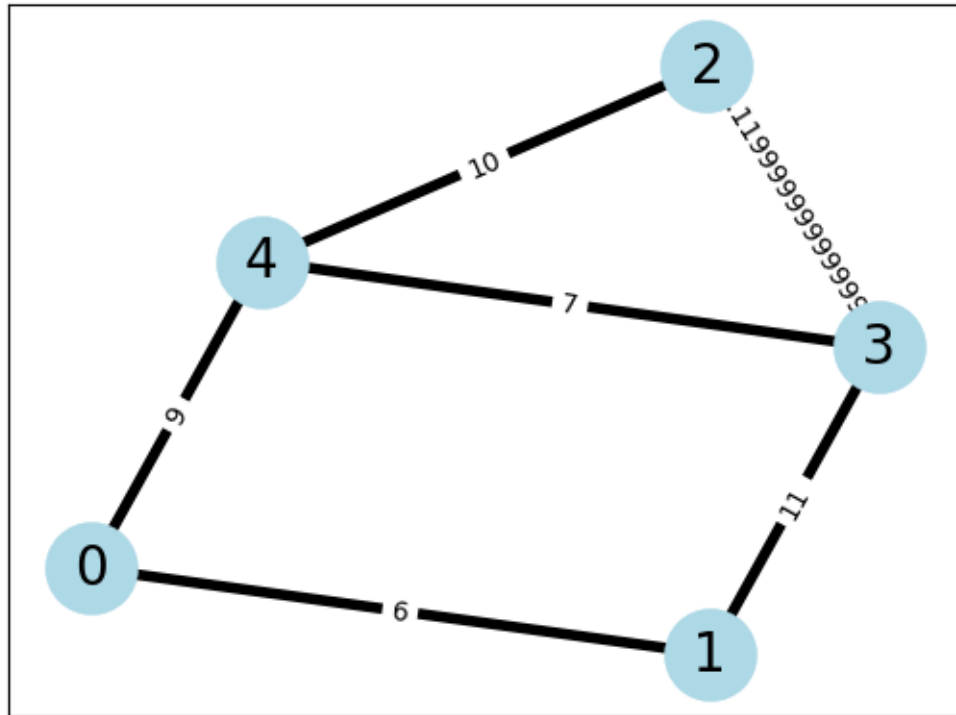
	source	destination	benefit
1	0	2	26.6

```
[243]: source, destination = get_max_benefit_road_segment(r2_max_benefit_matrix)
print(f"({source}, {destination})")
```

```
(2, 3)
```

```
[244]: CityMap.add_road_segment(r2_city_map, source, destination)
CityMap.visualize_city_map(r2_city_map)
```

```
{(0, 1): 6, (0, 4): 9, (1, 3): 11, (4, 2): 10, (4, 3): 7, (3, 2):  
6.119999999999999}
```



3 R3

```
[245]: r3_city_map = Simulator.generate_map()  
r3_city_map
```

```
[245]: <networkx.classes.graph.Graph at 0x14d8950d0>
```

```
[246]: r4_city_map = r3_city_map.copy()  
r4_city_map
```

```
[246]: <networkx.classes.graph.Graph at 0x14f974160>
```

```
[247]: CityMap.get_city_map_statistics(r3_city_map)
```

```
node degree and node clustering  
0 9 0.08333333333333333  
1 9 0.11111111111111111  
2 6 0.06666666666666667  
3 6 0  
4 8 0.14285714285714285  
5 5 0
```

6 9 0.138888888888889
7 5 0.1
8 11 0.163636363636364
9 11 0.163636363636364
10 8 0.03571428571428571
11 6 0.2666666666666666
12 12 0.136363636363635
13 10 0.088888888888889
14 16 0.116666666666667
15 7 0.2857142857142857
16 9 0.0555555555555555
17 6 0.066666666666667
18 11 0.07272727272727272
19 4 0.3333333333333333
20 6 0.066666666666667
21 9 0.19444444444444445
22 5 0.1
23 8 0.21428571428571427
24 6 0.2
25 7 0.09523809523809523
26 6 0.2
27 9 0.2222222222222222
28 6 0.13333333333333333
29 11 0.163636363636364
30 7 0.14285714285714285
31 13 0.1666666666666666
32 4 0.1666666666666666
33 7 0.047619047619047616
34 10 0.088888888888889
35 5 0.1
36 1 0
37 4 0
38 3 0
39 7 0.14285714285714285
40 11 0.163636363636364
41 7 0.09523809523809523
42 10 0.13333333333333333
43 8 0.03571428571428571
44 8 0.14285714285714285
45 16 0.0916666666666666
46 2 0
47 10 0.13333333333333333
48 13 0.1794871794871795
49 10 0.1111111111111111
50 4 0
51 6 0.066666666666667
52 8 0.17857142857142858
53 4 0.1666666666666666

54 9 0.08333333333333333
55 9 0.16666666666666666
56 11 0.2
57 6 0.13333333333333333
58 7 0.09523809523809523
59 9 0.16666666666666666

the adjacency list

0 20 3 35 59 14 27 47 32 5
1 12 52 50 58 39 15 13 8 22
2 11 3 54 8 48 20
3 10 38 13 31
4 22 14 55 6 44 5 45 15
5 18 31 54
6 25 45 31 12 46 27 21 36
7 12 18 22 25 45
8 14 23 40 35 52 51 15 34 42
9 31 28 56 49 48 55 46 11 47 45 58
10 29 16 45 54 50 30 42
11 34 48 42 14
12 31 43 55 21 27 53 18 14 29
13 49 56 17 40 14 21 39 34
14 23 42 22 59 30 52 21 16 29 31
15 42 52 54 55
16 18 53 20 48 34 55 43
17 38 45 39 30 42
18 58 52 21 50 47 28 59
19 57 49 53 45
20 24 51 49
21 30 54 35 28
22 57
23 43 31 37 29 40 54
24 29 43 48 49 26
25 48 33 58 59 42
26 45 59 39 33 29
27 49 34 31 41 40 56
28 33 40 30
29 51 45 34 47 44
30 44 59
31 39 34 40 56 47
32 47 44 41
33 49 39 51 34
34 47 44
35 49 42
36
37 56 50 51
38 47
39 41


```

40 54 45 56 58 48
41 45 56 52 43
42 48 43
43 47 45
44 56 57 45
45 51 49 57
46
47 59
48 53 49 59 55 56
49
50
51
52 54 57
53
54 58
55 57 58 56
56 59
57
58
59

