PROJECT TITLE

ANALYSIS OF SINGAPORE METRO STATIONS NETWORK

Team Members:

TEAM 13

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1. Introduction:

As the population grows, so does the need for traffic and the number of vehicles on the road. As a result, we are dealing with a number of issues, including environmental pollution, traffic congestion, and auto accidents. Only when there are fewer cars on the road will this be lessened.

This can be done by expanding public transit. Mass Rapid Transit is one of the most popular ways to enhance public transportation. Many developed nations as well as developing nations like India have already utilised this. establishing metro stations necessitates research into local community and geographic elements. The population in the area of that particular metro rail station must be understood before the station can be built.

This will make it easier for people to locate the station and use it, allowing them to use the metro system more efficiently. A station's importance will increase if it is located in a populated area, and vice versa if a station is less important but is located in a populated area.

Uses of social network analysis include locating the most powerful individuals in social networks, important internet or urban network infrastructure nodes, rumour and disease spreaders. In the same way, centrality measurements could be used to pinpoint the key MRT stations.

The most significant stations in Singapore's metro networks were discovered through network analysis. Stations are regarded as nodes in this context. To do this, we used various centrality metrics, including degree centrality, betweenness centrality, and Eigenvector centrality.

The most significant vertices in a graph are identified using indicators of centrality in graph theory and network research. To identify the highly connected groups inside a network, we created various graph properties such as degree centrality, betweenness centrality, and proximity centrality.

2. Literature Review Summary Table

S. No.	*Authors and Year (Reference)*	*Title (Study)*	*Concept / Theoretical model/ Framework*	*Methodology used/ Implementation*	*Dataset details/ Analysis*	*Relevant Finding*	*Limitations/ Future Research/ Gaps identified*
1	Niraj Sharma 2.rajni Dhyani, 2013	Critical issues related to metro rail projects India	R42—Government and Private Investment Analysis, Transportation Planning, Transportation System	Identifying different problems while constructing metro networks and proposing a solution to them	Daily passengers who use metro	Rail-based 'Mass Rapid Transit System' has been widely accepted as a solution for most of the traffic and environmental pollution related problems which major cities throughout the world are facing now	Theoretical analysis. Experimental results are required.
2	C. Premshankar R. Vidya V. Midhun Raj K. Sateesh Kumar	Analysis of road metro buffer of buffer area of Kochi metro using tools of network analysis, 2014	System design, Centrality, Network Analysis	Used the tools of social network analysis to study the road network of Kochi	Kochi Road networks	It helps to eliminate the future bottlenecks in the existing road network by supporting traffic density reduction and enhancing connectivity to Kochi Metro rail stations.	Some other parts in Kochi should be included
3	Yew-Yih Cheng, Roy Ka-Wei Lee, Ee-eng Lim and	Measuring centralities for Transportation networks beyond structures	Network, Control flow and delay Centrality, Visual Analytics	Network analytics Visual analytics Transportation Network	Singapore subway networks	Most centrality measures in social network analysis research unfortunately consider only topological structure of the network and are oblivious of transportation factors	Can be used for other most used subways

	Feida Zhu, 2015						
8	Wu, Xingtang, Hairong Dong, Chi Kong Tse, Ivan WH Ho, and Francis CM Lau, 2018	Analysis of metro network performance from a complex network perspective	Routing algorithm, Metro system robustness analysis	Node occupying probability, Metro topological efficiency	Six metro networks are compared in terms of the node occupying probability and a few other performance parameters	node occupying probability, is introduced for evaluating the level of utilization of stations	dynamic operational factors not considered. Tokyo and Hong Kong systems are the most robust under random attack and target attack
9	Li, Linbo, Huan Ren, Shanshan Zhao, Zhengyu Duan, Yahua Zhang, and Anming Zhang, 2017	Two-dimensional accessibility analysis of metro stations in Xi'an, China	Attraction accessibility Radiation accessibility Space syntax method	Model for evaluating metro station attraction accessibility	The improvement of walking environment is a key factor in improving the station's overall accessibility	The radiation accessibility represents the ease of reaching other stations from the given station	The bicycle-sharing system has the potential to substantially improve the existing attraction accessibility
10	Chan, Saba, and Luis Miranda-Moreno, 2013	A station-level ridership model for the metro network in Montreal, Quebec	OLS regression , ridership models	Geographic information system (GIS)	Geographic information system (GIS) was used to aggregate the data within the	Geographic information system (GIS) was used to aggregate the data within the buffer area and join them to the corresponding metro station.	The ridership models need to be validated using longitudinal data

					buffer area and join them to the correspon ding metro station.		
11	Mariña s-Colla do, Irene, Elisa Frutos Bernal, Maria Teresa Santos Martin, Angel Martin del Rey, Roberto Casado Vara, and Ana Belen Gil-Go nzález, 2021	A Mathemati cal Study of Barcelona Metro Network	Complex Network Analysis, Structural Network Analysis, measures, clustering analysis	Reduced Model as a simple method of network reduction that preserves the network skeleton (backbone structure) by properly removing 2-degree nodes of weighted and unweighted network representations	Data are very useful to transit planners, from the day-to-da y operation of the transit system to the strategic long-term planning of the network	Results will be of great help in planning and restructuring transport to cope with the new social conditions, after the pandemic	Detailed analysis of the structural characteri stics of this subway network considerin g other different topologica l representa tions such as reduced L-space, P-space, C-space, etc. must be tackled
4	Gattuso , Domeni co, and Ernesto Miriell o, 2005	Compared analysis of metro networks supported by graph theory.	Network's covering, Analysis of indicators, Comparative analysis, metro transit network evaluation, graph indicators, geographical indicators	Metro network analysis	The results of an applicatio n on the metro networks of 13 big metropoli tan areas were illustrated	Assessment of transit network performances involves different levels of investigation	The future research will be addressed on operationa l performan ces and on their relationshi ps with graph indicators

5	Sun, Daniel Jian, and Shituo Guan, 2016	Measuring vulnerability of urban metro network from line operation perspective	Metro network, Vulnerability Disruption, Passenger flow Line operation	Method for evaluating vulnerability, Basic topological property, Vulnerability analysis of Shanghai metro network	Field passenger traffic data were adopted to measuring vulnerability of metro network	The metro lines carrying a large number of passengers generally have a significant impact on the network vulnerability	To deal with line disruptions, strategies, such as providing shuttle buses may be incorporated
6	Zhang, Guohua, Chengtang Wang, Yuyong Jiao, Hao Wang, Weimin Qin, Wu Chen, and Guoqiang Zhong, 2020	Collapse risk analysis of deep foundation pits in metro stations using a fuzzy Bayesian network and a fuzzy AHP	Fuzzy Bayesian Network Modelling, Risk Identification and Fault Tree Construction	Fuzzy Bayesian network (FBN) and a fuzzy analytical hierarchy process (FAHP)	Similar results with the same model and similar input data but also is more flexible and interpretable than a traditional BN and is the inheritance and development of a traditional BN	Proposed approach can provide effective decision-making support for planners and engineers	Developing a data-driven BN model by collecting a large number of foundation pit cases along with field monitoring data to further reduce subjectivity and enhance the robustness of the proposed model

3. Objective of the project:

This project's main goal is to analyse the Singapore metro systems and identify the most significant stations. Every metro network can use this to locate the key station while it is being built.

