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An assessment of the topological characteristics of Australian cities

Colin Gu[1], Ankit Goel[1,2], Sai Chand[1], Vinayak Dixit[1]

[1]Research Centre for Integrated Transport Innovation, School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW 2052

[2]Indian Institute of Technology (BHU), Varanasi, Uttar Pradesh, India.

Email for correspondence: saichand.chakka@unsw.edu.au

Abstract

The analysis of the road network structure of cities can provide invaluable information to transport authorities in managing traffic congestion and improving safety and accessibility. A comparison of networkwide structural characteristics of different cities can be useful to benchmark and test different traffic management strategies. This paper presents the preliminary results from an ongoing research study on the assessment of topological characteristics of the 30 most populous cities in Australia. Key metrics such as node density, edge density, node degree, centrality measures, and clustering coefficient are evaluated. The results show a significant variation in each of the metrics across the cities. Apart from a few exceptions, typically, the bigger cities are observed to have shorter edges, higher node density, higher edge density, lower average centrality measures and lower clustering coefficient.

1 Introduction

The road network structure of a city can be studied and analysed by network science and its mathematical scaffold – graph theory; it is a relatively young discipline that has emerged only in the 21st century. Studies about network structure and its behaviour have been studied in diverse disciplines across different countries, such as telecommunication networks, biological systems and social networks. Transport networks are as vital and relatable to daily human activity as the above systems; its complexity and importance have aroused interests from many researchers worldwide. In transportation, there have been several applications of network science in the recent years, such as the impacts of network structure on safety (Marshall and Garrick 2011; Moeinaddini et al. 2014; Mohan et al. 2017), resiliency (Latora and Marchiori, 2002), accessibility and economy (Xiao et al. 2016).

2 Metrics considered in the study

A network contains two essential items, nodes and edges. Edges are the roads in the network, whereas nodes are the intersections (and dead-ends). The number of edges connecting to a node is its node degree, the mean of all node degrees in a network is the average node degree.

Degree centrality of a node, which indicates the relative importance of a node in the network is measured by dividing its node degree by n-1, where n is the total edge

number of the network, with the average degree centrality being the mean of degree centralities of all the nodes in the network. Closeness centrality of a node is measured by the reciprocal of the sum of all distances between a node to all other nodes in the network. The node is considered more valuable if it is closer to other nodes. Betweenness centrality is an evaluation of how frequent a node is used, measured by the number of shortest paths that pass through this node divided by the total number of edges (Boeing 2017).

The clustering coefficient C_i of a node shows how well its neighbours are connected; it is a measurement of local node density and connectivity, with a higher C_i indicating a denser local network. It is calculated using the formula $C_i = \frac{2L_i}{k_i(k_i-1)}$, where L_i is the number of edges between each neighbor of the node i, with k_i node degree, this formula guarantees a value between 0 and 1, where $C_i = 0$ means no connection between any surrounding nodes, $C_i = 1$ account for every neighbouring node is connected with each other in this cluster. The average weighted clustering coefficient is the average of the weighted clustering coefficient of each node based on their edge lengths.

3 Data and Results

The top thirty Australian cities by population were considered in this study (Australian Bureau of Statistics 2019). Most of the cities are along the eastern coast (Figure 1). The study area for these cities is focussed on the central business districts (CBD) and its close surroundings with sizes between 100-200 km^2 for the top 5 populous cities and 25-100 km^2 of land area for smaller cities. OpenStreetMap was used to extract the road network information using the coding package OSMNX in Python.