```

```

[248]: CityMap.visualize_city_map(r3_city_map, location_size=60, location_font_size=1,
↳road_widths=1)

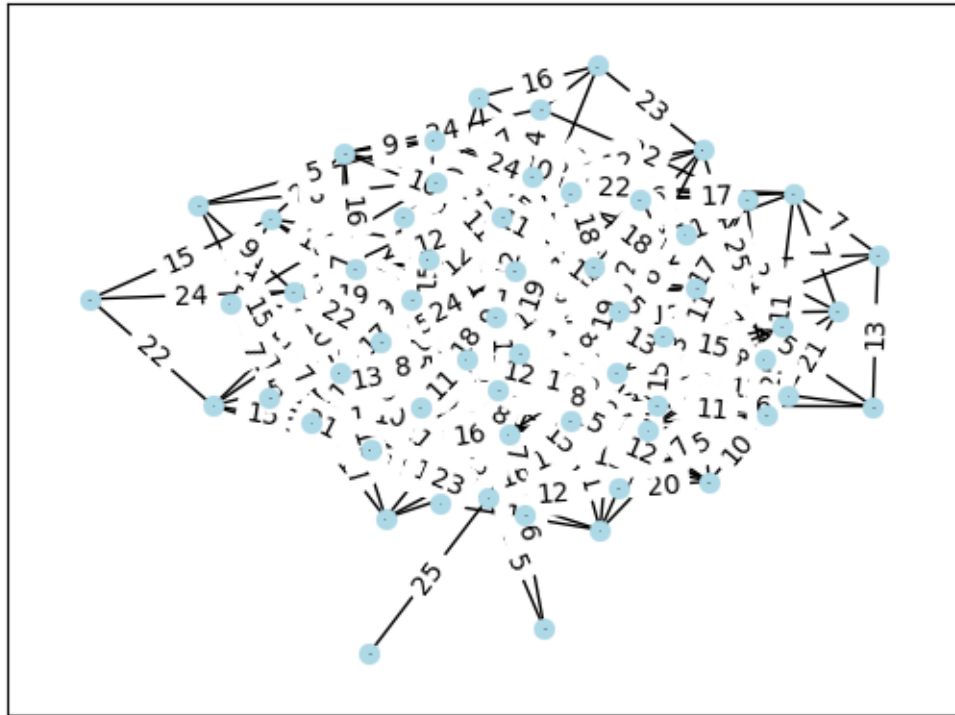
```

```

{(0, 20): 15, (0, 3): 15, (0, 35): 22, (0, 59): 15, (0, 14): 8, (0, 27): 18, (0,
47): 7, (0, 32): 15, (0, 5): 17, (1, 12): 7, (1, 52): 18, (1, 50): 14, (1, 58):
5, (1, 39): 13, (1, 15): 10, (1, 13): 25, (1, 8): 6, (1, 22): 7, (2, 11): 15,
(2, 3): 9, (2, 54): 11, (2, 8): 20, (2, 48): 23, (2, 20): 7, (3, 10): 12, (3,
38): 22, (3, 13): 5, (3, 31): 5, (4, 22): 5, (4, 14): 23, (4, 55): 11, (4, 6):
21, (4, 44): 8, (4, 5): 16, (4, 45): 18, (4, 15): 15, (5, 18): 5, (5, 31): 15,
(5, 54): 24, (6, 25): 12, (6, 45): 6, (6, 31): 11, (6, 12): 10, (6, 46): 5, (6,
27): 7, (6, 21): 16, (6, 36): 25, (7, 12): 5, (7, 18): 17, (7, 22): 21, (7, 25):
5, (7, 45): 14, (8, 14): 22, (8, 23): 21, (8, 40): 18, (8, 35): 23, (8, 52): 20,
(8, 51): 14, (8, 15): 10, (8, 34): 16, (8, 42): 6, (9, 31): 9, (9, 28): 10, (9,
56): 19, (9, 49): 16, (9, 48): 22, (9, 55): 16, (9, 46): 6, (9, 11): 16, (9,
47): 19, (9, 45): 17, (9, 58): 13, (10, 29): 5, (10, 16): 5, (10, 45): 24, (10,
54): 12, (10, 50): 10, (10, 30): 19, (10, 42): 5, (11, 34): 12, (11, 48): 15,
(11, 42): 5, (11, 14): 10, (12, 31): 10, (12, 43): 9, (12, 55): 5, (12, 21): 8,
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15, (13, 56): 25, (13, 17): 16, (13, 40): 17, (13, 14): 22, (13, 21): 5, (13,
39): 16, (13, 34): 21, (14, 23): 12, (14, 42): 15, (14, 22): 12, (14, 59): 18,
(14, 30): 11, (14, 52): 13, (14, 21): 18, (14, 16): 21, (14, 29): 25, (14, 31):
25, (15, 42): 22, (15, 52): 24, (15, 54): 23, (15, 55): 25, (16, 18): 13, (16,
53): 5, (16, 20): 7, (16, 48): 18, (16, 34): 18, (16, 55): 18, (16, 43): 18,
(17, 38): 15, (17, 45): 6, (17, 39): 23, (17, 30): 12, (17, 42): 17, (18, 58):
24, (18, 52): 15, (18, 21): 15, (18, 50): 12, (18, 47): 20, (18, 28): 15, (18,
59): 21, (19, 57): 7, (19, 49): 18, (19, 53): 13, (19, 45): 7, (20, 24): 21,
(20, 51): 25, (20, 49): 15, (21, 30): 7, (21, 54): 16, (21, 35): 23, (21, 28):

```

21, (22, 57): 7, (23, 43): 19, (23, 31): 18, (23, 37): 17, (23, 29): 8, (23, 40): 24, (23, 54): 9, (24, 29): 11, (24, 43): 6, (24, 48): 11, (24, 49): 17, (24, 26): 22, (25, 48): 10, (25, 33): 7, (25, 58): 20, (25, 59): 8, (25, 42): 15, (26, 45): 15, (26, 59): 23, (26, 39): 24, (26, 33): 6, (26, 29): 24, (27, 49): 24, (27, 34): 25, (27, 31): 15, (27, 41): 15, (27, 40): 11, (27, 56): 18, (28, 33): 9, (28, 40): 13, (28, 30): 7, (29, 51): 12, (29, 45): 24, (29, 34): 19, (29, 47): 18, (29, 44): 6, (30, 44): 6, (30, 59): 10, (31, 39): 17, (31, 34): 17, (31, 40): 8, (31, 56): 5, (31, 47): 10, (32, 47): 9, (32, 44): 8, (32, 41): 5, (33, 49): 13, (33, 39): 10, (33, 51): 17, (33, 34): 12, (34, 47): 19, (34, 44): 25, (35, 49): 25, (35, 42): 7, (37, 56): 10, (37, 50): 16, (37, 51): 23, (38, 47): 24, (39, 41): 9, (40, 54): 7, (40, 45): 12, (40, 56): 9, (40, 58): 25, (40, 48): 18, (41, 45): 15, (41, 56): 15, (41, 52): 10, (41, 43): 24, (42, 48): 8, (42, 43): 19, (43, 47): 12, (43, 45): 18, (44, 56): 11, (44, 57): 22, (44, 45): 11, (45, 51): 7, (45, 49): 25, (45, 57): 11, (47, 59): 22, (48, 53): 6, (48, 49): 15, (48, 59): 12, (48, 55): 11, (48, 56): 8, (52, 54): 19, (52, 57): 17, (54, 58): 12, (55, 57): 11, (55, 58): 10, (55, 56): 13, (56, 59): 24}



```

[249]: def get_traffic_times() -> Tuple[datetime, datetime]:
        # (8 AM - 6 PM) # 10 hour time span
        start_time = datetime.strptime('08:00', '%H:%M').time()
        end_time = datetime.strptime('18:00', '%H:%M').time()

        start_date = datetime.now() - timedelta(days=30)
  