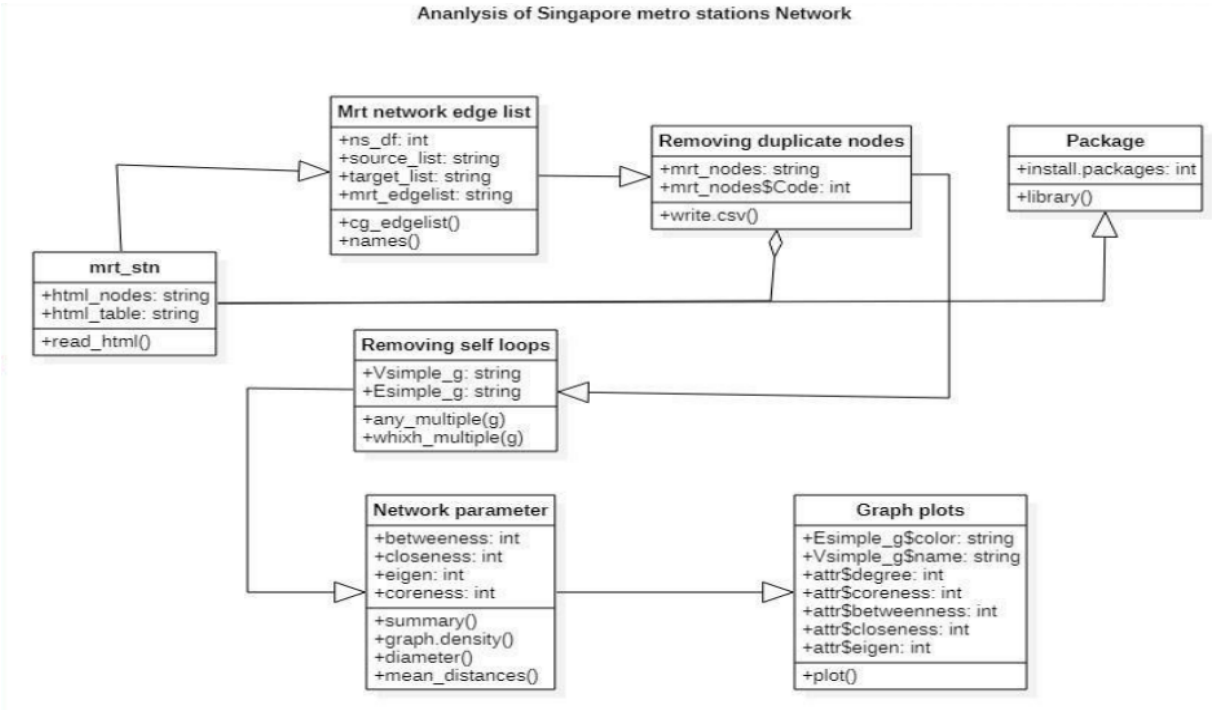
We utilised the stations that will also be announced in this project. As a result, we are able to identify the significant stops even before trains to those stations are announced. This is a really helpful element of the paper that sets it apart from other publications already published.

4. Innovation component in the project:

Using network analysis and visualisation techniques is one creative way to examine the network of Singapore Metro stations. Researchers and urban planners can learn more about how effectively the system works and where it might be improved by modelling the network as a graph and examining its attributes.

For instance, researchers can determine the most significant and well-connected stations in the network as well as the existence of clusters or communities by using metrics like degree centrality, betweenness centrality, and clustering coefficients. They can also employ network visualisation tools, such as heat maps and network diagrams, to visualise the effects of suggested network changes or upgrades, identify bottlenecks and congestion areas, and gain a better understanding of passenger flow patterns.

System Design:



5. Work done and implementation

a. Methodology adapted:

For the purpose of executing our project, we used the R language. R is a language and environment for statistical computing and graphics. Similar to the S language and environment created by John Chambers and colleagues at Bell Labs, it is a GNU project (previously AT&T, now Lucent Technologies). R is considered to be an improved version of S.

Software Requirements

● R 4.2.2

● RStudio 2022.12.0+353

Hardware Requirements

● i5 or above

● 600 mb hard disk space

● 8 GB ram

b. Dataset or Data collection:

Source of dataset: List of Singapore MRT stations - Wikipedia

In this section, we provide an overview of our primary movement data source: For the sake of urban planning, the station locations are based on the Urban Redevelopment Authority's planning zones. If a station is situated on the boundary of two or more planning areas, as is the case with Farrer Park station, numerous locations will be shown.
Instead of merely considering the above-ground parts of the station, this considers the complete station area, including both subterranean and above-ground elements. Network characteristics and public transportation: - The public rail system used in this study is composed of the North-South, East-West, North-East, Circle, and Downtown lines.
There are 123 stations total on the five lines, 15 of which are interchange stations that link two or more lines. The network can handle around 2 million passengers each day. In the research regions, each MRT station has some access features, such as a bus stop and bus interchange, taxi stand, "park & ride" programme, bicycle and motorbike parking, and more (limited spaces and only in Bukit Batok station). As a result, it was expected that all modes of transportation, such as foot, bus, taxi, car, bicycle, and motorcycle, could be used to get to the stations.

c. Tools used:

● rvest: It is a software that enables data harvesting (or scraping) from websites. It was created to connect with Magrittr and make it easier to express simple web scraping tasks. It was influenced by libraries such as Lovely Soup and RoboBrowser.

● igraph: Igraph is a collection of tools for creating, editing, and analysing networks and graphs. Although it was created in C, Python and R packages are also available. There is also a Mathematica interface. The programme is frequently used in academic research on network science and related subjects.

