What is degree centrality ?

- ✓ degree centrality is defined as the number of links incident upon a node (i.e., the number of ties that a node has) divided by the number of nodes in the graph except the node itself.
- ✓ Dc(v) = Number of nodes incident to v/total number of nodes in the graph minus one.

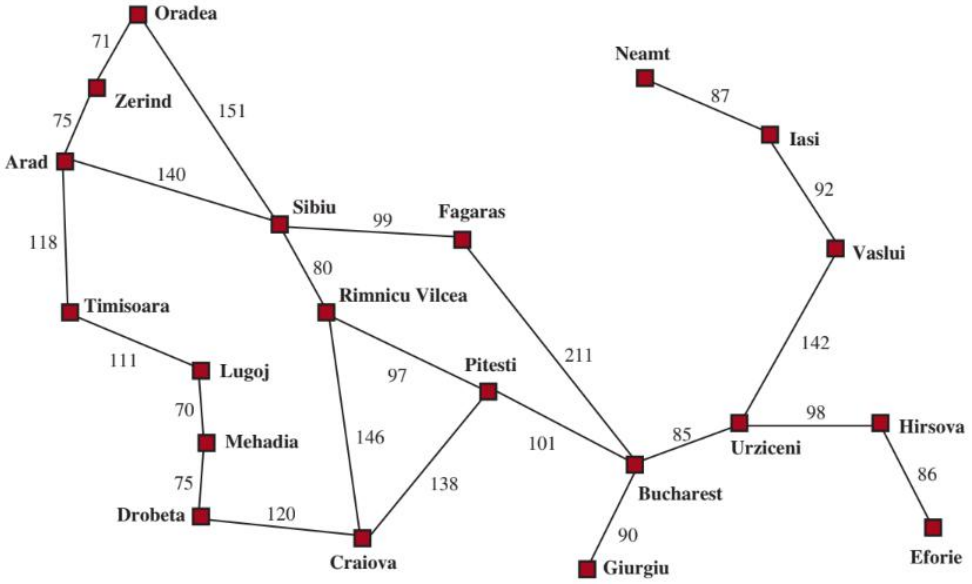
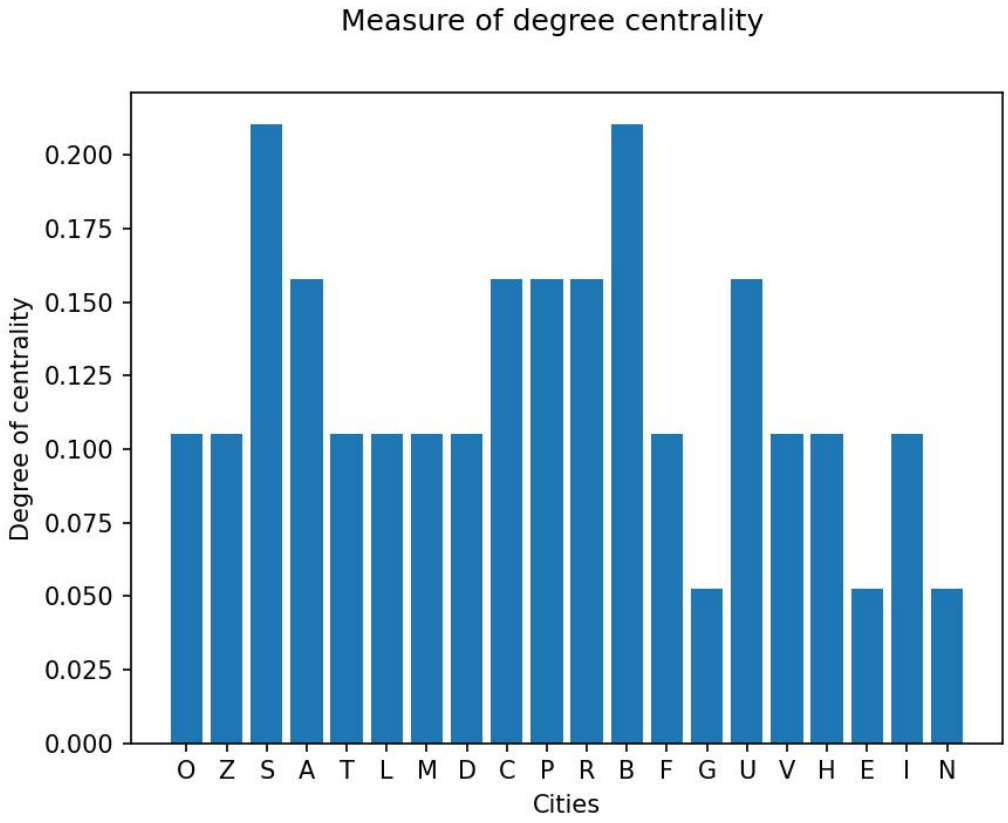


