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Impacts of signalised crossings on pedestrian access to train stations

Tim Zhang[1], Emily Moylan[1]

[1]University of Sydney

Email for correspondence (presenting author): tzha3352@uni.sydney.edu.au

Abstract

Pedestrian access and egress time is a significant barrier to public transport mode choice. Walking time in urban environments can be greatly increased due to the time spent waiting at signalized intersections. The prevalence of crossings made during the red light indicates that pedestrians are sensitive to their waiting time at signalised crossings.

This study uses a GIS-based approach to determine the impacts of signalised intersections on pedestrian access and egress from Sydney train stations. These values are converted to an average delay for each crossing. Considering two types of pedestrian crossing behaviour, expected delay at each crossing is estimated based on observed phase durations. The service areas from each station were produced for a range of intersection delay scenarios extending to 20 minutes of access time and overlaid with census data to determine the population and jobs accessible from the station at each increment of walking time.

Results indicate that signalised pedestrian crossings can cause average delays of up to 60 seconds among train riders within 20 minutes walking. Stations most impacted by signalised crossings were in close proximity to many intersections with long cycle lengths and short green phases. Such findings have implications on the design of urban areas around existing and planned railway stations in Sydney, particularly regarding the trade-off between prioritising pedestrian movement against vehicular traffic at intersections.

1 Introduction

Walking as a mode of transport is an important complement to public transport for the origin-to-hub and hub-to-destination legs of a trip. However, in most urban environments, pedestrians are required to share the road network with motor vehicles. Pedestrian movement at intersections can either be unregulated, prioritised by a pedestrian crossing, or regulated by a signalised crossing.

Signalised pedestrian crossings (or pelican crossings) in Sydney, Australia are usually actuated and consist of green, flashing red, and solid red phases. In most places, pedestrians must press the button before the phase begins for the walking light to turn green. Flashing red time is intended for individuals already in the intersection to complete their crossing. Therefore, pedestrians can only cross at specific times which are often synchronised with the parent intersections, causing delay in a walking trip.

Walking time can be a deterrent to choosing public transport as the primary mode. Given the volume of pedestrian movements around transit stations, the design of adjacent intersections has implications on the perception of transit itself. This study aims to quantify the delaying effect that signalised intersections have on walking trips from railway stations in Sydney. This study also applies a classification model to predict average delays at intersections which were not directly surveyed. Signalised intersections require microscopic models to capture their effects on walking access and ridership.

2 Literature review

2.1 Walking access

The attractiveness of a mode can be quantified in terms of accessibility, which is defined as the ease of reaching opportunities (Hansen, 1959). Two examples of measures used to quantify accessibility are cumulative opportunities with a generalised travel cost threshold and gravity-based models that discount distant opportunities.

For a fixed set of spatially located opportunities, the accessibility depends on how easy it is to move in a given mode. Walking mobility is moderated by subjective assessment of the walking environment. There are many factors that influence perceived pedestrian accessibility including directness of the route (Lo, 2009), traffic safety, security from crime (Guzman et al., 2022; Jehle et al., 2022), comfort (Cambra and Moura, 2020) and the built environment (Jeffrey et al., 2019; Jehle et al., 2022; Koo et al., 2022). At a macro scale, factors such as population density, job density and intersection density are correlated with increased walking activity (El-Geneidy et al., 2014; Jiang et al., 2012; Wang and Cao, 2017).

At a micro-access scale, streetscape factors can significantly contribute to explaining walking mode choice (Koo et al., 2022). Improving micro-access can extend acceptable walking distance (El-Geneidy et al., 2014) and spatial attributes have also been found to better predict walking distance than trip attributes, individual characteristics and socioeconomic environment (Tao et al., 2020). Mesoscopic analysis also assigns an aggregated urban form attribute to travellers, who each have individual travel and socioeconomic attributes. This makes it harder to discern environmental impacts on walking from competing individual factors (Park et al., 2017).