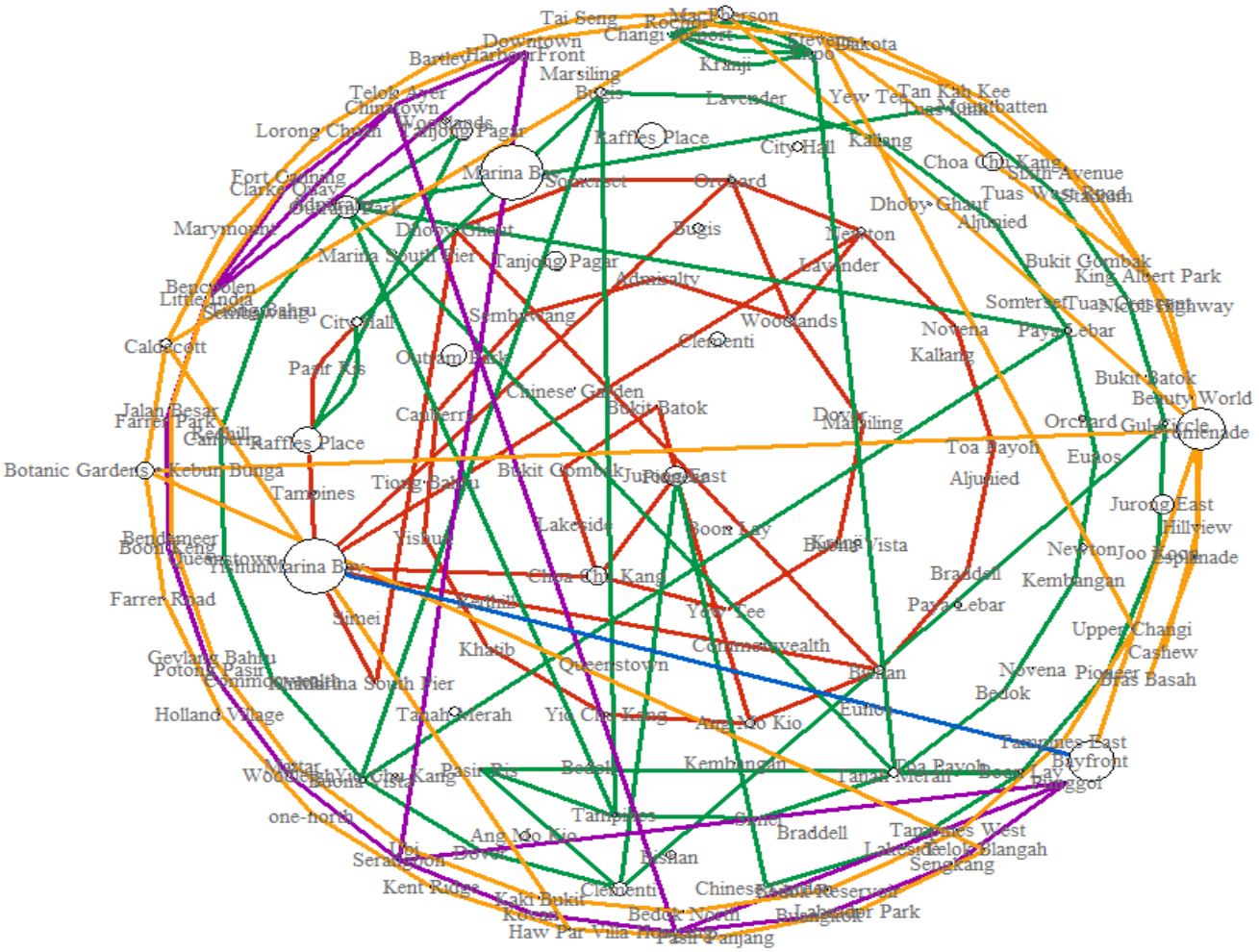
● plyr: It makes data separation, manipulation, and reassembling straightforward. This stage of the data editing procedure is typical. Crucially, plyr offers a set of functions for managing the input and output data format that are syntactically consistent.

d. Screenshot and Demo along with Visualization:

Betweeness graph:

Nodes with high betweenness centrality lie on many shortest paths between other nodes in the network, making them important for information flow or for controlling the spread of diseases.

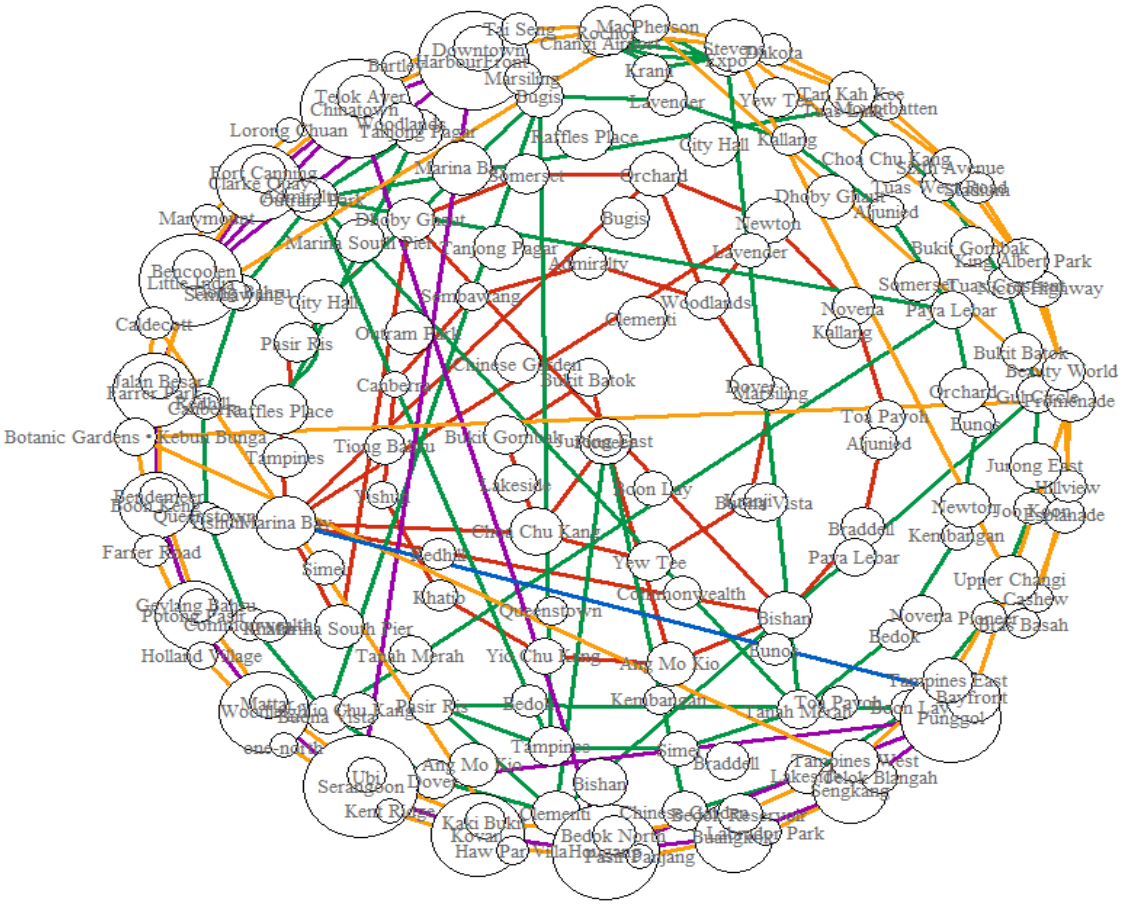
```
# plot betweenness graph

plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,

    vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",

    vertex.label.font=1, vertex.label=V(simple_g)$label, vertex.label.color="grey40",

    vertex.size=V(simple_g)$betweenness*100)

# show the node(s) that holds the largest betweenness value

V(simple_g)$name[betweenness(simple_g)==max(betweenness(simple_g))]
```



Closeness graph:

Nodes with high closeness centrality are close to many other nodes in the network, making them potentially important for efficient communication, information transfer, or disease control.