Figure 1.A simplified road map of part of Romania, with road distances in miles.

Cities	Degree of centrality
Oradea	0.10526315789473684
Zerind	0.10526315789473684
Sibiu	0.21052631578947367
Arad	0.15789473684210525
Timisoara	0.10526315789473684
Lugoj	0.10526315789473684
Mehadia	0.10526315789473684
Drobeta	0.10526315789473684
Craiova	0.15789473684210525
Pitesti	0.15789473684210525
Rimniscu	0.15789473684210525
Bucharest	0.21052631578947367

Fagaras	0.10526315789473684
Giurgiu	0.05263157894736842
Urziceni	0.15789473684210525
Vaslui	0.10526315789473684
Hirsova	0.10526315789473684
Isai	0.10526315789473684
Efori	0.05263157894736842
Neamt	0.05263157894736842

Table 1. Degree centrality of the road map part of Romania using Dijkstras shortes path



Bar Graph 1. The first letter of the cities in the x-Axis and degree of centrality in the y-Axis

Observation:

- ✓ Sibiu and Bucharest have highest degree of centrality, because they have more number of incident roads to them.

The number of connected roads for these cities is 4. In contrast Neamt, Efori and Giurgiu cites have the least degree of centrality. They have connected only to one city.

What is Degree of Closeness?

- ✓ In a connected graph,closeness centrality (or closeness) of a node is a measure of centrality in a network, calculated as the sum of the length of the shortest paths between the node and all other nodes in the graph. Thus the more central a node is, the closer it is to all other nodes.
- ✓ Closeness was defined by Bavelas (1950) as the reciprocal of the farness,that is:
- ✓ $C(x) = \frac{N}{\sum_y d(y,x)}$ where d(x,y) is the shortest distance between x and y.
- ✓ so we need to calculate the sum of all the shortest distances from any city to a certain city at a particular time and divide the number of nodes except the city in experiment to find the closeness of the city.
- ✓ To calculate the closeness centrality of the graph, we can use Dikstras shortest path graph algorithm or A* search algorithm.But in this analysis we have used dijkstras shortest path algorithm to find the shortest distance from any city to the solution city.