2.2 Walking access to transit stations and transit ridership

Considerable attention has been paid to walking around transit stations (Malekzadeh and Chung, 2020), since walking accessibility to and from transit stops is a key determinant of transit ridership (Cui et al., 2022). The drawing catchment of a transit stop is influenced by its local access and broader transit access (Wu et al., 2023b) which is dependent on connectivity to other transit stops. Local access is improved by higher surrounding job and population density that increases demand (Jeffrey et al., 2019) and more developed walking networks to meet this demand (Lahoorpoor and Levinson, 2020). Past research underscores how attributes influencing transit ridership extend beyond transit network-based factors to include land use and walking access/egress attributes. Jiang et al., (2012) found that pedestrians tend to walk further to stations with more walkable corridors. Pedestrians also walk further to integrated-boulevard stations than arterial-edge and below-expressway stations due to walkable features such as shaded corridors and busy and interesting environments (Jiang et al., 2012).

Among the research on correlates of walking mode choice, walking distance is often considered the key determinant of walking mode choice (Cui et al., 2022; Durand et al., 2016; Gutiérrez et al., 2011). Durand et al. (2016) found that probability of active access decreases by 12% for each mile increase in distance from origin to transit stop. Similarly, Gutiérrez et al., (2011) found a negative linear relationship between walking distance and transit station boardings per resident. This relationship supports the use of an 800m network distance as transit boarding rate decreases to half that experienced for walking distance less than 50m.

However, using walking distance only ignores the impacts of intersections on walking time. Pedestrians have been observed performing trade-offs between waiting time and risk when crossing during the red light (Zhu et al., 2021), which suggests that pedestrians perceive intersection waiting time to contribute significantly to their total travel time. This motivates the need to quantify the intersection delay that occurs during station access and egress to understand how it might reduce the effective drawing catchment of transit riders.

2.3 Impacts of intersections on walking access

Discussions concerning impacts of intersections on walking access focus on pedestrian safety at intersections and pedestrian behaviour (Dianchen Zhu et al., 2021; Gorrini et al., 2018; Govinda et al., 2020). Signalised intersections are generally viewed favourably for road safety reasons (Guzman et al., 2022) and some positive correlations have been observed between traffic signal density and walking (Rothman et al., 2014; Wu et al., 2023a).

However, analysis of the impacts of intersections on walking accessibility is limited and disputed. Some researchers found that walking egress declines with the number of intersections (Wang and Cao, 2017). Other research has found intersection density to be insignificant with respect to active mode share (Chan and Farber, 2020; Gan et al., 2021), or less significant when compared to other spatial attributes such as population density, job density, mixed-use index and pedestrian network density (Tao et al., 2020). Since pedestrian considerations in intersection design tend to focus on safety, signalised intersections are unlikely to be optimised for walking accessibility.

2.4 Past approaches

Experimental methods in measuring walking access include travel surveys and isochrones. Travel surveys are conducted to gain an understanding of the walking environment and are combined with personal attributes in regression models to determine the influence of the built environment on walking experience and mode choice (Gan et al., 2021; Guzman et al., 2022; Jehle et al., 2022; Park et al., 2017; Tao et al., 2020). This form of analysis is often costly and suffers from biases including recollection bias (Clarke et al., 1981), proxy bias and under-representation (Wang et al., 2022).

Isochrones are defined as the set of all points which can be reached from an origin within a certain time, used in urban planning as a measure of accessibility (Marciuska and Gamper, 2010). Network-based isochrones represent walking accessibility more accurately than radial catchment areas as the latter does not consider the walking network (Lahoorpoor and Levinson, 2020; Nigro et al., 2019). To evaluate walking accessibility, isochrones can be programmatically created using GIS tools and road network data such as OpenStreetMap (Jeffrey et al., 2019; Lahoorpoor and Levinson, 2020; Rossetti et al., 2020; Zazzi et al., 2018).

There has been extensive attention on the details of how isochrones have been implemented for transit access analysis. Ridership predictions using network distance models with distance-decay weighting outperform Euclidean distance models and cumulative accessibility measures using all-or-nothing functions (Gutiérrez et al., 2011). However, Gamper et al. (2011) found little benefit in using a convex hull or network path-based catchment area when compared to a radial catchment area for the purposes of predicting ridership.

The most common walking time used for assessing access to rail stations is 10 minutes (Calthorpe, 2004; El-Geneidy et al., 2014; Jeffrey et al., 2019; Jehle et al., 2022). However, isochrones of 5, 10 and 15 minute walking distance roughly equal to 400m, 800m, and 1.2km respectively appear in the literature (Caselli et al., 2022; Lahoorpoor and Levinson, 2020).