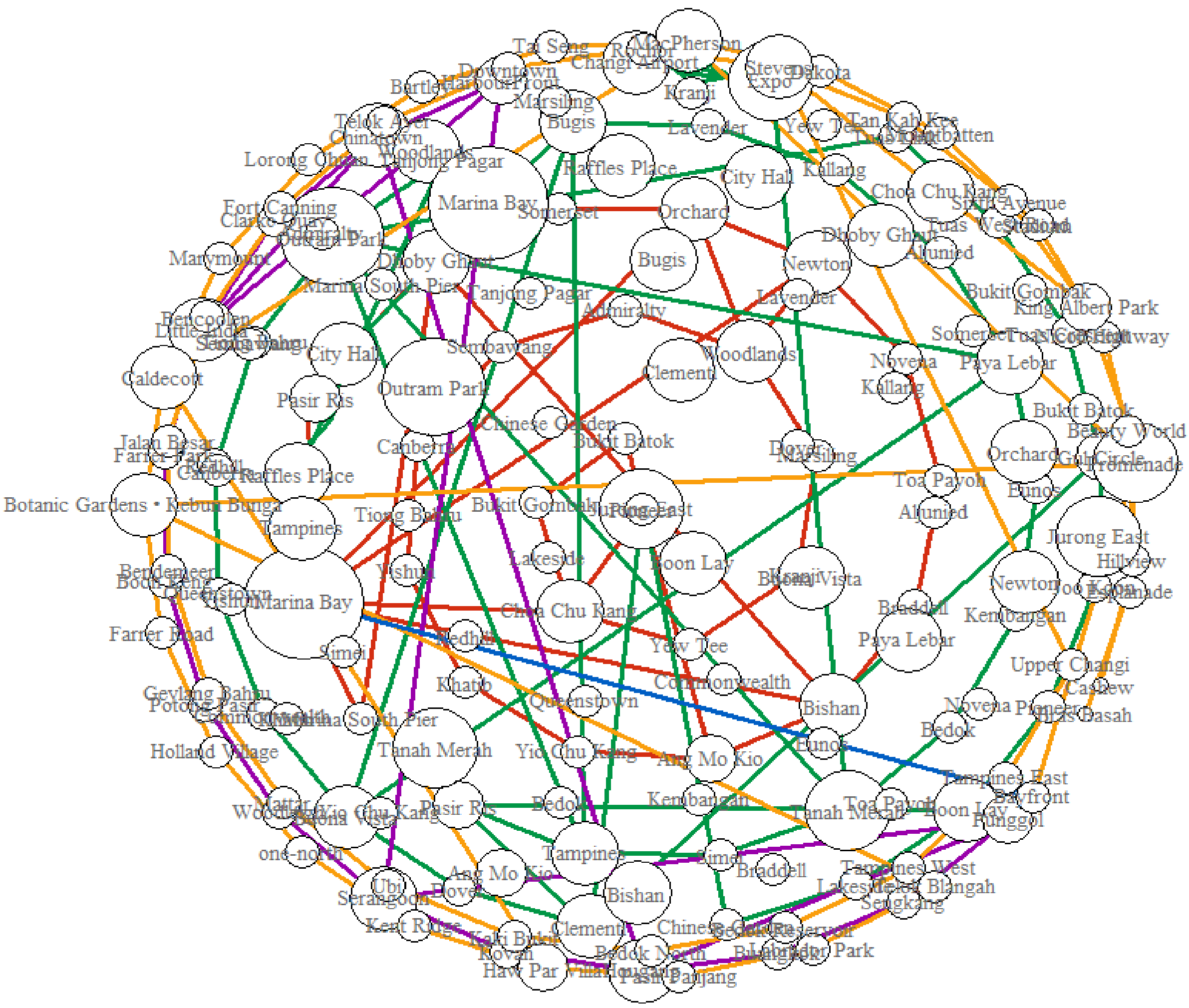
```
# plot closeness graph

plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,

    vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",

    vertex.label.font=.7, vertex.label=V(simple_g)$label, vertex.label.color="grey40",

    vertex.size=V(simple_g)$closeness*50)

#show the node(s) that holds the largest closeness value

V(simple_g)$name[closeness(simple_g)==max(closeness(simple_g))]
```



Degree Centrality Graph:

Nodes with high degree centrality are well-connected to many other nodes in the network, making them potentially important for information diffusion, communication, or disease spread. marina bay