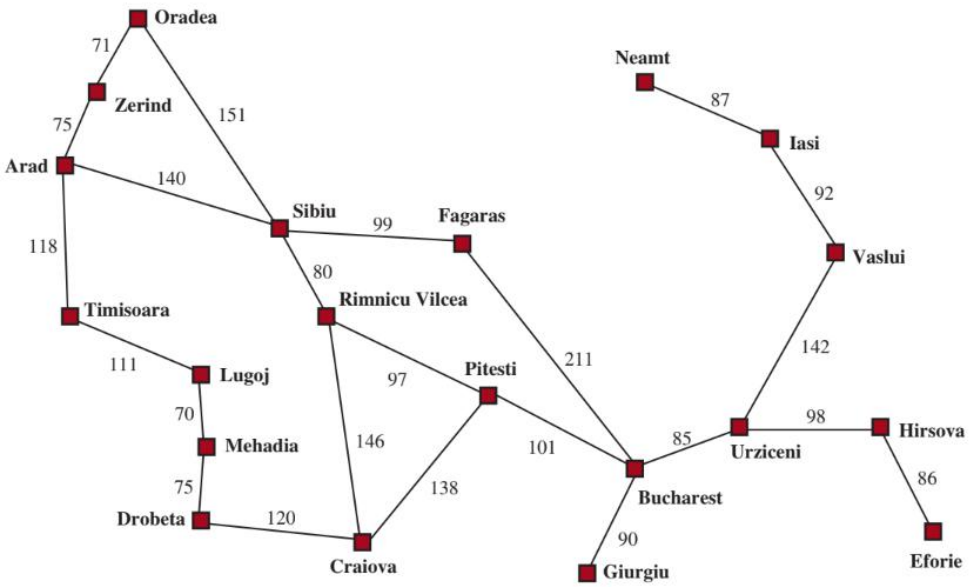
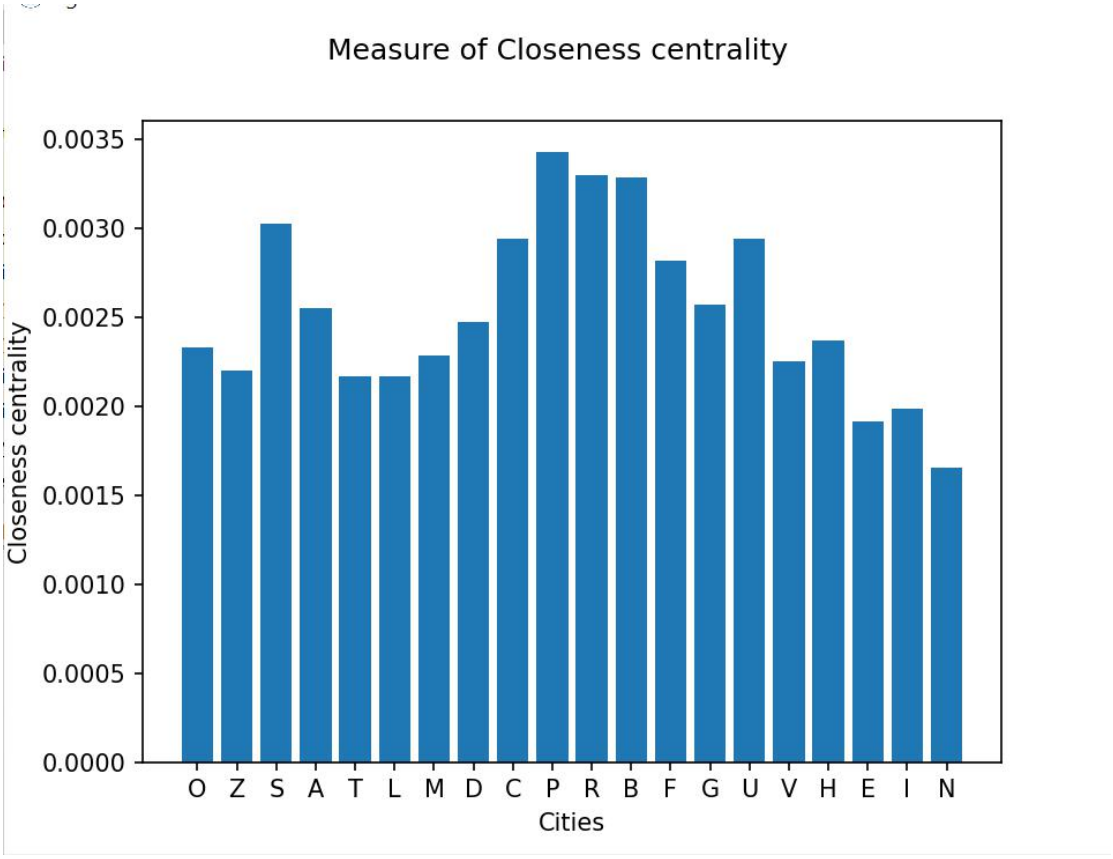


Figure 2.A simplified road map of part of Romania, with road distances in miles.