Isochrones are commonly overlaid with population and employment data to determine the number of reachable residents and jobs to account for differences in density (Cui et al., 2022; Lahoorpoor and Levinson, 2020). Countable opportunities can be represented at the mesh block level (the finest census resolution with roughly 30 to 60 dwellings) (Wu et al., 2023a) while other studies analysing travel mode (Jehle et al., 2022) and population access (Caselli et al., 2022) use data at the household level.

Many studies using surveys focus on travel time instead of distance, because it is easier for respondents to estimate (van Soest et al., 2020). Studies using a spatial lens often focus on first and last-mile analysis (Ha et al., 2023) and examine predictors of walking distance (El-Geneidy et al., 2014; Jiang et al., 2012; Tao et al., 2020; Wang and Cao, 2017). But analysing walking accessibility using walking distance overlooks the impact that intersection delay can

have, which is significant as the contribution to travel time has been identified as a common reason for why commuters choose not to walk to train stations (Jehle et al., 2022).

The bulk of the literature conducts cross-sectional studies of walking access, comparing accessibility of different areas under the *status quo* (Cui and Levinson, 2018; Wu et al., 2023a; Wu et al., 2023b). A limitation of this approach is that it provides a weaker argument for causality between built environment factors and walking access.

By comparison, longitudinal studies observe walking access changes over time across a range of locations. Cambra and Moura (2020) conducted a longitudinal study comparing walking access before and after a built environment intervention, identifying that the scale of the walkability intervention is a significant factor in influencing walking behaviour. Smaller scale interventions were found to potentially improve the walking experience but are not as effective in increasing walking activity. Similarly, Lahoorpoor and Levinson (2020) predicted accessibility following hypothetical changes to station access while constraining other land use changes. This work sets a precedent for modelling hypotheticals for a pseudo-longitudinal analysis of walking-to-transit behaviour.

3 Methodology

The impact of signalised intersection delay on walking access to transit is evaluated by comparing station accessibility to jobs and residential populations with and without the influence of signalised intersections. This is undertaken at 8 major stations in the Sydney Trains network—Lidcombe, Auburn, Strathfield, Burwood, Ashfield, Parramatta, Central and Town Hall—and the scope of analysis encompasses all signalised intersections within 500 m of the stations.

3.1 Measuring intersection phasing

The extent to which pedestrians are delayed at signalised intersections depends on the durations of the cycle, the pedestrian green phase and the flashing red phases. However, the signals use Sydney Coordinated Adaptive Traffic System (SCATS) which coordinates traffic signals according to vehicular and pedestrian traffic flows. Hence, the length of different cycles measured at the same intersection can vary. Regardless, it is assumed that the measurements taken in this study are representative of the average cycle and phase lengths of each intersection. The variation between cycle lengths at an intersection is small compared to the cycle length, so the pedestrian delay varies more based on randomised arrival at the intersection than by differences between cycles.

Intersection delay is modelled based on signal phases and pedestrian traffic volumes which were observed for a minimum of 3 cycles. Measurements around each station differed by time of day and by day of week. A summary of these observations is presented in Table 1.

Table 1: Intersection phasing measurements taken for the surveyed stations, averaged across all intersections within 500m of each station.