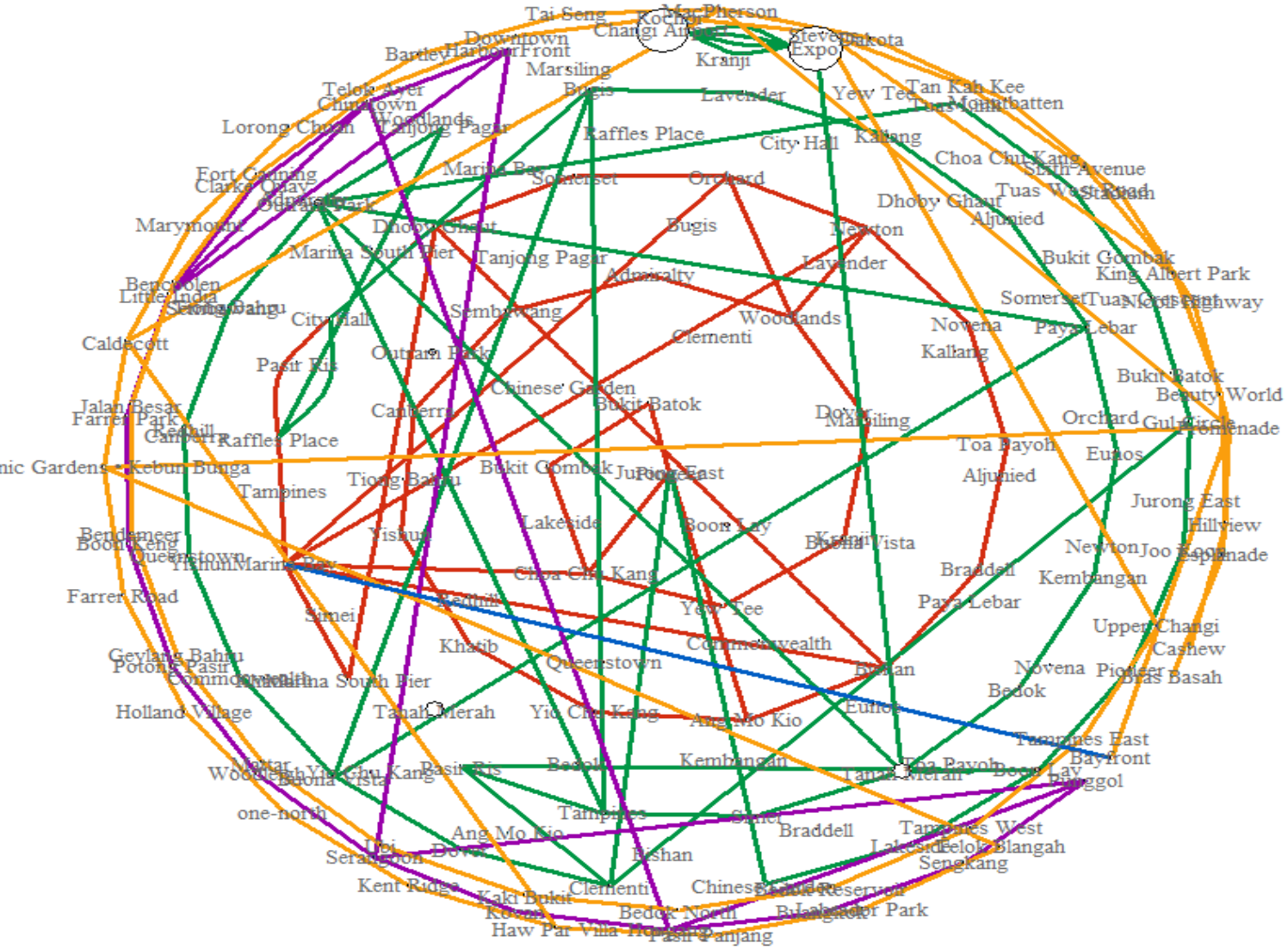
```
# plot degree graph

plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,

    vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",

    vertex.label.font=1.5, vertex.label=V(simple_g)$label, vertex.label.color="grey40",

    vertex.size=V(simple_g)$degree*3.5)

# show the node(s) that holds the largest degree value

V(simple_g)$name[degree(simple_g)==max(degree(simple_g))]
```



Eigen Vector Graph:

Nodes with high eigenvector centrality are connected to other nodes that are themselves well-connected, making them influential in the network. These nodes may be important for information diffusion or spreading opinions.

```
# plot eigenvector graph

plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,

    vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",

    vertex.label.font=1, vertex.label=V(simple_g)$label, vertex.label.color="grey40",

    vertex.size=V(simple_g)$eigen*10)

# show the node(s) that holds the largest eigenvector value

V(simple_g)$name[which.max(V(simple_g)$eigen)]
```



Coreness Graph:

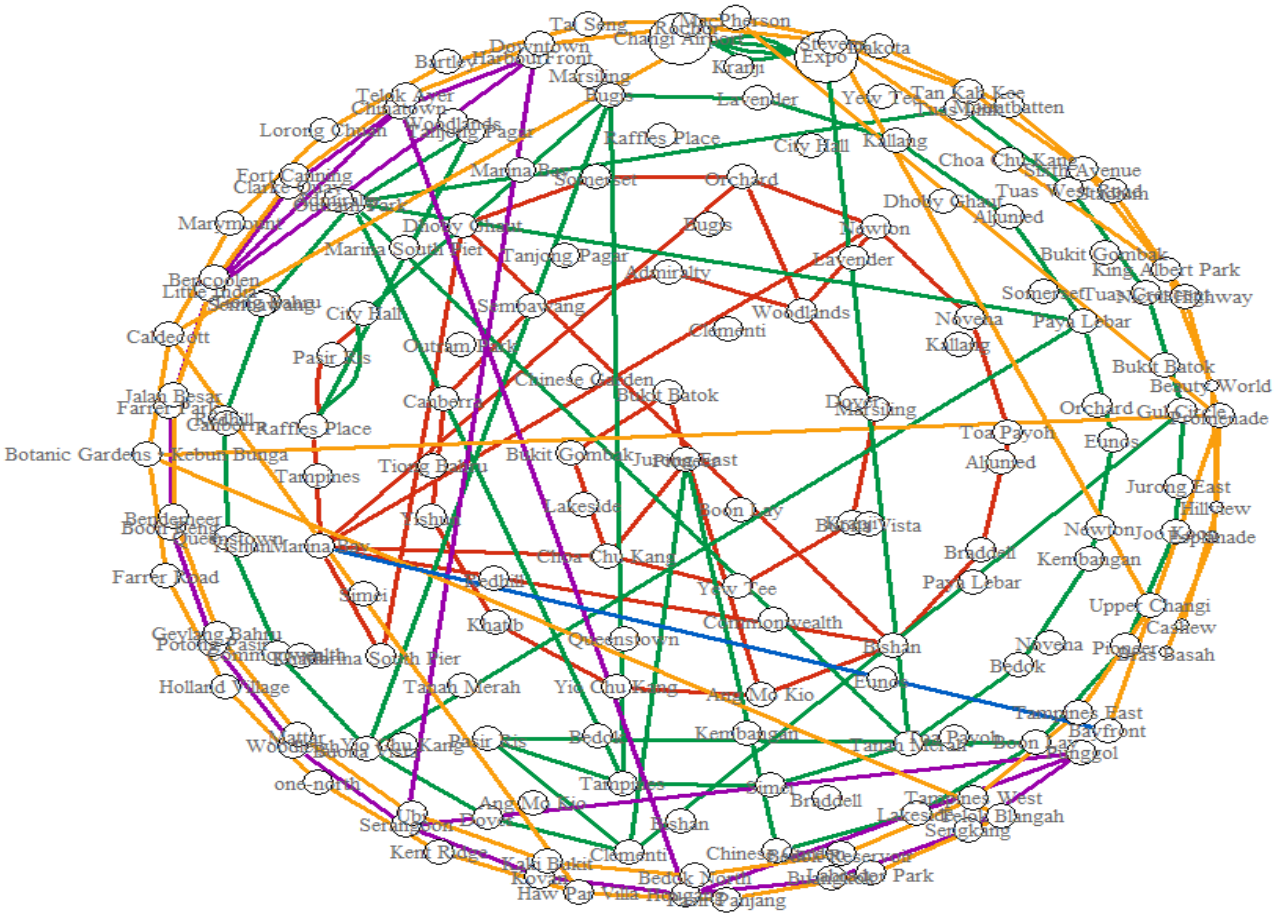
Nodes with high coreness centrality are highly connected to other nodes in the network that are also highly connected, forming a dense core or backbone of the network. These nodes may be important for maintaining the network's structure and function.