Cities	Closeness centrality
Oradea	0.002332433095998036
Zerind	0.002197547999074717
Sibiu	0.003023070803500398
Arad	0.00255170561375235
Timisoara	0.002170436371944254
Lugoj	0.0021687022029448695
Mehadia	0.002287778446718844
Drobeta	0.0024733142410830514
Craiova	0.002938447262604392
Pitesti	0.0034289839379173436
Rimniscu	0.003294607248135946
Bucharest	0.003287766049489531
Fagaras	0.002819409407924024
Giurgiu	0.0025679145830517637
Urziceni	0.002941631831552872
Vaslui	0.0022493192849532377
Hirsova	0.0023670113367385073
Isai	0.0019155156769835669
Efori	0.0019843342036553525
Neamt	0.0016543317370483238

Table 2. Closeness centrality of the road map part of Romania using Dijkstras shortes path



Bar Graph 2. The first letter of the cities in the x-Axis and Closeness centrality in the y-Axis

Cities	Closeness centrality
Oradea	0.0232586607907944 68
Zerind	0.002197547999074717
Sibiu	0.0030197075651621106
Arad	0.00255170561375235
Timisoara	0.002170436371944254
Lugoj	0.0021687022029448695
Mehadia	0.002287778446718844
Drobeta	0.0024733142410830514
Craiova	0.002938447262604392
Pitesti	0.0034289839379173436

Rimniscu	0.003294607248135946
Bucharest	0.003287766049489531
Fagaras	0.0028164838422769047
Giurgiu	0.0025679145830517637
Urziceni	0.002941631831552872
Vaslui	0.0022493192849532377
Hirsova	0.0023670113367385073
Isai	0.0019155156769835669
Efori	0.0019843342036553525
Neamt	0.0016543317370483238