```

```

    random_start_datetime = datetime.combine(start_date.date(), start_time)

    random_end_datetime = random_start_datetime + timedelta(hours=10)

    return random_start_datetime, random_end_datetime

traffic_start_datetime, traffic_end_datetime = get_traffic_times()

print("Traffic start datetime:", traffic_start_datetime)
print("Traffic end datetime", traffic_end_datetime)

```

Traffic start datetime: 2024-01-14 08:00:00

Traffic end datetime 2024-01-14 18:00:00

```

[250]: r3_r4_trips = Simulator.generate_trips(city_map,
                                             traffic_start_datetime,
                                             traffic_end_datetime,
                                             TimeDeltaDiff.SECONDS)

r3_r4_number_of_trips = 0

for trip in r3_r4_trips:
    r3_r4_number_of_trips += trip.number_of_trips

r3_r4_number_of_trips

```

[250]: 36000

```

[251]: r3_r4_trips

```

```

[251]: {Trip(source=14, destination=48, numer_of_trips=9): Trip(source=14,
destination=48, numer_of_trips=9),
Trip(source=41, destination=23, numer_of_trips=10): Trip(source=41,
destination=23, numer_of_trips=10),
Trip(source=14, destination=52, numer_of_trips=12): Trip(source=14,
destination=52, numer_of_trips=12),
Trip(source=59, destination=3, numer_of_trips=6): Trip(source=59,
destination=3, numer_of_trips=6),
Trip(source=19, destination=47, numer_of_trips=10): Trip(source=19,
destination=47, numer_of_trips=10),
Trip(source=31, destination=0, numer_of_trips=14): Trip(source=31,
destination=0, numer_of_trips=14),
Trip(source=20, destination=21, numer_of_trips=9): Trip(source=20,
destination=21, numer_of_trips=9),
Trip(source=50, destination=46, numer_of_trips=12): Trip(source=50,
destination=46, numer_of_trips=12),
Trip(source=41, destination=3, numer_of_trips=9): Trip(source=41,
destination=3, numer_of_trips=9),
Trip(source=56, destination=55, numer_of_trips=6): Trip(source=56,

```

destination=55, numer_of_trips=6),
 Trip(source=6, destination=29, numer_of_trips=17): Trip(source=6,
 destination=29, numer_of_trips=17),
 Trip(source=58, destination=38, numer_of_trips=11): Trip(source=58,
 destination=38, numer_of_trips=11),
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 destination=53, numer_of_trips=12),
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 Trip(source=4, destination=17, numer_of_trips=10): Trip(source=4,
 destination=17, numer_of_trips=10),
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 Trip(source=12, destination=40, numer_of_trips=15): Trip(source=12,
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 Trip(source=2, destination=28, numer_of_trips=6): Trip(source=2,
 destination=28, numer_of_trips=6),
 Trip(source=16, destination=57, numer_of_trips=10): Trip(source=16,
 destination=57, numer_of_trips=10),
 Trip(source=5, destination=24, numer_of_trips=12): Trip(source=5,
 destination=24, numer_of_trips=12),
 Trip(source=50, destination=15, numer_of_trips=14): Trip(source=50,
 destination=15, numer_of_trips=14),
 Trip(source=15, destination=55, numer_of_trips=7): Trip(source=15,
 destination=55, numer_of_trips=7),
 Trip(source=18, destination=45, numer_of_trips=8): Trip(source=18,
 destination=45, numer_of_trips=8),
 Trip(source=58, destination=28, numer_of_trips=10): Trip(source=58,
 destination=28, numer_of_trips=10),
 Trip(source=55, destination=45, numer_of_trips=13): Trip(source=55,
 destination=45, numer_of_trips=13),
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 destination=7, numer_of_trips=3),
 Trip(source=28, destination=55, numer_of_trips=10): Trip(source=28,
 destination=55, numer_of_trips=10),
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 destination=28, numer_of_trips=13),
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 destination=5, numer_of_trips=5),
 Trip(source=12, destination=29, numer_of_trips=11): Trip(source=12,
 destination=29, numer_of_trips=11),
 Trip(source=18, destination=41, numer_of_trips=13): Trip(source=18,
 destination=41, numer_of_trips=13),
 Trip(source=31, destination=24, numer_of_trips=9): Trip(source=31,
 destination=24, numer_of_trips=9),
 Trip(source=0, destination=44, numer_of_trips=9): Trip(source=0,
 destination=44, numer_of_trips=9),

Trip(source=9, destination=57, number_of_trips=11): Trip(source=9, destination=57, number_of_trips=11),
 Trip(source=18, destination=40, number_of_trips=12): Trip(source=18, destination=40, number_of_trips=12),
 Trip(source=43, destination=23, number_of_trips=11): Trip(source=43, destination=23, number_of_trips=11),
 Trip(source=46, destination=10, number_of_trips=7): Trip(source=46, destination=10, number_of_trips=7),
 Trip(source=51, destination=44, number_of_trips=8): Trip(source=51, destination=44, number_of_trips=8),
 Trip(source=48, destination=39, number_of_trips=13): Trip(source=48, destination=39, number_of_trips=13),
 Trip(source=2, destination=30, number_of_trips=17): Trip(source=2, destination=30, number_of_trips=17),
 Trip(source=9, destination=23, number_of_trips=13): Trip(source=9, destination=23, number_of_trips=13),
 Trip(source=37, destination=59, number_of_trips=10): Trip(source=37, destination=59, number_of_trips=10),
 Trip(source=44, destination=11, number_of_trips=11): Trip(source=44, destination=11, number_of_trips=11),
 Trip(source=2, destination=58, number_of_trips=11): Trip(source=2, destination=58, number_of_trips=11),
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...}

```

```

[252]: r3_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r3_city_map,
↳r3_r4_trips)
r3_benefit_matrix

```

```

[252]:
      source  destination  benefit
1533      14           47   2954.0
1318      12           23   2828.0
112       12           47   2418.0
661        9           40   2258.8
1519      14           34   2251.4
...
155        7           43    84.0
802        7           16    84.0
955       22           58    81.6
951       10           48    72.8
74        42           44    70.4

```

[1535 rows x 3 columns]

```

[253]: ##### k = 1 # Recommended road to build first is the road segment
r3_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r3_benefit_matrix)
r3_max_benefit_matrix

```

```

[253]:
      source  destination  benefit
1533      14           47   2954.0

```

```

[254]: source, destination = get_max_benefit_road_segment(r3_max_benefit_matrix)
print(f"({source}, {destination})")

```

(14, 47)