#plot coreness graph

plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,

vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",

```
    vertex.label.font=1, vertex.label=V(simple_g)$label, vertex.label.color="grey40",
    vertex.size=V(simple_g)$coreness*3)
# show the node(s) that holds the largest coreness value
V(simple_g)$name[coreness(simple_g)==max(coreness(simple_g))]
```



6. Results and discussion along with Visualization

The following output shows us the centrality measures for each of the stations

```
> attr
```

	degree	coreness	betweenness	closeness	eigen
Jurong East	5	2	0.0453124553	0.2320917	9.583689e-03
Bukit Batok	2	2	0.0009554473	0.1896956	2.823616e-03
Bukit Gombak	2	2	0.0013319411	0.1937799	2.205381e-03
Choa Chu Kang	4	2	0.0405467308	0.2382353	6.384219e-03
Yew Tee	2	2	0.0058719109	0.1966019	1.679291e-03
Kranji	2	2	0.0014398422	0.1701681	6.271045e-04
Marsiling	2	2	0.0009977956	0.1659836	9.389753e-04
Woodlands	4	2	0.0183082980	0.1901408	3.293275e-03
Admiralty	2	2	0.0090044345	0.1629779	8.411666e-04
Sembawang	2	2	0.0043210183	0.1426056	2.187371e-04
Canberra	2	2	0.0013381641	0.1332237	7.209740e-05
Yishun	2	2	0.0027254646	0.1398964	8.228166e-05
Khatib	2	2	0.0072851583	0.1578947	2.714424e-04
Yio Chu Kang	2	2	0.0121581134	0.1828442	1.051036e-03
Ang Mo Kio	3	2	0.0205836848	0.2177419	4.116808e-03
Bishan	4	2	0.0212472445	0.2354651	6.553641e-03
Braddell	2	2	0.0036384731	0.1928571	1.761452e-03
Toa Payoh	2	2	0.0003538694	0.1670103	8.007154e-04
Novena	2	2	0.0021452605	0.1845103	1.581669e-03
Newton	4	2	0.0169691922	0.2231405	5.803020e-03
Orchard	4	2	0.0134971288	0.2231405	6.166813e-03
Somerset	2	2	0.0011177962	0.1980440	3.464358e-03
Dhoby Ghaut	4	2	0.0077612583	0.2165775	8.297465e-03
City Hall	4	2	0.0237465400	0.2219178	1.947958e-02
Raffles Place	4	2	0.0601784038	0.2477064	2.157339e-02
Marina Bay	7	2	0.1247772288	0.2691030	1.318683e-02
Marina South Pier	2	2	0.0010035967	0.2195122	5.145731e-03

Pasir Ris	3	2	0.0102760588	0.1990172	4.790662e-02
Tampines	4	2	0.0104049194	0.1990172	7.539235e-02
Simei	2	2	0.0006358046	0.1716102	1.002065e-01
Tanah Merah	5	2	0.0244514385	0.1901408	3.429866e-01
Bedok	2	2	0.0030441881	0.1613546	8.816761e-02
Kembangan	2	2	0.0005453069	0.1441281	2.512795e-02
Eunos	2	2	0.0029309830	0.1610338	1.674579e-02
Paya Lebar	4	2	0.0157665788	0.1896956	4.478853e-02
Aljunied	2	2	0.0014711683	0.1610338	1.188634e-02
Kallang	2	2	0.0004002785	0.1554702	4.838949e-03
Lavender	2	2	0.0043589744	0.1760870	8.317081e-03
Bugis	4	2	0.0244635606	0.2109375	2.988626e-02
Tanjong Pagar	2	2	0.0401787353	0.2268908	3.792656e-02
Outram Park	6	2	0.0511150388	0.2160000	1.367763e-01
Tiong Bahru	2	2	0.0065778264	0.1800000	3.497620e-02
Redhill	2	2	0.0017652031	0.1545802	9.255143e-03
Queenstown	2	2	0.0006172410	0.1456835	3.665580e-03
Commonwealth	2	2	0.0042819021	0.1649695	6.049269e-03
Buona Vista	4	2	0.0157177664	0.1947115	2.159114e-02
Dover	2	2	0.0072480235	0.1928571	9.422560e-03
Clementi	4	2	0.0336075764	0.2183288	1.774963e-02
Chinese Garden	2	2	0.0071544670	0.1985294	8.939232e-03
Lakeside	2	2	0.0047922440	0.1836735	2.773911e-02
Boon Lay	4	2	0.0123631271	0.1772429	1.068762e-01
Pioneer	2	2	0.0014665274	0.1528302	2.759373e-02
Joo Koon	2	2	0.0014773914	0.1620000	8.332254e-03
Gul Circle	3	2	0.0108752334	0.1836735	7.194830e-03
Tuas Crescent	2	2	0.0017983525	0.1623246	3.957734e-03
Tuas West Road	2	2	0.0017124956	0.1620000	9.329376e-03
Tuas Link	2	2	0.0054716324	0.1808036	3.499398e-02
Expo	5	4	0.0055690915	0.1607143	1.000000e+00
Changi Airport	4	4	0.0000000000	0.1386986	9.580453e-01
[illegible]					
HarbourFront	3	2	0.0007077387	0.4814815	5.874520e-16
Chinatown	4	2	0.0012414433	0.4814815	6.313251e-16
Clarke Quay	2	2	0.0000000000	0.3714286	4.154386e-16
Little India	4	2	0.0011834320	0.4482759	4.706928e-16
Farrer Park	2	2	0.0005917160	0.3611111	2.095867e-16
Boon Keng	2	2	0.0003132614	0.3250000	6.672866e-17
Potong Pasir	2	2	0.0004176819	0.3333333	4.244314e-17
Woodleigh	2	2	0.0008005569	0.3939394	1.970459e-16
Serangoon	4	2	0.0017403411	0.5000000	2.773129e-16
Kovan	2	2	0.0001740341	0.4062500	3.738751e-16
Hougang	4	2	0.0013922729	0.4642857	3.851480e-16
Buangkok	2	2	0.0001740341	0.3421053	2.687918e-16
Sengkang	2	2	0.0001044205	0.3250000	1.207101e-16
Punggol	3	2	0.0008353637	0.4333333	4.620735e-16
Bras Basah	1	1	0.0000000000	0.1519700	6.911157e-05
Esplanade	2	1	0.0055690915	0.1788079	2.885524e-04
Promenade	5	2	0.0930537185	0.2160000	1.135643e-03
Nicoll Highway	2	2	0.0074904281	0.1796009	2.911450e-04
Stadium	2	2	0.0024074719	0.1537002	7.993600e-05
Mountbatten	2	2	0.0003469080	0.1382253	4.260126e-05
Dakota	2	2	0.0033693004	0.1588235	9.793142e-05
MacPherson	4	2	0.0322763662	0.1866359	3.662788e-04
Tai Seng	2	2	0.0067525235	0.1588235	9.423288e-05
Bartley	2	2	0.0017217775	0.1382253	2.715924e-05
Lorong Chuan	2	2	0.0003991182	0.1257764	1.916152e-05
Marymount	2	2	0.0041072050	0.1426056	5.284333e-05
Caldecott	4	2	0.0238763198	0.1646341	2.014683e-04
Botanic Gardens • Kebun Bunga	4	2	0.0386970646	0.1870670	3.651308e-04
Farrer Road	2	2	0.0099547511	0.1594488	9.336769e-05
Holland Village	2	2	0.0048033415	0.1391753	2.469500e-05
one-north	2	2	0.0002784546	0.1251932	9.738097e-06
Kent Ridge	2	2	0.0009049774	0.1269592	1.596319e-05

