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The Node-Place model, accessibility, and station level transit ridership

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Abstract

This paper uses Sydney rail data to examine the relationship between station level ridership and local and regional accessibility. We use *net transit* accessibility, which is the additional number of opportunities reachable by transit over walking to represent the regional connectivity value provided by transit. We map accessibility at transit stations, and use the number of opportunities within walking distance as an indicator of local access. We find elements of place (or local) access, including access to jobs and to residents within walking distance (local access), and nodal (or regional) access, including transit access to distant jobs and residential locations are both significant indicators of station level ridership. In particular, the number of jobs within walking distance of a transit station is the best single predictor of transit ridership. This paper highlights the importance of high density around station areas for transit ridership.

1. Introduction

Transit is a sustainable mode of transport that has a wide range of well documented social (Lewis-Workman and Brod, 1997), economical and environmental benefits (Miller et al., 2016). Increasing transit patronage is becoming increasingly relevant for meeting greenhouse gas emissions reduction targets (García et al., 2022), and for accommodating population growth and urban transport needs without extensive road infrastructure investment (Stanley and Hensher, 2009).

Transit stations serve as key points on multi-stage trips between origins, through the initial (boarding/ tap-on) transit station, on to the transit service, to a final (alighting / tapoff) station, to the ultimate destination. We hypothesize that different accessibility measures, namely access to regional opportunities at different distance bands, and place-based access to local residents and jobs are important factors for station level ridership. In the Node-Place model (Bertolini, 1999), each station is a balance between serving through traffic (the 'node' value), and connecting people and facilitating local interactions (the 'place' value). Density and land use has also been considered for node-place models (Cao et.al., 2020). Our approach combines distinct measures of local and regional accessibility. Local accessibility, such as the number of jobs and residents within walking distance from a transit station underpins the potential number of transit riders, while regional accessibility to distant job locations reflects the convenience of transit as a mode of transport. We posit that both types of accessibility contribute to station level transit ridership. In this paper we plot the Node - Place model using regional and local accessibility to represent node value and place intensity. This paper extends the application of accessibility in explaining ridership by using the node-place accessibility concept, and seeks to disentangle the effect of access to different opportunities at different travel time thresholds on station level ridership.

2. Data and methods

Station level transit ridership is measured by the total number of people entering or exiting transit stations in a time period. In this paper, we use publicly available Sydney Trains and Metro station level Opal smartcard daily tap-on and tap-off data from the Transport for New South Wales (TfNSW). We also investigate ridership during the AM peak period (07:00 09:59) and PM peak period (16:00 - 18:59).

Accessibility is the ease of reaching desired destinations (Hansen, 1959), and is often measured as the cumulative number of opportunities reachable within a specific travel time threshold by a certain mode of transport. This paper uses OpenTripPlanner (OTP) to map transit and walking catchment areas at Mesh Block (MB) level, and accessibility is calculated as the number of jobs or population reachable within a travel time threshold of combined walking and travelling on public transport, including transfers. We use 'net transit' accessibility to reflect the performance of transit services, which is accessibility by transit less accessibility by walking. Regional access is the sum of jobs and residents within 30 minutes by net transit; local access is the sum of jobs with 10 minutes and residents within 20 minutes by walking.

This paper uses models to establish the connection between accessibility and station level transit ridership, and to identify accessibility variables that are of significance for transit ridership. Both linear models, and linear models with log transformations are used; accessibility related variables are used as explanatory varibles that predict station level ridership.

How the number of opportunities at different distance bands affect transit ridership is of interest to researchers, but it has been difficult to estimate the effect of these job numbers due to strong correlation with other adjacent distance bands. Specifically, this paper investigates the following set of relations using regression models:

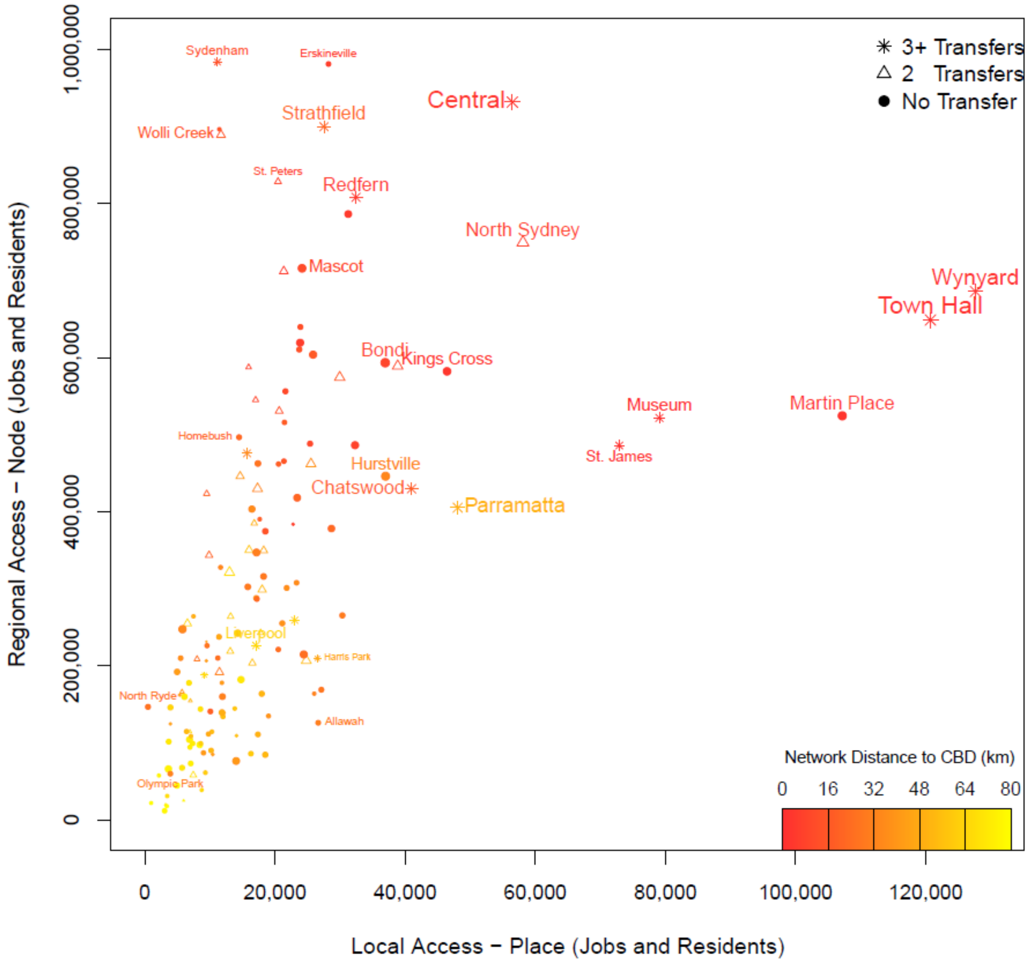
- Morning tap-on/Afternoon tap-off, as a function of walking access to population and net transit access to jobs
- Morning tap-off/Afternoon tap-on, as a function of walking access to jobs and net transit access to residents
- Daily total ridership, as a function of walking access to jobs and net transit access to residents
- Daily total ridership, as a function of walking access to residents, and net transit access to jobs

3. Results

Figure 1 shows the Node - Place model using combined jobs and resident numbers. Stations with strong place values tend to also have strong node values (RSQ= 0.57), meaning that local activities can strengthen node value of public transport nodes, which is also consistent with the Node - Place model proposition by Bertolini (1999). Among stations with similar place values, those closer to the CBD tend to have greater regional access to jobs, and a better balance between place and node values. Transit stations in Sydney CBD have Node - Place balances that differ from other stations; the 'Parramatta' station area is Sydney's second CBD, which has similar Node - Place balance with stations in the primary CBD. Transit stations in Sydney

CBD are clustered in Figure 1; this can be explained by the overall higher land use intensity in CBD.

Figure 1. Node - Place diagram for transit stations in Sydney. Regional access is the sum of jobs and residents within 30 minutes by net transit; local access is the sum of jobs with 10 minutes and residents within 20 minutes by walking. Icon sizes correspond to station-level ridership



Accessibility variables in a linear model predicting station level ridership have good model fit, and model coefficients are shown in Table 1. Results from linear models confirm that station level ridership is determined jointly by different types of accessibility. All accessibility variables that are significant have positive signs, meaning that accessibility has a positive effect on ridership. Models using the combination of local access to jobs and net transit access to residents better explain transit ridership (models 2,3,5), compared to models using local access to residents and net transit access to jobs (models 1,4,6). Overall, more than half of the variation in station-level ridership can be explained by accessibility variables, highlighting the importance of accessibility for transit patronage.

Table 1. Linear model coefficients

Access Variables	AM Peak		PM Peak		All Day	
(Discrete Travel Time)	Tap-on	Tap-off	Tap-on	Tap-off	Tap on&off	Tap on&off
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Walk 20 - Residents	0.096 ***	-	-	0.150 ***	-	1.740 ***
Walk 10 - Jobs	-	0.448 ***	0.392 ***	-	1.423 ***	-
NetTransit 30 - Residents	-	0.011 **	0.011 **	-	0.082 ***	-
NetTransit 30 - Jobs	0.002	-	-	0.000	-	-0.002
Adj. R^2	0.24	0.66	0.66	0.28	0.54	0.26

Significance levels *** 0.0001; ** 0.001; * 0.01; $^+$ 0.1

Table 2. Log-log model coefficients

Access Variables	AM Peak		PM Peak		All Day	
(Discrete Travel Time)	Tap-on	Tap-off	Tap-on	Tap-off	Tap on&off	Tap on&off
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Walk 20 - Residents	0.290 **	-	-	0.275 **	-	0.265 *
Walk 10 - Jobs	-	0.890 ***	0.840 ***	-	0.487 ***	-
NetTransit 30 - Residents	-	0.313 *	0.480 ***	-	0.236 **	-
NetTransit 30 - Jobs	0.174 **	-	-	0.150 *	-	0.280 ***
Sum. Coefficients	0.464	1.203	1.320	0.425	0.723	0.545
Adj. R^2	0.24	0.50	0.56	0.20	0.50	0.25