```

[255]: CityMap.add_road_segment(r3_city_map, source, destination)

```

```

[256]: CityMap.visualize_city_map(r3_city_map, location_size=60, location_font_size=1,
↳road_widths=1)

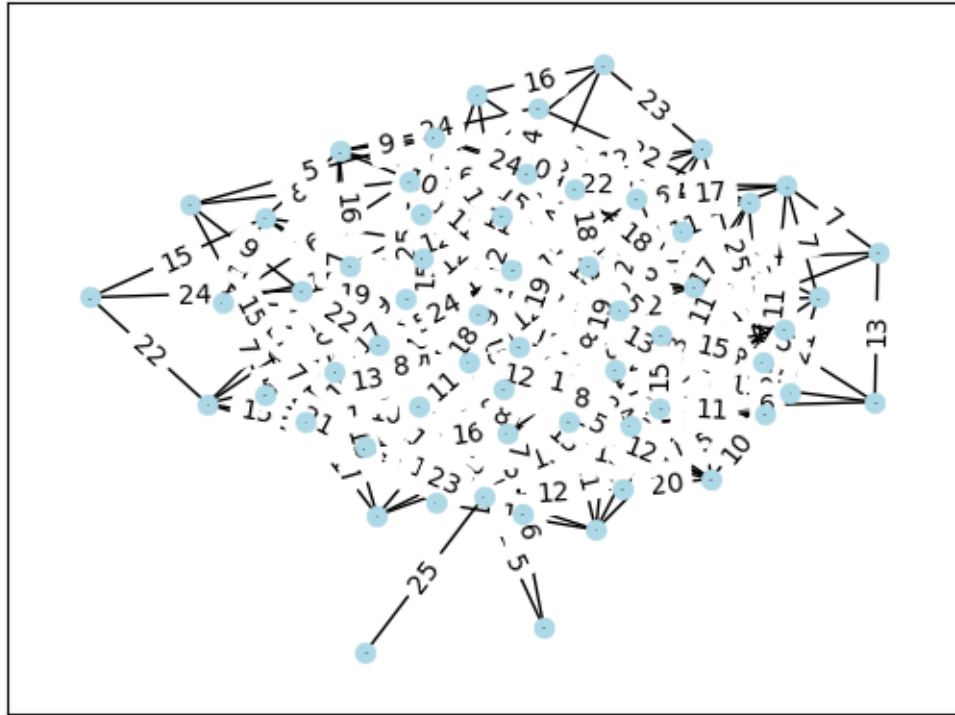
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```
[257]: r3_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r3_city_map,
    ↪r3_r4_trips)
r3_benefit_matrix
```

```
[257]:
```

	source	destination	benefit
1318	12	23	2828.0
112	12	47	2818.0
1519	14	34	2495.2
135	1	14	2487.2
661	9	40	2258.8
...
155	7	43	84.0
802	7	16	84.0
955	22	58	81.6
951	10	48	72.8
74	42	44	70.4

[1534 rows x 3 columns]

```
[258]: ##### k = 2 # Recommended road to build first is the road segment
r3_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r3_benefit_matrix)
r3_max_benefit_matrix
```



```
[258]:      source  destination  benefit
      1318      12      23  2828.0
```

```
[259]: source, destination = get_max_benefit_road_segment(r3_max_benefit_matrix)
      print(f"({source}, {destination})")
```

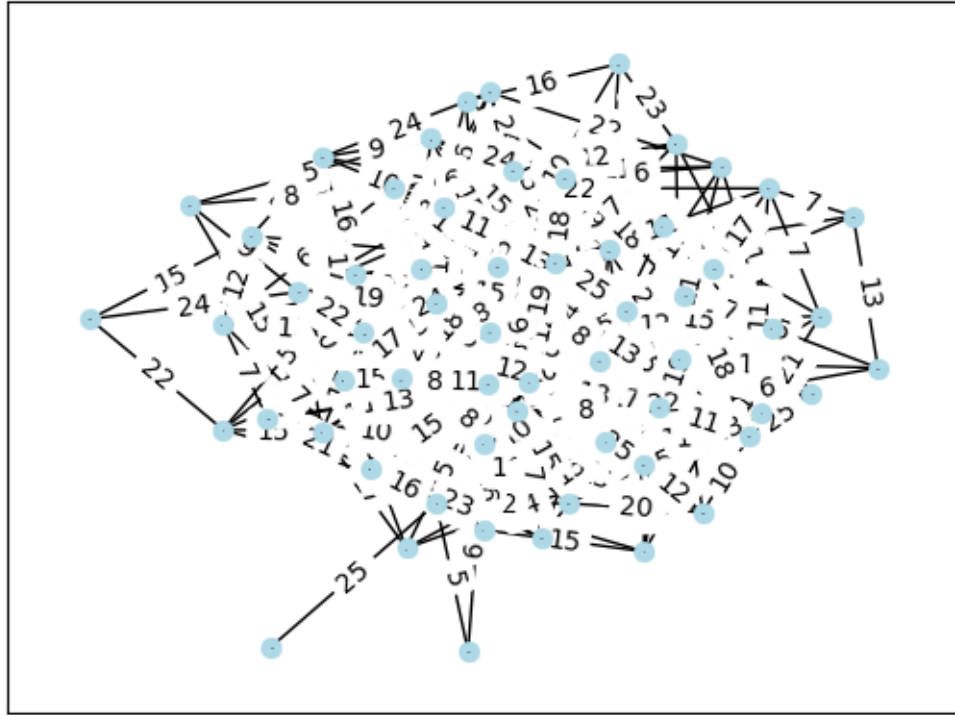
```
(12, 23)
```

```
[260]: CityMap.add_road_segment(r3_city_map, source, destination)
```

```
[261]: CityMap.visualize_city_map(r3_city_map, location_size=60, location_font_size=1,
      ↪road_widths=1)
```

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```
[262]: r3_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r3_city_map,
↳ r3_r4_trips)
r3_benefit_matrix
```

```
[262]:
```

	source	destination	benefit
112	12	47	2818.0
1518	14	34	2495.2
135	1	14	2487.2
661	9	40	2258.8
132	31	37	2246.0
...
155	7	43	84.0
802	7	16	84.0
955	22	58	81.6
951	10	48	72.8
74	42	44	70.4

[1533 rows x 3 columns]

```
[263]: ##### k = 3 # Recommended road to build last is the road segment
r3_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r3_benefit_matrix)
r3_max_benefit_matrix
```

```
[263]:      source destination  benefit
      112         12         47   2818.0
```

```
[264]: source, destination = get_max_benefit_road_segment(r3_max_benefit_matrix)
print(f"({source}, {destination})")
```