Haw Par Villa	3	2	0.0099941989	0.1438721	5.691089e-05
Pasir Panjang	2	2	0.0004977376	0.1267606	2.018106e-05
Labrador Park	2	2	0.0017113354	0.1391753	2.734843e-05
Telok Blangah	2	2	0.0066434621	0.1591356	9.400321e-05
Bayfront	2	2	0.0903585103	0.2403561	3.430394e-03
Cashew	1	1	0.0000000000	0.1419355	8.619243e-19
Hillview	2	1	0.0014618865	0.1641791	2.726130e-17
Beauty World	2	1	0.0027845458	0.1913043	5.158441e-17
King Albert Park	3	2	0.0045596937	0.2244898	2.092153e-16
Sixth Avenue	2	2	0.0001392273	0.1880342	8.588912e-17
Tan Kah Kee	2	2	0.0005917160	0.2115385	1.829457e-16
Stevens	4	2	0.0087713192	0.2588235	1.798368e-16
Rochor	2	2	0.0048729551	0.2417582	1.193115e-16
Downtown	2	2	0.0044552732	0.2268041	1.812990e-17
Telok Ayer	2	2	0.0040375914	0.2135922	2.694202e-17
Fort Canning	2	2	0.0036199095	0.2018349	0.000000e+00
Bencoolen	2	2	0.0032022276	0.1913043	0.000000e+00
Jalan Besar	2	2	0.0027845458	0.1818182	0.000000e+00
Bendemeer	2	2	0.0023668639	0.1732283	0.000000e+00
Geylang Bahru	2	2	0.0019491820	0.1654135	0.000000e+00
Mattar	2	2	0.0019491820	0.1654135	0.000000e+00
Ubi	2	2	0.0023668639	0.1732283	0.000000e+00
Kaki Bukit	2	2	0.0027845458	0.1818182	0.000000e+00
Bedok North	2	2	0.0032022276	0.1913043	0.000000e+00
Bedok Reservoir	2	2	0.0036199095	0.2018349	0.000000e+00
Tampines West	2	2	0.0040375914	0.2135922	2.390939e-17
Tampines East	2	2	0.0044552732	0.2268041	2.532434e-17
Upper Changi	2	2	0.0048729551	0.2417582	1.253153e-16

>

By examining these different measures of centrality for each station in the Singapore metro network, we can gain insights into which stations are the most important connectors in the network, and which stations are the most central to the overall transportation system.

```
> V(simple_g)$name[degree(simple_g)==max(degree(simple_g))]
[1] "Marina Bay"
>
> # plot closeness graph
> plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,
+      vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",
+      vertex.label.font=.7, vertex.label=V(simple_g)$label, vertex.label.color="grey40",
+      vertex.size=V(simple_g)$closeness*50)
> #show the node(s) that holds the largest closeness value
> V(simple_g)$name[closeness(simple_g)==max(closeness(simple_g))]
[1] "Serangoon"
>
> # plot betweenness graph
> plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,
+      vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",
+      vertex.label.font=1, vertex.label=V(simple_g)$label, vertex.label.color="grey40",
+      vertex.size=V(simple_g)$betweenness*100)
> # show the node(s) that holds the largest betweenness value
> V(simple_g)$name[betweenness(simple_g)==max(betweenness(simple_g))]
[1] "Marina Bay"
>
> # plot eigenvector graph
> plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,
+      vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",
+      vertex.label.font=1, vertex.label=V(simple_g)$label, vertex.label.color="grey40",
+      vertex.size=V(simple_g)$eigen*10)
> # show the node(s) that holds the largest eigenvector value
> V(simple_g)$name[which.max(V(simple_g)$eigen)]
[1] "Expo"
>
> #plot coreness graph
> plot(simple_g, layout=glay, edge.color=E(simple_g)$color, edge.width=3, edge.curve=1,
+      vertex.label.cex=.7, vertex.color="white", vertex.frame.color="black",
+      vertex.label.font=1, vertex.label=V(simple_g)$label, vertex.label.color="grey40",
+      vertex.size=V(simple_g)$coreness*3)
> # show the node(s) that holds the largest coreness value
> V(simple_g)$name[coreness(simple_g)==max(coreness(simple_g))]
[1] "Expo"           "Changi Airport"
```

We perform a centrality analysis of the metro stations in Singapore, we can obtain different measures of centrality for each station, including betweenness centrality, degree centrality, closeness centrality, eigenvector centrality, and coreness centrality.

Betweenness centrality: This measure quantifies the extent to which a station lies on the shortest paths between all pairs of stations in the network. Stations with high betweenness centrality serve as important connectors in the network, facilitating the flow of passengers between different parts of the system.

The Marina Bay metro station is an important transportation hub that plays a critical role in connecting people to key attractions and facilitating the flow of people and commerce in the area. Its location, connections to major metro lines, and efficient transportation services make it a vital part of Singapore's public transportation network.

1. **Connects to key attractions:** The Marina Bay metro station connects to several key attractions in the area, such as the Marina Bay Sands integrated resort, Gardens by the Bay, and the Marina Bay Cruise Centre. This makes it a convenient and accessible location for tourists and locals alike to access these popular destinations.
2. **Access to the Central Business District:** The Marina Bay metro station is located near the Central Business District, which is the heart of Singapore's economy. Many businesses and financial institutions are located in this area, and the Marina Bay metro station serves as an important transportation link for workers to commute to and from work.
3. **Intersection of major metro lines:** The Marina Bay metro station serves as an intersection between the Downtown Line and the Circle Line, which are two of the main metro lines in Singapore. This makes it a convenient transfer point for commuters who need to switch between different lines to reach their destination.
4. **Efficient transportation:** The Marina Bay metro station is part of Singapore's efficient and reliable public transportation system. With frequent train services and modern facilities, commuters can expect a smooth and comfortable ride to their destination.

Closeness centrality:

This measure quantifies the average distance between a given station and all other stations in the network. Stations with high closeness centrality are more central to the network, as they can be reached more easily from other stations.

