

Evolution of Sydney's Bus Network: 1925 to 2020

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1. Introduction

The evolution of railway and highway networks has been widely studied (Levinson, 2008; Cats, 2017; Barrington-Leigh and Millard-Ball, 2015; Wang et al., 2019). Similar research for bus networks is less common because unlike roads and railways, bus networks lend themselves to frequent modifications and it is unlikely that these modifications have been documented and preserved over decades. But an understanding of the dynamics of bus network evolution is invaluable as their flexibility enables planners to tailor services to suit a region's characteristics. Fortunately, Sydney's bus network changes since 1925 have been archived by historians and transit enthusiasts. Our research leverages this treasure trove of historic information to investigate the evolution of the Greater Sydney region's bus network over nearly a century, from 1925 to 2020, with a motivation to inform future public transport planning decisions.

Figure 1 compares Sydney's bus network in 1925 and 2020. To gain insights into the network's evolution, we studied changes in the network's structure. Through network structure analysis, our study attempts to answer the following questions: how did network connectivity change, how circuitous or direct was the network, was the network mono-centric or poly-centric, and how did the accessibility offered by the network change.

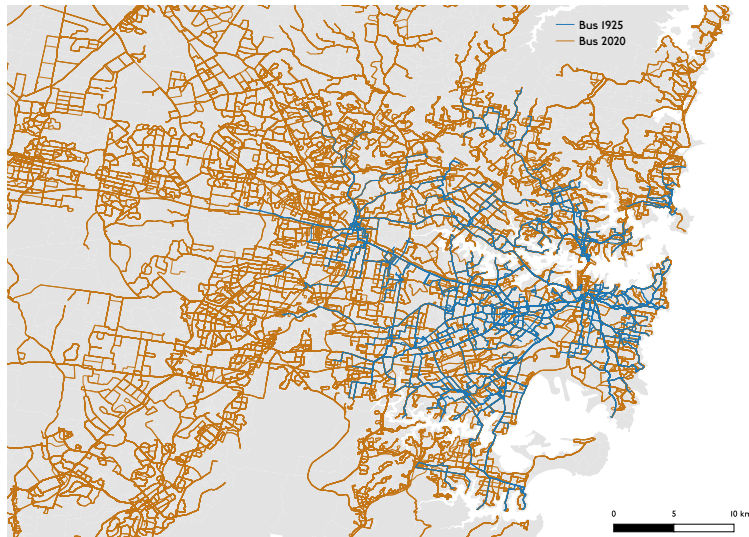


Figure 1: Sydney's bus network in 1925 (blue) and 2020 (brown) illustrating the widespread suburban expansion.

Many studies have employed network structure analyses to predict network evolution dynamics (Chatterjee, Manohar, and Ramadurai, 2016; Yang et al., 2014; Chen, Li, and He, 2007). Our study conducts a longitudinal investigation into the Greater Sydney region's bus network evolution. In the following sections, we describe the procedure employed in converting historic archives into

a state-of-the-art spatio-temporal database. We also present preliminary results from a network structure analysis of the historic bus networks.

2. Data and Method

Over the last decade, it has become standard practice to document transit network and service information in the form of General Transit Feed Specification (GTFS) files. For the Greater Sydney region, Transport for New South Wales (TfNSW), the state transport authority, collates information from the region’s various transit service operators and publishes GTFS bundles regularly at Transport for NSW (2021). The majority of GTFS released by TfNSW from March 2013 onward have been archived at Open Mobility Data (2021). [However, the GTFS for 2013 and 2014 are incomplete making 2015 the earliest year with a reliable published GTFS.](#) For the years prior to 2015, we generated GTFS files based on historic bus route and timetable information archived by Henderson (2021). The archives date back to 1925 and provide systematically arranged records of changes in streets traversed, timetables, and operating arrangements for every bus route. Using this information, we generated bus networks for every year since 1925 by digitising street lists to geo-referenced routes while tracking temporal relevance.