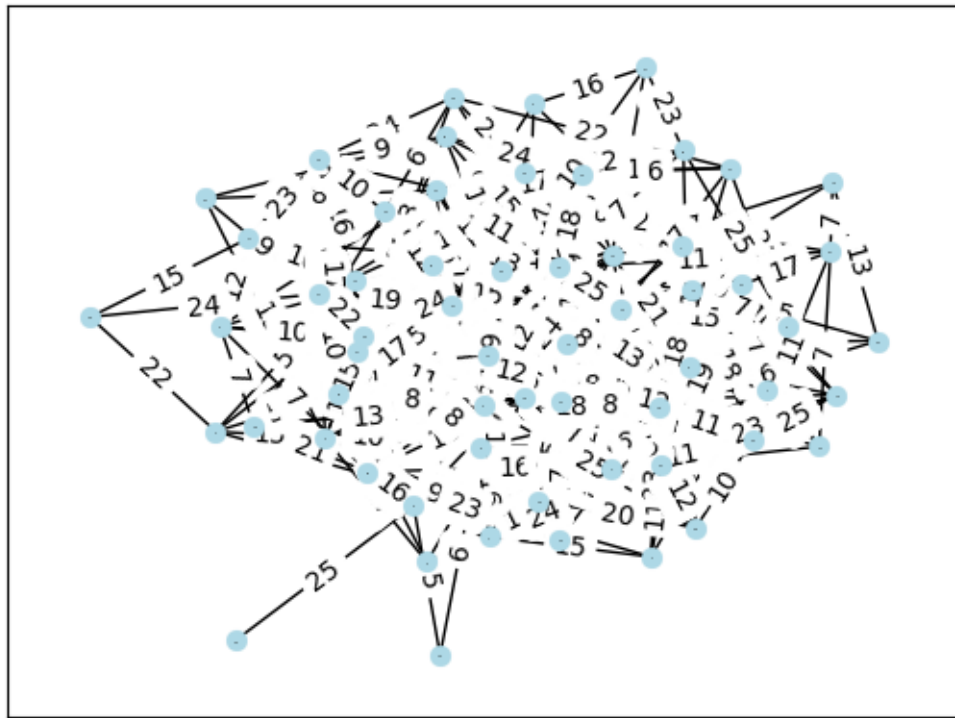
(12, 47)

```
[265]: CityMap.add_road_segment(r3_city_map, source, destination)
```

```
[266]: CityMap.visualize_city_map(r3_city_map, location_size=60, location_font_size=1,
↳road_widths=1)
```

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4 R4

```
[267]: r4_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r4_city_map,
    ↪r3_r4_trips, shrinkage_factor=0.8)
r4_benefit_matrix
```

```
[267]:
```

	source	destination	benefit
1318	12	23	1359.0
543	1	18	1115.2

135	1	14	1067.8
132	31	37	1053.0
728	49	56	1051.4
...
155	7	43	42.0
955	22	58	40.8
393	21	55	39.0
951	10	48	36.4
74	42	44	35.2

[1535 rows x 3 columns]

```
[268]: ##### k = 1 # Recommended road to build first is the road segment
r4_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r4_benefit_matrix)
r4_max_benefit_matrix
```

```
[268]:      source destination benefit
1318      12           23  1359.0
```

```
[269]: source, destination = get_max_benefit_road_segment(r4_max_benefit_matrix)
print(f"({source}, {destination})")
```

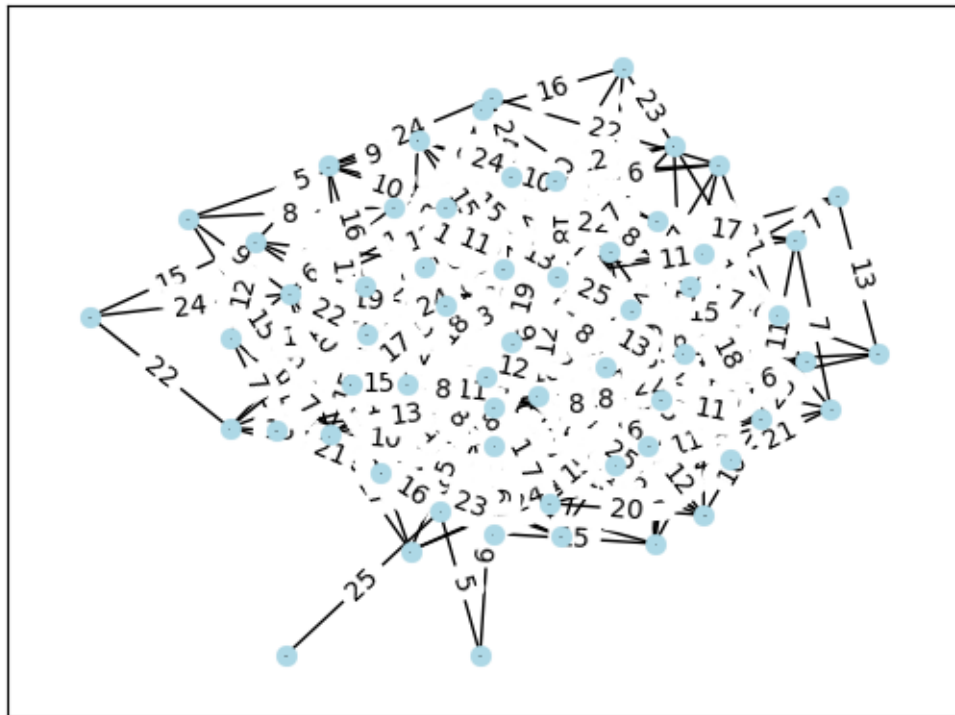
(12, 23)

```
[270]: CityMap.add_road_segment(r4_city_map, source, destination)
```

```
[271]: CityMap.visualize_city_map(r4_city_map, location_size=60, location_font_size=1,
↪road_widths=1)
```

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 59): 24}



```
[272]: r4_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r4_city_map,
↳r3_r4_trips, shrinkage_factor=0.8)
r4_benefit_matrix
```

```
[272]:
```

	source	destination	benefit
543	1	18	1115.2
135	1	14	1067.8
132	31	37	1053.0
728	49	56	1051.4
298	42	59	1044.0
..
155	7	43	42.0
955	22	58	40.8
393	21	55	39.0
951	10	48	36.4
74	42	44	35.2

[1534 rows x 3 columns]

```
[273]: ##### k = 2 # Recommended road to build first is the road segment
r4_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r4_benefit_matrix)
r4_max_benefit_matrix
```

```
[273]:
```

	source	destination	benefit
543	1	18	1115.2

```
[274]: source, destination = get_max_benefit_road_segment(r4_max_benefit_matrix)
print(f"({source}, {destination})")
```