The Serangoon metro station is an important transportation hub that connects residential areas to other parts of Singapore, facilitates intermodal transportation, and plays a critical role in

Singapore's public transportation system. Its location, connectivity, and role in facilitating the movement of people and goods make it an essential component of Singapore's transportation infrastructure.ll,

1. **Connectivity:** Serangoon metro station is an interchange station, which means it connects the North East Line and the Circle Line. This makes it a convenient transfer point for commuters who need to switch between different lines to reach their destination. It also makes the station an important link for people traveling to or from the northeastern part of Singapore.
2. **Access to residential areas:** The station is located in an area with several residential estates such as Serangoon Gardens, Braddell Heights, and Upper Serangoon. The station is thus a crucial transportation link for residents living in these areas to access various parts of Singapore, including schools, workplaces, and other amenities.
3. **Proximity to shopping malls:** Serangoon metro station is located near several shopping malls such as NEX, which is one of the largest shopping malls in Singapore. The station is thus an important transportation hub for shoppers who want to visit these malls to buy goods or services.
4. **Intermodal transportation:** The station is designed to facilitate intermodal transportation. It has bus bays that connect to several bus services, including feeder buses that provide connectivity to the nearby housing estates. This makes it easy for commuters to switch from one mode of transportation to another, allowing them to reach their destinations quickly and efficiently.
5. **Role in Singapore's public transportation system:** The Serangoon metro station is an important part of Singapore's public transportation system, which is known for its efficiency, reliability, and convenience. The station is designed to handle large volumes of commuters during peak hours, ensuring that people can reach their destinations on time.

Eigenvector centrality:

This measure takes into account the centrality of a station's neighboring stations. Stations with high eigenvector centrality are connected to other stations that themselves have high centrality, making them important connectors in the network.

The Expo metro station is an important transportation hub that connects residential areas to other parts of Singapore, facilitates intermodal transportation, and plays a critical role in Singapore's public transportation system. Its location, connectivity, and role in facilitating the movement of people and goods make it an essential component of Singapore's transportation infrastructure.

1. **Connectivity**: The Expo metro station is an interchange station, connecting the East West Line and the Downtown Line. This makes it a convenient transfer point for commuters who need to switch between different lines to reach their destination. It also makes the station an important link for people traveling to or from the eastern part of Singapore.
2. **Access to Changi Airport:** The Expo metro station is located near Changi Airport, one of the busiest airports in the world. The station is thus an important transportation link for passengers traveling to or from the airport. Additionally, the station is located near several airport-related facilities such as the Singapore Expo and Changi Business Park.
3. **Proximity to Exhibition Centers:** The station is located near the Singapore Expo, one of the largest exhibition centers in Singapore. The station is thus an important transportation hub for people attending events and exhibitions at the Expo.
4. **Access to Residential Areas:** The station is located near several residential areas such as Tampines and Bedok. The station is thus a crucial transportation link for residents living in these areas to access various parts of Singapore, including schools, workplaces, and other amenities.
5. **Intermodal transportation:** The station is designed to facilitate intermodal transportation. It has bus bays that connect to several bus services, including feeder buses that provide connectivity to the nearby housing estates. This makes it easy for commuters to switch from one mode of transportation to another, allowing them to reach their destinations quickly and efficiently.
6. **Role in Singapore's public transportation system:** The Expo metro station is an important part of Singapore's public transportation system, which is known for its efficiency, reliability, and convenience. The station is designed to handle large volumes of commuters during peak hours, ensuring that people can reach their destinations on time.

Degree centrality:

This measure simply counts the number of edges that connect a given station to other stations in the network. Stations with high degree centrality have many connections to other stations and are therefore well-connected to different parts of the network.

The Marina Bay metro station is an important transportation hub that plays a critical role in connecting people to key attractions and facilitating the flow of people and commerce in the area. Its location, connections to major metro lines, and efficient transportation services make it a vital part of Singapore's public transportation network.

5. **Connects to key attractions:** The Marina Bay metro station connects to several key attractions in the area, such as the Marina Bay Sands integrated resort, Gardens by the Bay, and the Marina Bay Cruise Centre. This makes it a convenient and accessible location for tourists and locals alike to access these popular destinations.
6. **Access to the Central Business District:** The Marina Bay metro station is located near the Central Business District, which is the heart of Singapore's economy. Many businesses and financial institutions are located in this area, and the Marina Bay metro station serves as an important transportation link for workers to commute to and from work.
7. **Intersection of major metro lines:** The Marina Bay metro station serves as an intersection between the Downtown Line and the Circle Line, which are two of the main metro lines in Singapore. This makes it a convenient transfer point for commuters who need to switch between different lines to reach their destination.
8. **Efficient transportation:** The Marina Bay metro station is part of Singapore's efficient and reliable public transportation system. With frequent train services and modern facilities, commuters can expect a smooth and comfortable ride to their destination.

Coreness centrality:

This measure is based on the concept of k-cores, which are subgraphs of the network where all nodes have at least k connections to other nodes in the subgraph. The coreness centrality of a station is the highest value of k for which the station is a member of the k-core subgraph. Stations with high coreness centrality are important hubs in the network, as they are connected to many other stations.

Both the Changi Airport and Expo metro stations are essential components of Singapore's transportation infrastructure. Their location, connectivity, and role in facilitating the movement of people and goods make them important transportation hubs for commuters traveling to or from different parts of Singapore.

1. **Connectivity**: Both stations are interchange stations, connecting multiple lines within the transportation network. The Changi Airport station connects the East West Line and the Changi Airport Branch Line, while the Expo station connects the East West Line and the Downtown Line. This makes them convenient transfer points for commuters who need to switch between different lines to reach their destination.
2. **Access to important areas:** Both stations are located near important areas in Singapore. The Changi Airport station is located directly below the airport terminal buildings, providing a convenient transportation link for passengers traveling to or from the airport. The Expo station is located near Changi Business Park and several commercial and residential areas, making it an important transportation hub for people traveling to or from these locations.
3. **Role in airport operations:** The Changi Airport station plays a crucial role in the efficient operation of Changi Airport. It provides a reliable and efficient transportation link for airport staff, who need to move around the airport complex. The Expo station is also important for events held at the Singapore Expo, providing convenient access for visitors.
4. **Intermodal transportation:** Both stations are designed to facilitate intermodal transportation. They have bus bays that connect to several bus services, allowing commuters to switch from one mode of transportation to another easily.
5. **Coreness graph:** Both stations have high coreness values in the coreness graph, indicating their importance as central transportation hubs within the network of stations in Singapore. Their connectivity with multiple other nodes within the transportation network makes them crucial transfer points for commuters.

From the results obtained from the different centrality measures applied to the MRT network, we could often see that the station 'Marina Bay' of NSL network frequently appears as one of the significant nodes suggesting that it could likely be the most important node in the MRT network. The consequences of removing such a node might break the network into different

smaller networks and reduce connectivity among the network, seriously impairing the connectivity and coverage of the MRT services.

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