2.1. Digitising historic bus networks

We developed a Python script to read the archived data in text format, identify the street lists and timelines of relevance for each route, and produce geo-referenced routes in shapefile format – a commonly used geospatial vector data format. For the script to work smoothly, we arranged the archived information in a standardised format by assigning unique route names and establishing timelines across years before feeding the documents into the script. The geo-referencing module of the script uses the Python package, OSMnx (Boeing, 2017), built to facilitate analyses on street networks from OpenStreetMap (OpenStreetMap contributors, 2021). Using OSMnx, we converted street lists into geo-referenced routes in two steps. First, we matched consecutive streets in a route’s street list with OSMnx street intersections. Where there were multiple intersections with the same street names, we chose the one closest to the previous intersection on the route. If such an intersection is the first one on the route, we initially chose one at random and later edited the street list to avoid such intersections through manual checks. This process converted a list of streets into a list of geo-referenced street intersections. In the second step, we obtained the shortest path between each pair of intersections on a route and merged the individual paths to get the entire route.

Timelines, on the other hand, describe the start and end year a bus route operated. By integrating timelines and digitised routes, we generated a bus network for each year since 1925 to [2015](#).

The archives also report summaries of timetables under operation at different points in time for each route. The summaries include off-peak run time, first and last trip start times and locations, and average off-peak frequency by day of week. We arranged this information for each route into standard tables reflecting the unique route names given to the digitised routes. We also prepared separate timelines for schedules as route paths and timetables did not necessarily change in the same year.

What we could not obtain is historic bus stop information. As a result, we made certain assumptions. All the stops serviced by buses today were assumed to have been serviced historically. For streets with bus services in the past, but not today, we populated stops at every 400 m – the region’s guideline for stop spacing (NSW Government, 2013, p. 6) and the average stop spacing in the current bus network. [The fabricated stops correspond to 27% of stops on an average across years with](#)

the maximum at 30% in 1952. Consequently, the data generated may be limited in studying the impacts of stop location and spacing.

We used the digitised routes, formatted timetables and the generated stops to develop historic bus GTFS files. The method and assumptions involved in GTFS generation will be documented in a forthcoming article.

2.2. Network structure analysis

To study the structural attributes of the bus networks, we built directed graphs with stops as nodes and segments of bus routes between stops as edges. Two nodes were connected by an edge when a route serviced the two stops. In case of edges serviced by multiple routes, we assigned the number of routes traversing the edges as weights. For distance calculations, we assigned the distance between the stops connected by edges as an additional attribute.

For each network graph, we calculated the degree, density, betweenness centrality and clustering coefficient using the built-in functions from NetworkX package (Hagberg, Schult, and Swart, 2008) written in Python. The definitions of the attributes explored are as follows:

- The degree of a node is the sum of its edges, in other words, the number of routes servicing a stop. It was calculated considering the weights on the edges that connect to nodes.
- Density is the ratio of actual edges in the network to all possible edges.
- Betweenness centrality measures the importance of nodes in terms of their contribution to network connectivity and cohesion. It is calculated as the sum of the fraction of all shortest paths that pass through every node in the network.
- Clustering coefficient indicates the extent to which nodes in the network tend to cluster together. A node's clustering coefficient is the fraction of all possible triangles (clusters) that can be formed through that node.

A comparison of average values of the above attributes for the digitised historic networks (1925 to 2015) are presented in the next section. The validation and integration of the digitised networks with those available from Open Mobility Data (2021) is in progress and will be published at a later date. We also intend to extend this analysis to include the network structure variables of circuitry and accessibility.

3. Results and Discussion

Figure 2 presents the evolution of Sydney's bus network from 1925 to 2015 depicted as a change in the number of routes and the total length of the routes by year. In 1925, there were 281 routes running over a cumulative length of 4,540 km compared to 898 routes spanning 25,394 km in 2015. Both the number of routes, and route lengths, increased over time excepting the drop around 1931 which corresponds to the imposition of heavy taxes on bus services (entirely run by private operators at the time) competing with trams (Travers, 1982). However, the popularity of buses meant that Government had to arrange bus operations starting 1932.

Interestingly, the average degree of nodes indicate similar connectivity levels in 1925 and 2013, as shown in Figure 3. The magnitude of the degree is as high as 5, suggesting an average of 5 routes servicing stops, in part, because we considered route variations as separate routes. The drop in bus operations after the introduction of taxes in 1931 is more pronounced in degree measurements. The increase in the late 1950s could be attributed to the tram-to-bus conversions carried out around this period.