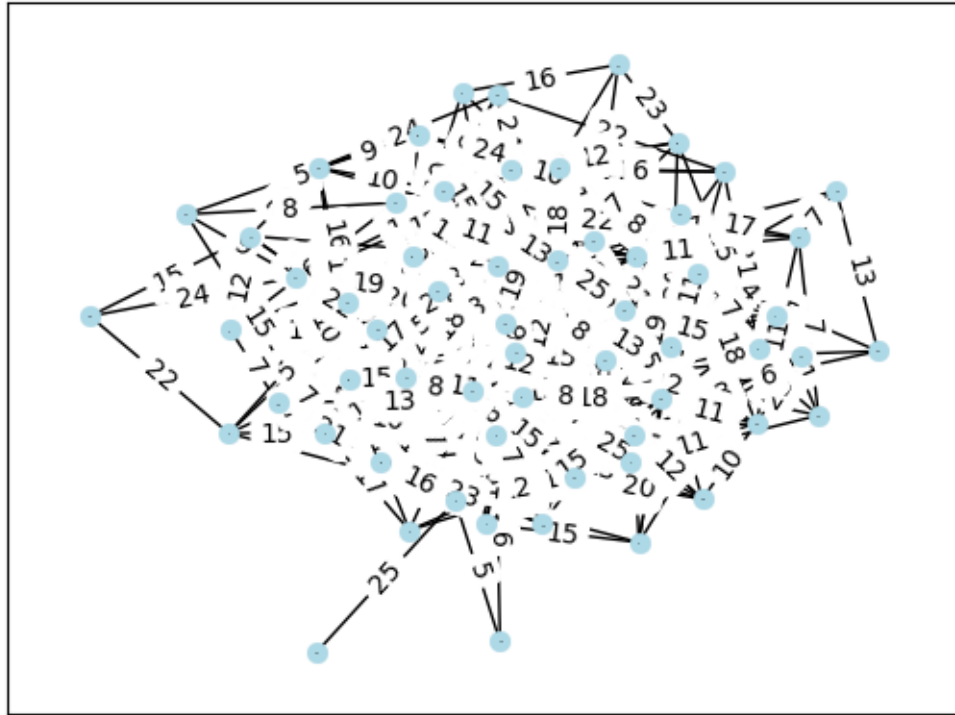
(1, 18)

```
[275]: CityMap.add_road_segment(r4_city_map, source, destination)
```

```
[276]: CityMap.visualize_city_map(r4_city_map, location_size=60, location_font_size=1,
↳road_widths=1)
```

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 (55, 56): 13, (56, 59): 24}



```
[277]: r4_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r4_city_map,
    ↪r3_r4_trips, shrinkage_factor=0.8)
r4_benefit_matrix
```

```
[277]:
```

	source	destination	benefit
135	1	14	1067.8
132	31	37	1053.0
727	49	56	1051.4
298	42	59	1044.0
1531	14	47	1026.0
...
155	7	43	42.0
954	22	58	40.8
393	21	55	39.0
950	10	48	36.4
74	42	44	35.2

[1533 rows x 3 columns]

```
[278]: ##### k = 3 # Recommended road to build last is the road segment
r4_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r4_benefit_matrix)
r4_max_benefit_matrix
```

```
[278]:      source  destination  benefit
      135         1         14    1067.8
```

```
[279]: source, destination = get_max_benefit_road_segment(r4_max_benefit_matrix)
      print(f"({source}, {destination})")
```

```
(1, 14)
```

```
[280]: CityMap.add_road_segment(r4_city_map, source, destination)
```

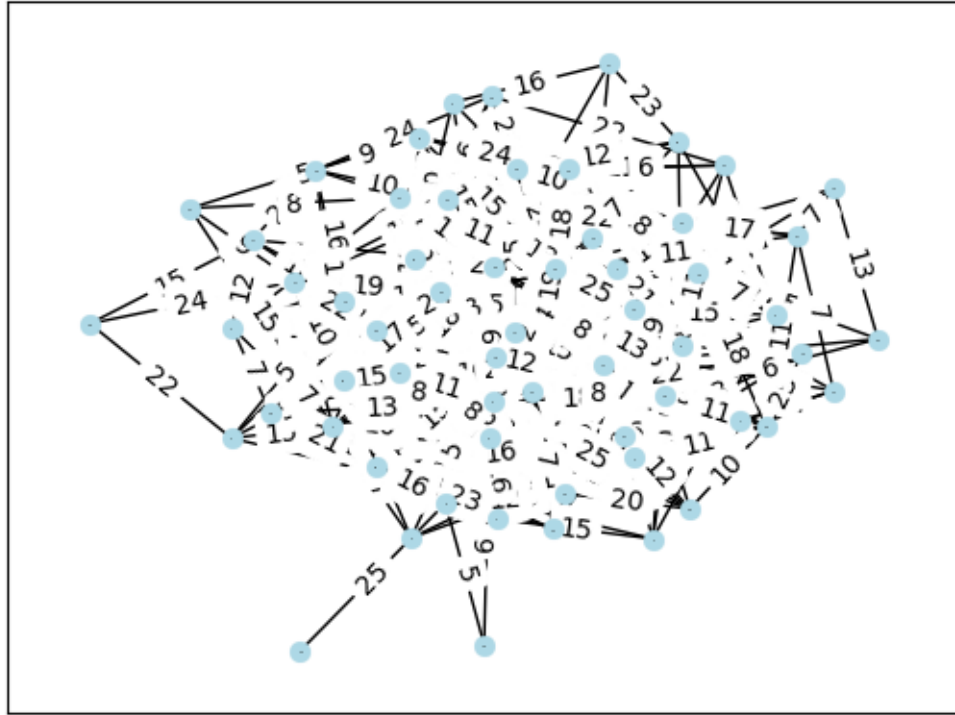
```
[281]: CityMap.visualize_city_map(r4_city_map, location_size=60, location_font_size=1,
      ↪road_widths=1)
```

```
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(55, 58): 10, (55, 56): 13, (56, 59): 24}

```



5 R5

```

[282]: r5_city_map = Simulator.generate_map(connectedness=0.10)
       r5_city_map

```

```

[282]: <networkx.classes.graph.Graph at 0x14ebf2a60>

```

```

[283]: CityMap.get_city_map_statistics(r5_city_map)

```

```

node degree and node clustering
0 9 0.08333333333333333
1 9 0.11111111111111111
2 6 0.06666666666666667
3 6 0
4 8 0.14285714285714285
5 5 0
6 9 0.13888888888888889

```

7 5 0.1
8 11 0.16363636363636364
9 11 0.16363636363636364
10 8 0.03571428571428571
11 6 0.26666666666666666
12 12 0.13636363636363635
13 10 0.08888888888888889
14 16 0.11666666666666667
15 7 0.2857142857142857
16 9 0.05555555555555555
17 6 0.06666666666666667
18 11 0.07272727272727272
19 4 0.33333333333333333
20 6 0.06666666666666667
21 9 0.19444444444444445
22 5 0.1
23 8 0.21428571428571427
24 6 0.2
25 7 0.09523809523809523
26 6 0.2
27 9 0.22222222222222222
28 6 0.13333333333333333
29 11 0.16363636363636364
30 7 0.14285714285714285
31 13 0.16666666666666666
32 4 0.16666666666666666
33 7 0.047619047619047616
34 10 0.08888888888888889
35 5 0.1
36 1 0
37 4 0
38 3 0
39 7 0.14285714285714285
40 11 0.16363636363636364
41 7 0.09523809523809523
42 10 0.13333333333333333
43 8 0.03571428571428571
44 8 0.14285714285714285
45 16 0.09166666666666666
46 2 0
47 10 0.13333333333333333
48 13 0.1794871794871795
49 10 0.11111111111111111
50 4 0
51 6 0.06666666666666667
52 8 0.17857142857142858
53 4 0.16666666666666666
54 9 0.08333333333333333