Table 3. Closeness centrality of the road map part of Romania using A* search

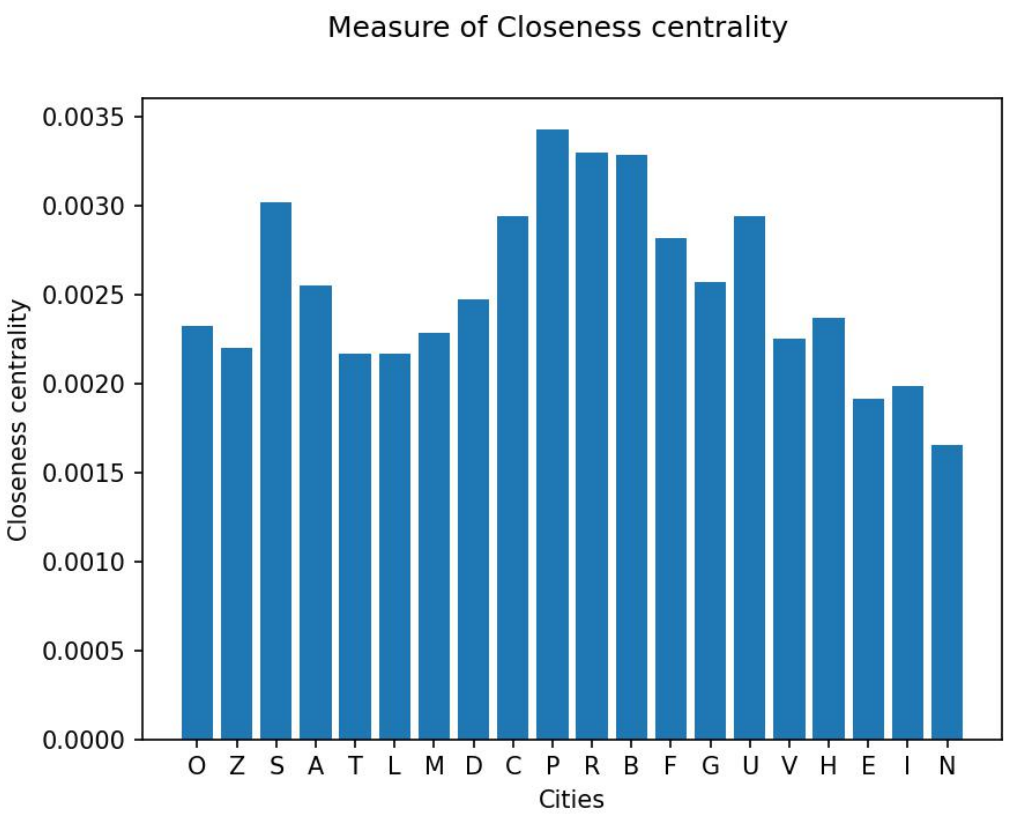


Table 3. Closeness centrality of the road map part of Romania using A* search

Observation:

- ✓ The two algorithm show the same result except some miner difference.For example there is small gap in measure of

Closeness centrality in city Oradea and Sibiu.But all other results are the same

- ✓ In the above bench marks Pitesti has the highest closeness centrality. Where as Neamt has the lowest closeness centrality.
- ✓ We can easy notice how the algorithm give as a valid result. Neamt is the farthest city in the road map graph, so we can say that it has a lowest closeness centrality . because closeness is the reciprocal of farness.

What is betweenness Centrality?

- ✓ In graph theory, betweenness centrality is a measure of centrality in a graph based on shortest paths. For every pair of vertices in a connected graph, there exists at least one shortest path between the vertices such that either the number of edges that the path passes through (for unweighted graphs) or the sum of the weights of the edges (for weighted graphs) is minimized. The betweenness centrality for each vertex is the number of these shortest paths that pass through the vertex.
- ✓ Betweenness centrality finds wide application in network theory: it represents the degree of which nodes stand between each other. For example, in a telecommunications network, a node with higher betweenness centrality would have more control over the network, because more information will pass through that node.
- ✓ Betweenness centrality was devised as a general measure of centrality: it applies to a wide range of problems in network theory, including problems related to social networks, biology, transport and scientific cooperation.
- ✓ Definition

- ✓ The betweenness centrality of a node {\displaystyle v} v is given by the expression:

  $g(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$

- ✓ where σ_{st} is the total number of shortest paths from node s to node t and $\sigma_{st}(v)$ is the number of those paths that pass through v.