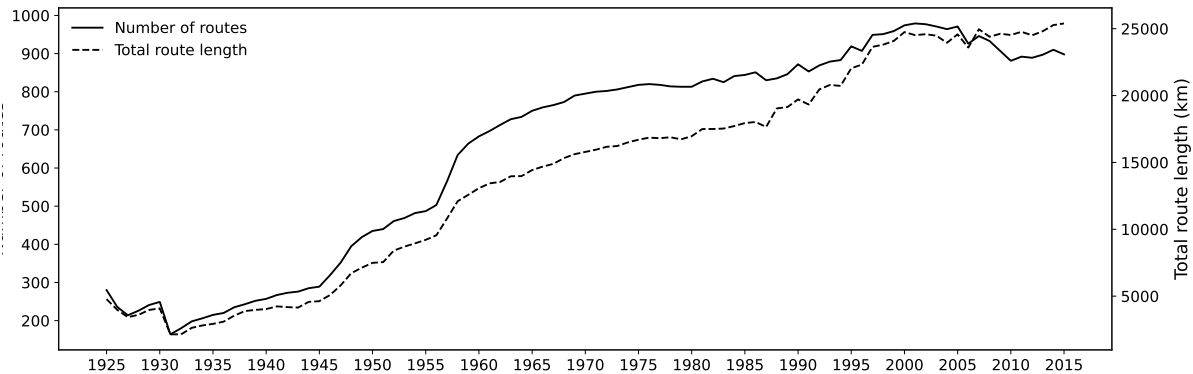


Figure 2: Number of routes and total route length of the Greater Sydney bus network: 1925 - 2015

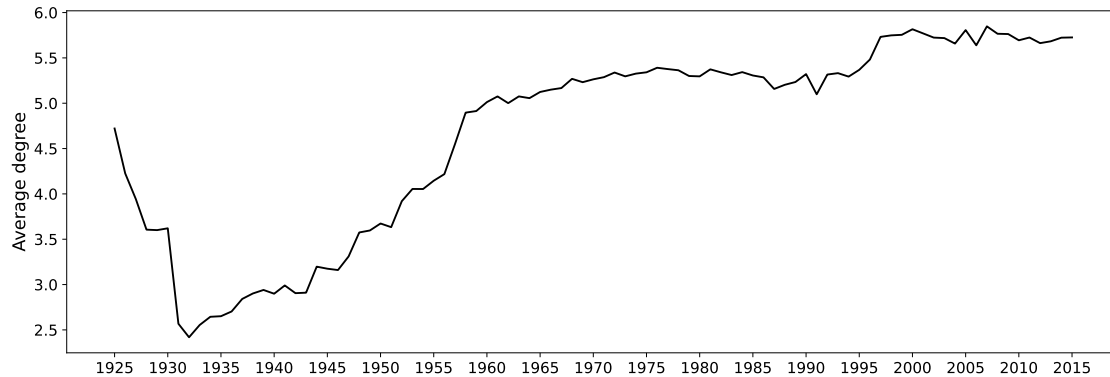


Figure 3: Average degree of nodes of the Greater Sydney bus network: 1925 - 2015

Figure 4 depicts the changes in the average levels of density, clustering coefficient and betweenness centrality over time. Network density shows a distinct downward trend suggesting Sydney's bus network has become less dense over time, which can be attributed to urban sprawl. The increase in clustering following the reduction of bus services in the early 1930s could be attributed to the concentration of bus services in areas without tram services. Similarly, the drop in the late 1950s could be a consequence of the increase in bus services due to tram-to-bus conversion. Betweenness centrality, on the other hand, [needs further exploration](#).

The results shown here are preliminary and need to be [validated and](#) extended to other network structure attributes like circuitry and accessibility to help interpret the evolution of the bus network. [Adding a spatial dimension to the network structure exploration will provide greater insight and will be undertaken in a future study. Another intended future research direction is to explore the interaction between trams and buses as tram routes were handed over to buses.](#) Once complete, the research is expected to provide useful insights into Sydney's bus network evolution dynamics for future planning considerations.

References

Barrington-Leigh, Christopher and Adam Millard-Ball. 2015. "A century of sprawl in the United States". In: *Proceedings of the National Academy of Sciences* 112.27, pp. 8244–8249.