Figure 1 – Map of Australia with the top 30 populous cities

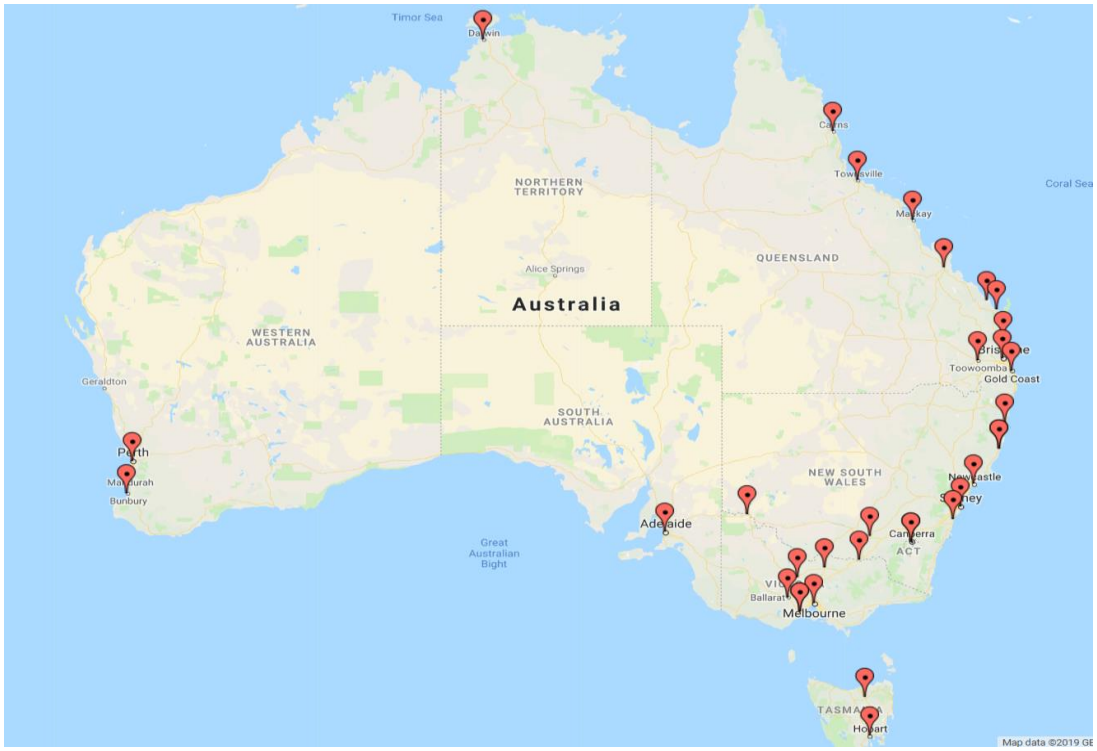

Table 1 presents the metrics for all the cities considered in the analysis. The metrics are colour-coded with the higher values in each column in Red and the lower values

in Green. As can be seen, the highly populated cities have a higher proportion of motorways, and primary roads and lower proportion of residential roads. Also, the bigger cities are observed to have shorter edges, but with higher edge density[1]. Similarly, the node density is higher for bigger cities, with the highest being in Adelaide and Melbourne. A network with higher node density and shorter edges means a high number of conflicting movements spaced shortly apart, which can have implications on safety as well as congestion.

The average weighted clustering coefficient showed a significant variation with more populous cities, typically having a lower value than the others. Sydney and Melbourne are the two cities with the least average weighted clustering coefficient, whereas Cairns has the highest. Similarly, the centrality measures of the most populous cities are significantly lower than the others. The average centrality measures and the clustering coefficients indicate that the smaller cities have a higher proportion of nodes that act as hubs in the network than the bigger cities.

4 Conclusions

The Australian population has been steadily increasing for decades, especially in capital cities. However, urban planning has not coped with this increasing rate, which is now leaving most of the largest cities in Australia in serious congestion issues. Assessing the structure of road networks and their topological characteristics can help in traffic management, planning, and improving safety and accessibility. This paper presented the preliminary results of an ongoing study on the assessment of topological characteristics of Australian cities. The ongoing research includes calculating more metrics to quantify the network structure, the correlations between the metrics considered in this study and modelling the relationships between the topological metrics, traffic congestion and travel time reliability.

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[1] Number of lanes not considered in the analysis.