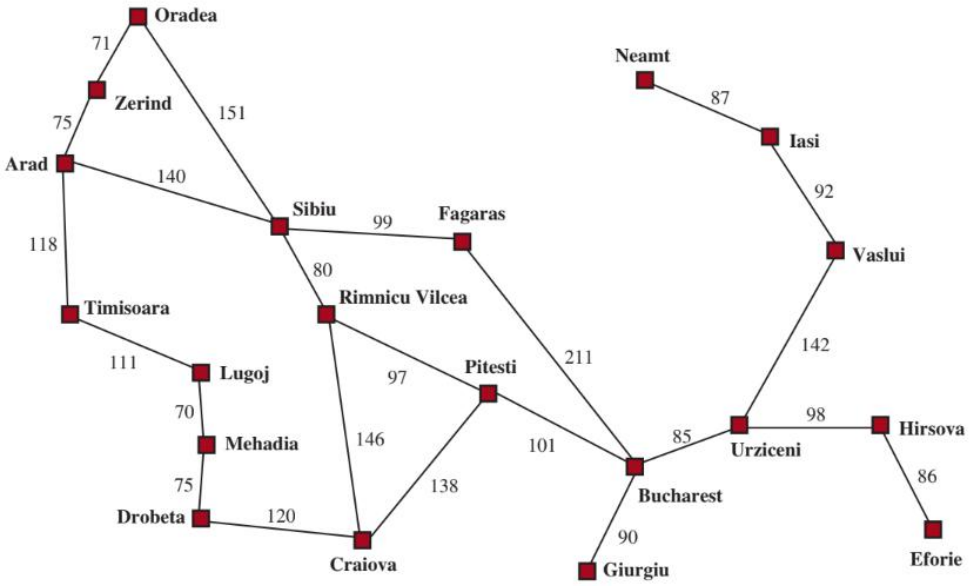
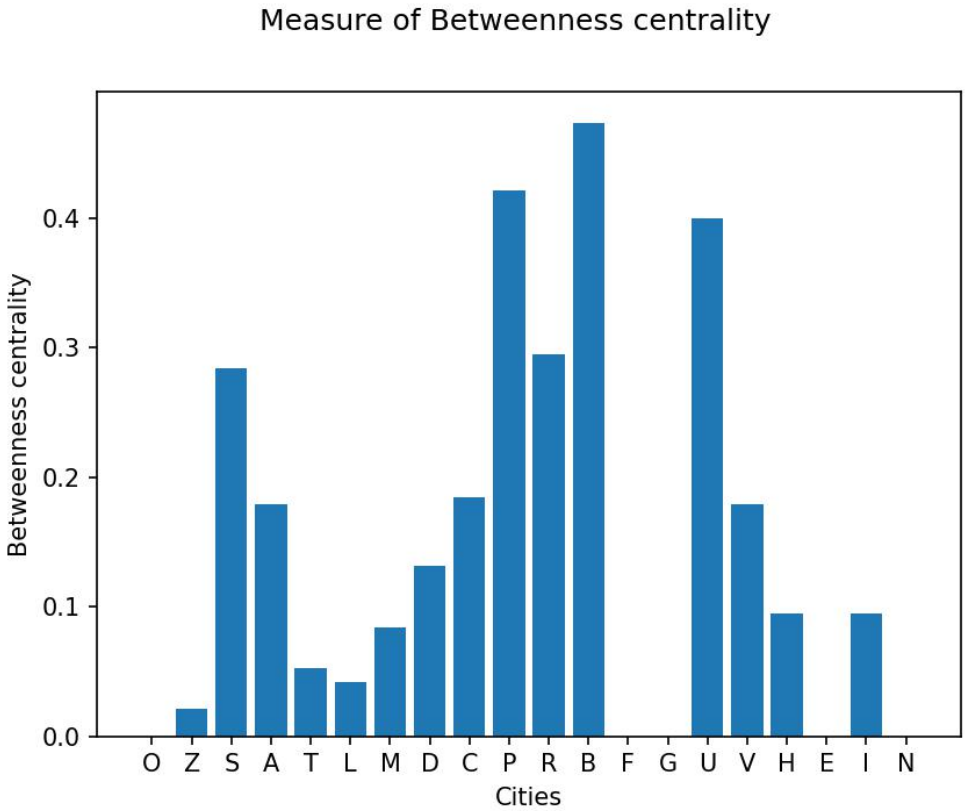


Figure 3.A simplified road map of part of Romania, with road distances in miles.

Cities	Betweenness centrality
Oradea	0.0
Zerind	0.021052631578947368
Sibiu	0.28421052631578947
Arad	0.17894736842105263
Timisoara	0.05263157894736842
Lugoj	0.042105263157894736
Mehadia	0.08421052631578947

Drobeta	0.13157894736842105
Craiova	0.18421052631578946
Pitesti	0.42105263157894735
Rimniscu	0.29473684210526313
Bucharest	0.47368421052631576
Fagaras	0.0
Giurgiu	0.0
Urziceni	0.4
Vaslui	0.17894736842105263
Hirsova	0.09473684210526316
Efori	0.0
Isai	0.09473684210526316
Neamt	0.0

Table 4. Betweenness centrality of the road map part of Romania using Dijkstras shortes path