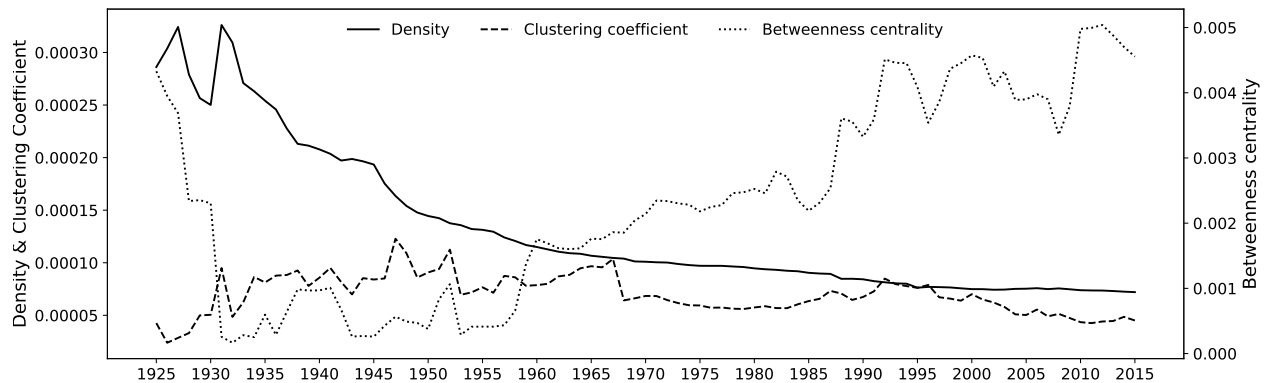


Figure 4: Average density, clustering coefficient and betweenness centrality of the Greater Sydney bus network: 1925 - 2015

- Boeing, Geoff. 2017. "OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks". In: *Computers, Environment and Urban Systems* 65, pp. 126–139.
- Cats, Oded. 2017. "Topological evolution of a metropolitan rail transport network: The case of Stockholm". In: *Journal of Transport Geography* 62, pp. 172–183.
- Chatterjee, Atanu, Manju Manohar, and Gitakrishnan Ramadurai. 2016. "Statistical analysis of bus networks in India". In: *PloS one* 11.12, e0168478.
- Chen, Yong-Zhou, Nan Li, and Da-Ren He. 2007. "A study on some urban bus transport networks". In: *Physica A: Statistical Mechanics and its Applications* 376, pp. 747–754.
- Hagberg, Aric A., Daniel A. Schult, and Pieter J. Swart. 2008. "Exploring Network Structure, Dynamics, and Function using NetworkX". In: *Proceedings of the 7th Python in Science Conference*. Ed. by Gaël Varoquaux, Travis Vaught, and Jarrod Millman. Pasadena, CA USA, pp. 11–15.
- Henderson, Robert. 2021. *Sydney Bus Routes. A History of Private and Government Bus Routes in Sydney*. <https://sydneybusroutes.com>. Accessed: 2021-07-14.
- Levinson, David. 2008. "Density and dispersion: the co-development of land use and rail in London". In: *Journal of Economic Geography* 8.1, pp. 55–77.
- NSW Government. 2013. *Sydney's Bus Future. Simpler, faster, better bus service*. <https://mysydneycbd.nsw.gov.au/sites/default/files/user-files/uploads/bus-future-final-web.pdf>. Accessed: 2021-07-22.
- Open Mobility Data. 2021. *Greater Sydney GTFS*. <https://transitfeeds.com/p/transport-for-nsw/237>. Accessed: 2021-07-14.
- OpenStreetMap contributors. 2021. *Planet dump retrieved from https://planet.osm.org*. <https://www.openstreetmap.org>.
- Transport for NSW. 2021. *TfNSW Open Data Hub and Developed Portal*. <https://opendata.transport.nsw.gov.au>. Accessed: 2021-07-14.
- Travers, Greg. 1982. *From city to suburb-a fifty year journey (the story of NSW government buses)*.
- Wang, Shiguang et al. 2019. "The evolution and growth patterns of the road network in a medium-sized developing city: a historical investigation of changchun, China, from 1912 to 2017". In: *Sustainability* 11.19, p. 5307.
- Yang, Xu-Hua et al. 2014. "Study on some bus transport networks in China with considering spatial characteristics". In: *Transportation Research Part A: Policy and Practice* 69, pp. 1–10.