55 9 0.16666666666666666
56 11 0.2
57 6 0.13333333333333333
58 7 0.09523809523809523
59 9 0.16666666666666666

the adjacency list

0 20 3 35 59 14 27 47 32 5
1 12 52 50 58 39 15 13 8 22
2 11 3 54 8 48 20
3 10 38 13 31
4 22 14 55 6 44 5 45 15
5 18 31 54
6 25 45 31 12 46 27 21 36
7 12 18 22 25 45
8 14 23 40 35 52 51 15 34 42
9 31 28 56 49 48 55 46 11 47 45 58
10 29 16 45 54 50 30 42
11 34 48 42 14
12 31 43 55 21 27 53 18 14 29
13 49 56 17 40 14 21 39 34
14 23 42 22 59 30 52 21 16 29 31
15 42 52 54 55
16 18 53 20 48 34 55 43
17 38 45 39 30 42
18 58 52 21 50 47 28 59
19 57 49 53 45
20 24 51 49
21 30 54 35 28
22 57
23 43 31 37 29 40 54
24 29 43 48 49 26
25 48 33 58 59 42
26 45 59 39 33 29
27 49 34 31 41 40 56
28 33 40 30
29 51 45 34 47 44
30 44 59
31 39 34 40 56 47
32 47 44 41
33 49 39 51 34
34 47 44
35 49 42
36
37 56 50 51
38 47
39 41
40 54 45 56 58 48

```

41 45 56 52 43
42 48 43
43 47 45
44 56 57 45
45 51 49 57
46
47 59
48 53 49 59 55 56
49
50
51
52 54 57
53
54 58
55 57 58 56
56 59
57
58
59

```

```

[284]: CityMap.visualize_city_map(r5_city_map, location_size=60, location_font_size=1,
↪road_widths=1)

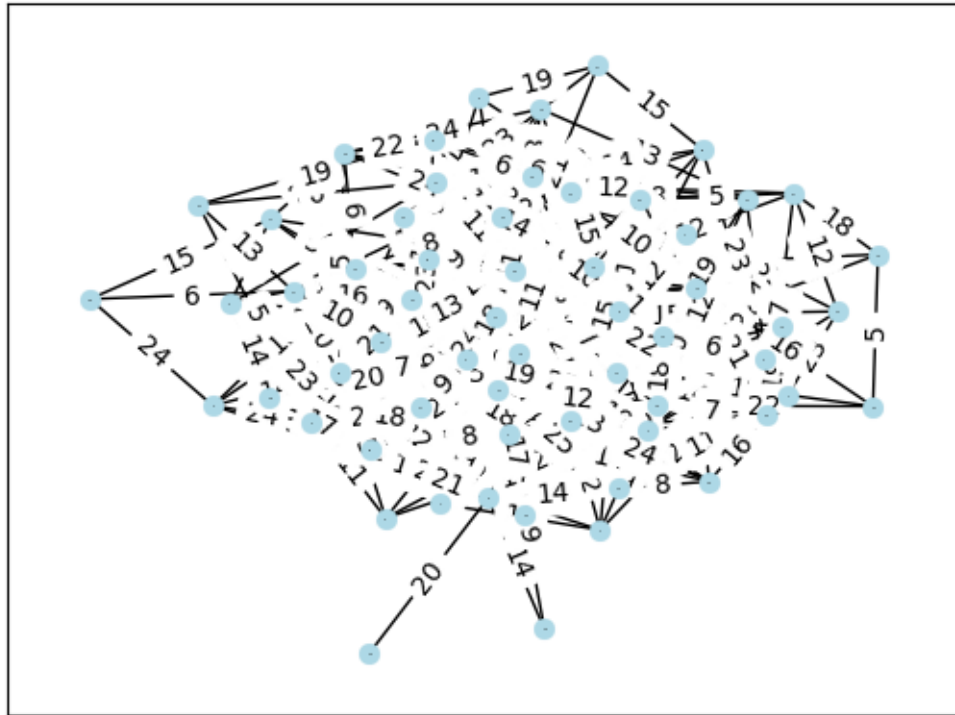
```

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```
[285]: r5_trips = Simulator.generate_trips(city_map,
                                           traffic_start_datetime,
                                           traffic_end_datetime,
                                           TimeDeltaDiff.SECONDS)

r5_number_of_trips = 0
```

```

for trip in r5_trips:
    r5_number_of_trips += trip.number_of_trips

r5_number_of_trips

```

[285]: 36000

[286]: r5_trips

[286]: {Trip(source=32, destination=43, number_of_trips=9): Trip(source=32, destination=43, number_of_trips=9),
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 Trip(source=1, destination=16, numer_of_trips=16): Trip(source=1, destination=16, numer_of_trips=16),
 Trip(source=50, destination=6, numer_of_trips=12): Trip(source=50, destination=6, numer_of_trips=12),
 Trip(source=20, destination=13, numer_of_trips=11): Trip(source=20, destination=13, numer_of_trips=11),
 Trip(source=46, destination=34, numer_of_trips=9): Trip(source=46, destination=34, numer_of_trips=9),

```

destination=34, numer_of_trips=9),
Trip(source=24, destination=57, numer_of_trips=8): Trip(source=24,
destination=57, numer_of_trips=8),
Trip(source=20, destination=29, numer_of_trips=8): Trip(source=20,
destination=29, numer_of_trips=8),
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destination=27, numer_of_trips=11),
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destination=42, numer_of_trips=10),
Trip(source=14, destination=3, numer_of_trips=9): Trip(source=14,
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Trip(source=7, destination=22, numer_of_trips=11): Trip(source=7,
destination=22, numer_of_trips=11),
Trip(source=59, destination=54, numer_of_trips=13): Trip(source=59,
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Trip(source=22, destination=9, numer_of_trips=11): Trip(source=22,
destination=9, numer_of_trips=11),
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Trip(source=29, destination=27, numer_of_trips=8): Trip(source=29,
destination=27, numer_of_trips=8),
...}

```

```

[287]: r5_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r5_city_map,
↳r5_trips)
r5_benefit_matrix

```

```

[287]:
      source  destination  benefit
112      12           47   4659.2
17       18           30   2812.0
132      31           37   2684.4
366      12           16   2653.2
500      23           47   2572.6

```

...
1480	27	42	98.8
535	11	27	96.0
39	6	15	89.6
1391	43	52	81.6
517	4	47	73.6

[1535 rows x 3 columns]

```
[288]: ##### k = 1 # Recommended road to build first is the road segment
r5_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r5_benefit_matrix)
r5_max_benefit_matrix
```