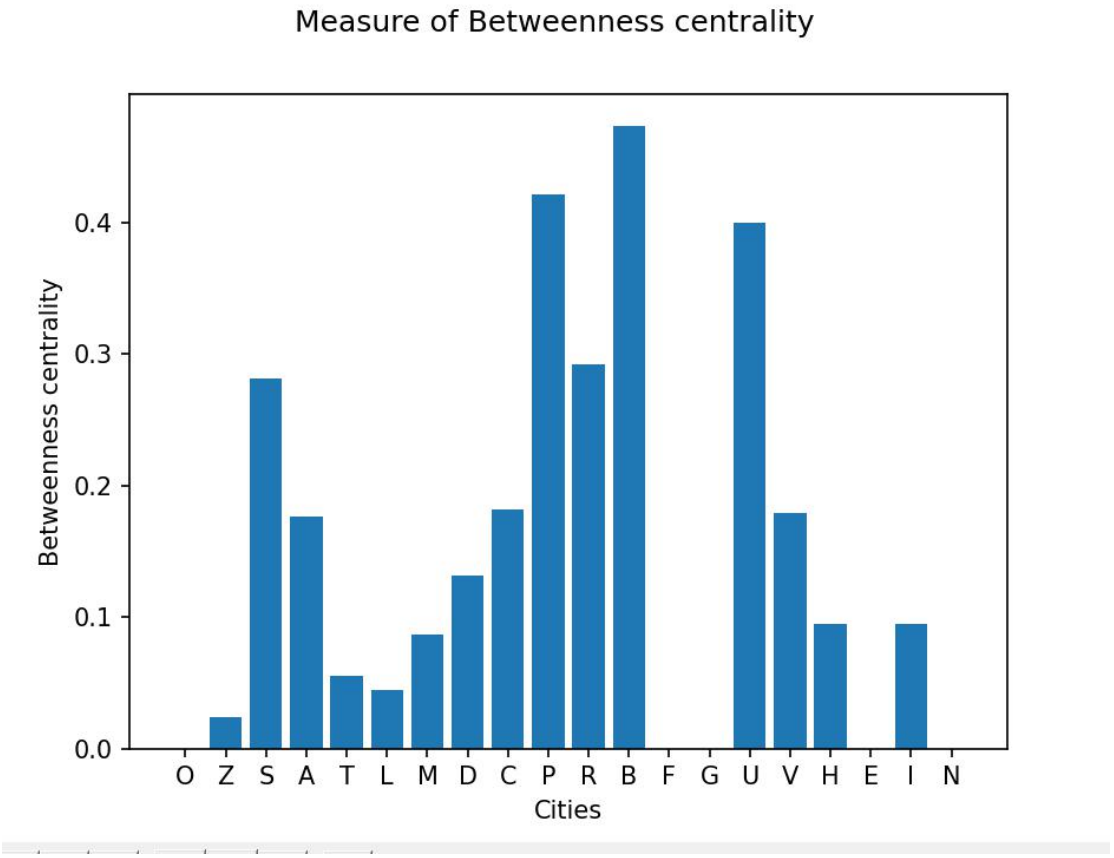


Bar Graph 4. The first letter of the cities in the x-Axis and Betweenness centrality in the y-Axis

Cities	Betweenness centrality

Oradea	0.0
Zerind	0.02368421052631579
Sibiu	0.28157894736842104
Arad	0.1763157894736842
Timisoara	0.05526315789473684
Lugoj	0.04473684210526316
Mehadia	0.0868421052631579
Drobeta	00.13157894736842105
Craiova	0.18157894736842106
Pitesti	0.42105263157894735
Rimniscu	0.29210526315789476
Bucharest	0.47368421052631576
Fagaras	0.0
Giurgiu	0.0
Urziceni	0.4
Vaslui	0.17894736842105263
Hirsova	0.09473684210526316
Efori	0.0
Isai	0.09473684210526316
Neamt	0.0

Table 5. Betweenness centrality of the road map part of Romania using A* search



Bar Graph 5. The first letter of the cities in the x-Axis and Betweenness centrality in the y-Axis

Observation:

- ✓ As showed in the above two tables and graphs the two algorithms showed slit differences in calculating the betweeness centrality of each nodes. But the result is still approximately similar.
- ✓ In the above bar graph the betweenness Centrality of Bucharest is the highest and the betweeness Centrality of Oradea,Fagaras , Giurgui,Efori and Neamt is zero.
- ✓ The highest value of betweenness Centrality indicates tha the city is the bridge between a lot of cities and the lowest value indicates, the city is in the border.