Significance levels *** 0.0001; ** 0.001; * 0.01; $^+$ 0.1

Access to jobs by walking from a transit station is highly important for ridership. Each job within 10 minutes by walking corresponds to about 0.4 transit trips during AM or PM peak hours. Access to residents have a positive impact on station level ridership, although each resident contributes to fewer transit riders compared to each job location during peak hours. For instance, each resident within 20 minutes by walking contributes to between 0.096 to 0.150 unlinked transit rides during either of the peak period.

For all-day ridership, walking access to residents contributes more to station ridership than access to jobs. Each resident within 20 minutes contributes to around 1.7 unlinked transit trips compared to 1.4 trips from each job location within 10 minutes. This is consistent with the idea that most trips (especially outside the peak period) are not work trips, so residents is a stronger predictor of off-peak travel.

Linear regression with log-log formulation is used to analyze the returns to scale between station level ridership and accessibility. Table 2 shows coefficients from the log-log model. Among the four accessibility variables, walking access to jobs has the highest returns to scale, meaning that improving the ease of walking to job locations near a transit station may be more effective for increasing transit ridership than improving the other three accessibility metrics. Since trips often begin and end at home locations, the importance of local job access variable highlights the importance of opportunities at destination train stations. Peak hour ridership at non-home end transit stations (model 2 & model 3 in table 2) have a super-linear relationship with access variables, meaning that a one percent increase in access to jobs and access to residents will induce more than one percent increase in ridership numbers at these non-home end stations. On the other hand, all day ridership, and peak hour ridership at home end stations have a sub-linear relationship with accessibility.

Both local (walking) and regional (net transit) access variables have significant effect on station level ridership. Among access measures, the number of adjacent job opportunities that are within walking distance is the most significant contributor of station level ridership. Local access to jobs and residents account for about two thirds (72.7%) of the variations in station level ridership. Regional access - net transit access to jobs and to residents are also identified as having notable effects on ridership (27.3%).

Compared to walking accessibility, net transit access appears less influential for station level ridership in Sydney. Transit access to jobs has less effect on station level ridership than transit access to residents. This is not because the level of transit services are irrelevant. Compared to significant differences in local access between transit stations, there is a lack of differentiation in net transit access among transit stations due to the dispersion of jobs in Sydney. The Sydney CBD and other centers account for a relatively small portion of all jobs, and job locations are mostly dispersed geographically (Sarkar et al., 2020), causing net transit accessibility from different transit stations to become more similar. This lack of variation in the number of jobs reachable by transit at different stations may explain why transit accessibility is not the most important factor in station level ridership.

4. Discussion and conclusions

We operationalize the Node-Place model using local and regional access, and characterize stations in terms of their place value in having good local access and being popular destinations themselves, and their node value in serving as transit hubs facilitating distant travel. We noted that stations with a high place value tend to also have high node value providing ease of reaching distant locations; stations with a high node value can serve merely as a transit hub without having good local access. Whether these node-dominant stations are in a steady state or a transitional phase into stations similar to those in city centers has implications for transport infrastructure planning, and is open to future research.

Accessibility alone is found to be a good indicator of station level transit ridership. Station level ridership is affected jointly by local and regional access. Both the number of jobs and residents within walking distance of a transit station (local access), and the number of jobs and residents reachable via transit (regional access) are important determinants for station level transit ridership. Among accessibility variables, the number of jobs within walking distance of a transit station is identified as the most important factor in station level ridership; jobs numbers within a 10-minute walking distance are especially important.

This paper finds that station level ridership generally has a sub-linear relationship with accessibility variables, which is consistent with previous findings in the literature (Cui et al., 2022, Wu et al., 2019). However, this paper finds that peak hour ridership at non-home end transit stations have a super-linear relationship with accessibility, where a one percent accessibility increase produces more than a one percent increase in ridership. This paper also finds that transit ridership scales faster with access to jobs than access to residents, so facilitating access to jobs may be more effective for increasing transit patronage; this is consistent with the literature that large and dense destinations have a substantial impact on transit usage (Barnes, 2005).

Findings from this research shed light on the potential to increasing transit ridership through land use intervention. To increase transit ridership in Sydney, providing more housing units near station areas, especially in new development locations might be more effective than converting people who already live near a transit station. About 17.6% of people include trains as part of their commute trips in Sydney (Australian Bureau of Statistics, 2017), but the percentage of residents with convenient access to a transit station is low compared to the concentration of job locations near station areas. About 10% of residents are within a 10-minute walk from transit stations, compared to 29% of all job locations. This suggests that access to transit stations from residential locations remains a major barrier to ridership, and that more infill housing units near existing station areas will enable more people to take transit in Sydney, and is probably more cost-effective than extending the rail network.

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