Table 2 - Network metrics for the top 30 populous Australian cities

S.No.	CITY	Area (km²)	Motorways (%)	Residential Roads (%)	Primary Roads (%)	Other roads (%)	Avg edge length (m)	Edge Density (km per sq.km)	Node density (no.of nodes per sq.km)	Avg Node Degree	Degree Centrality Avg*1000	Closeness Centrality Avg*1000	Betweenness Centrality Avg*1000	Clustering Coefficient Weighted Avg*1000
1	Sydney	113	0.3	64	12	24	109	22	82	4.84	0.52	0.14	5.35	0.65
2	Melbourne	159	0.3	62	13	25	100	22	95	4.64	0.31	0.14	3.71	0.76
3	Brisbane	103	0.7	57	13	28	110	23	88	4.79	0.53	0.14	5.74	1.13
4	Perth	120	0.6	55	14	30	108	19	80	4.4	0.46	0.13	5.11	0.97
5	Adelaide	109	0.0	72	8	19	101	24	97	4.84	0.46	0.15	5.4	1.02
6	Gold Coast	119	0.3	64	10	25	112	15	64	4.16	0.54	0.11	7.24	1.95
7	Newcastle	136	0.2	74	2	24	133	14	43	4.91	0.84	0.13	7.44	1.53
8	Canberra	129	1.0	50	6	43	120	12	45	4.46	0.77	0.13	8.15	2.13
9	Sunshine Coast	82	0.5	78	6	15	116	14	52	4.52	1.06	0.12	10.61	1.04
10	Wollongong	81	0.6	57	7	35	140	11	33	4.67	1.76	0.15	11.34	1.98
11	Geelong	53	0.2	72	1	26	112	18	69	4.76	1.3	0.18	11.46	2.35
12	Hobart	41	0.2	65	3	32	121	14	50	4.56	2.26	0.23	16.84	1.06
13	Townsville	35	0.0	61	8	31	122	20	73	4.65	1.85	0.24	12.17	4.22
14	Cairns	31	0.0	53	2	45	105	19	86	4.2	1.57	0.26	13.44	5.47
15	Darwin	24	0.0	65	6	29	116	14	53	4.47	3.46	0.25	21.5	4.14
16	Toowoomba	41	0.0	67	0	33	126	22	70	4.98	1.73	0.25	10.94	3.91
17	Ballarat	69	0.0	67	3	31	119	15	55	4.71	1.24	0.2	9.85	3.08
18	Bendigo	40	0.0	70	4	26	113	17	66	4.63	1.76	0.28	12.1	2.48
19	Albury	24	0.2	56	2	42	103	18	81	4.39	2.32	0.27	15.87	3.1
20	Launceston	62	0.6	77	0	22	131	11	38	4.59	1.94	0.19	14.01	2.1
21	Mackay	22	0.0	48	0	52	130	16	55	4.42	3.61	0.31	20.47	3.3
22	Rockhampton	26	0.0	70	4	26	131	19	57	5.13	3.43	0.26	17.73	2.58
23	Bunbury	21	0.0	74	9	18	129	18	58	4.73	3.82	0.35	18.91	3.1
24	Coffs Harbour	20	0.0	64	0	36	125	15	55	4.34	4.04	0.31	23.69	4.06
25	Bundaberg	32	0.0	64	4	33	123	17	59	4.78	2.55	0.29	14.98	1.61
26	Wagga Wagga	28	0.0	80	0	20	140	16	47	4.82	3.6	0.28	17.54	3.28
27	Hervey Bay	44	0.0	74	4	21	143	14	43	4.73	2.55	0.21	15.16	1.98
28	Mildura	31	0.0	79	0	21	101	14	65	4.26	2.14	0.31	14.73	1.67
29	Shepparton	23	0.0	65	0	35	93	17	78	4.58	2.56	0.33	16.85	2.07
30	Port Macquarie	26	0.0	76	3	22	127	17	58	4.53	3	0.25	18.73	2.6