```
[288]:      source destination benefit
112      12          47  4659.2
```

```
[289]: source, destination = get_max_benefit_road_segment(r5_max_benefit_matrix)
print(f"({source}, {destination})")
```

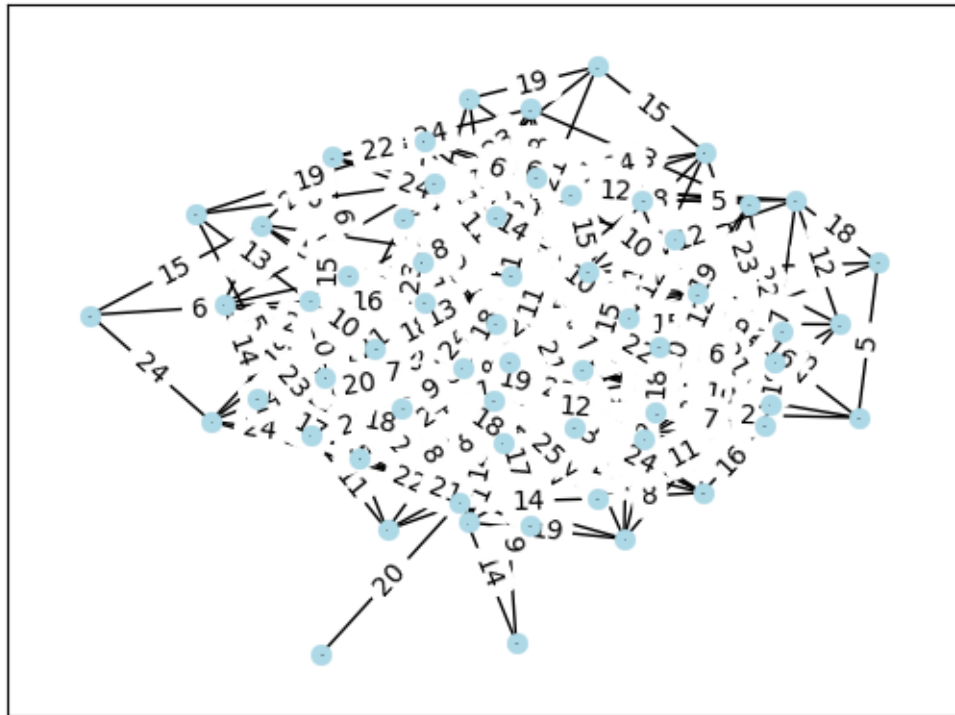
(12, 47)

```
[290]: CityMap.add_road_segment(r5_city_map, source, destination)
```

```
[291]: CityMap.visualize_city_map(r5_city_map, location_size=60, location_font_size=1,
↪road_widths=1)
```

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```
[292]: r5_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r5_city_map,
    ↪r5_trips)
r5_benefit_matrix
```

```
[292]:
```

	source	destination	benefit
131	31	37	2828.8
17	18	30	2812.0
1403	31	55	2533.6
365	12	16	2485.2
30	10	44	2410.2
...
1479	27	42	98.8
534	11	27	96.0
39	6	15	89.6
1390	43	52	81.6
516	4	47	73.6

[1534 rows x 3 columns]

```
[293]: ##### k = 2 # Recommended road to build first is the road segment
r5_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r5_benefit_matrix)
r5_max_benefit_matrix
```

```
[293]:
```

	source	destination	benefit
131	31	37	2828.8

```
[294]: source, destination = get_max_benefit_road_segment(r5_max_benefit_matrix)
print(f"({source}, {destination})")
```

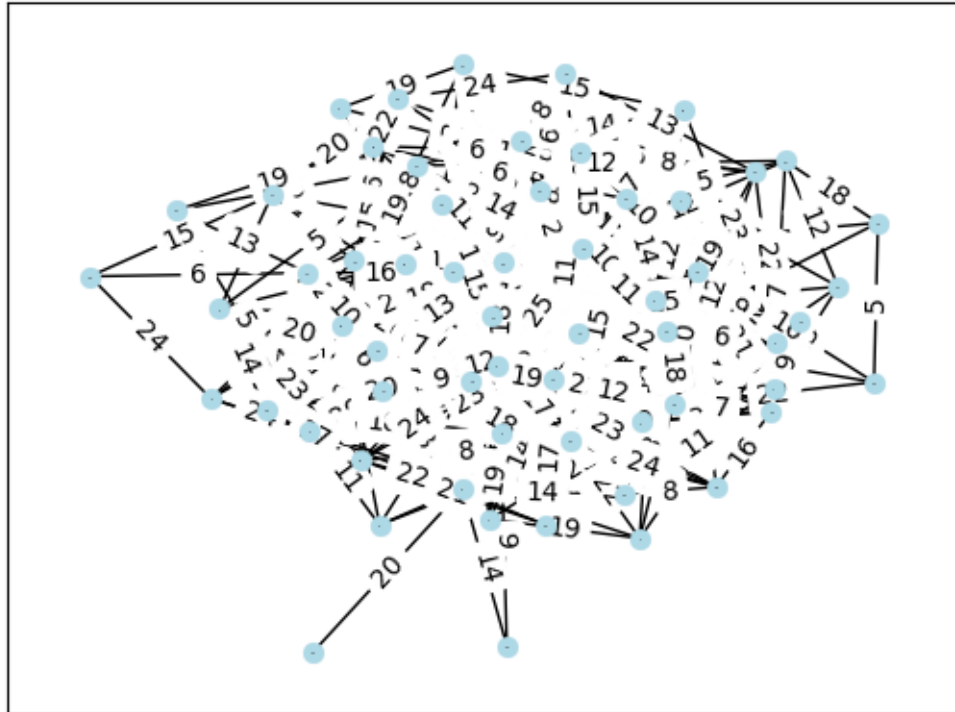
(31, 37)

```
[295]: CityMap.add_road_segment(r5_city_map, source, destination)
```

```
[296]: CityMap.visualize_city_map(r5_city_map, location_size=60, location_font_size=1,
↪road_widths=1)
```

```
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```
[297]: r5_benefit_matrix = TrafficAnalyzer.get_road_recommendations(r5_city_map,
↳r5_trips)
r5_benefit_matrix
```

```
[297]:
```

	source	destination	benefit
25	14	37	3399.48
17	18	30	2812.00
1402	31	55	2746.40
364	12	16	2485.20
549	0	31	2443.60
...
1478	27	42	98.80
533	11	27	96.00
39	6	15	89.60
1389	43	52	81.60
515	4	47	73.60

[1533 rows x 3 columns]

```
[298]: ##### k = 3 # Recommended road to build last is the road segment
r5_max_benefit_matrix = TrafficAnalyzer.get_max_road_benefit(r5_benefit_matrix)
r5_max_benefit_matrix
```

```
[298]:
```

	source	destination	benefit
25	14	37	3399.48

```
[299]: source, destination = get_max_benefit_road_segment(r5_max_benefit_matrix)
print(f"({source}, {destination})")
```

(14, 37)

```
[300]: CityMap.add_road_segment(r5_city_map, source, destination)
```

```
[301]: CityMap.visualize_city_map(r5_city_map, location_size=60, location_font_size=1,
↳road_widths=1)
```

```
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