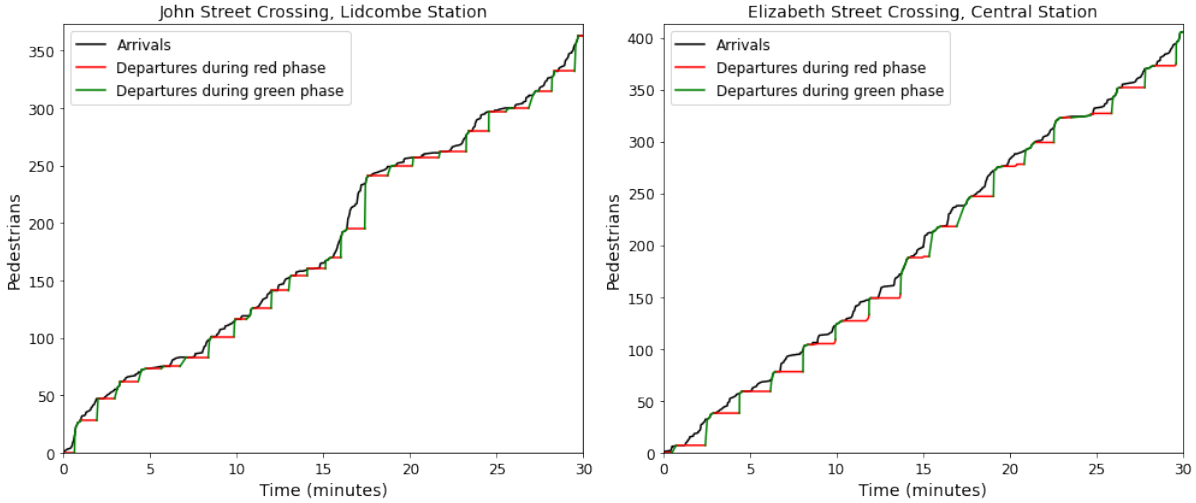
Station	Crossing locations	Cycle length (s)		Green time (s)		Flashing red time (s)		Solid red time (s)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lidcombe	14	128.9	24.5	8.6	2.7	16.1	5.2	104.1	24.2
Auburn	22	91.4	27.1	8.8	7.2	13.3	4.0	69.6	26.1
Strathfield	18	86.2	24.6	9.3	5.3	15.8	4.2	61.1	22.4
Burwood	30	91.7	15.0	6.9	1.0	13.4	1.3	71.5	15.2
Ashfield	35	81.2	26.8	11.7	17.9	11.5	2.8	58.0	27.0

Station	Crossing locations	Cycle length (s)		Green time (s)		Flashing red time (s)		Solid red time (s)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Parramatta	78	73.5	26.1	10.1	9.1	13.4	4.2	49.9	26.8
Central	44	93.9	27.0	17.1	18.8	16.5	8.2	60.3	18.6
Town Hall	133	84.5	18.4	16.1	14.6	11.9	4.2	56.5	19.8
Total	**374**	**85.7**	**25.2**	**12.8**	**13.4**	**13.3**	**4.9**	**59.7**	**25.7**

3.2 Measuring pedestrian arrivals and departures

The distribution of pedestrian delay is the convolution of the pedestrian arrival pattern and the phase timing. Using a queuing framework to capture the arrival rate and the service rate, pedestrian delay can be simulated over many cycles. Pedestrian crossings were observed through manual counts at Lidcombe and Central for 30 minutes during the weekday evening peak. The arrival curve illustrates that pedestrians arrive at each signalised intersection at random intervals following a uniform distribution. Near train stations, train arrivals increase the arrival rate similar to a platooning effect. However, for observed train arrival frequencies on the order of 3-4 minutes and signal cycles around 1-2 minutes, this effect is negligible. Pedestrian arrivals are almost linear between each green signal as shown in Figure 1. All pedestrians recorded in the observations are assumed to be train passengers.

Figure 1: Pedestrian arrivals and departures for two crossings adjacent to Lidcombe station (left) and Central station (right).



The arrival and departure rates assume perfect compliance with traffic signals. In this analysis, we assume that pedestrians cannot cross at a point further along the street to avoid a signalised crossing and they cannot cross during the solid red phase. To simplify the analysis further, crossings at unsignalised intersections are assumed to confer no delay.

3.3 Modelling delay caused by signalised crossings

Pedestrian behaviour at intersections varies depending on personal characteristics and environmental factors which have been excluded from the scope of this analysis. Instead three scenarios are considered for how pedestrians could traverse intersections. For all scenarios, let ***G*** be green time, ***S*** solid red time, ***F*** flashing red time, ***R*** total red time and ***T*** cycle time. For scenario 2 and 3, it is assumed that the green phase occurs each cycle regardless of actuation. This assumption is valid for crossings that experience high pedestrian volumes, including all observed intersections in the CBD and most observed intersections around suburban stations. Table 2 outlines the formulas used to calculate average waiting time in the

modelled scenario. Table 3 compares the average delay obtained from hand measurements and the modelled delay under each scenario for the two crossings that were observed.

Table 2: Modelled average delay scenarios.

Scenario	Assumption	Average waiting time
1	Pedestrians experience no delay at signalised crossings.	0
2	Pedestrians begin to cross during the green phase or flashing red phase.	$\frac{S^2}{2T}$
3	Pedestrians begin to cross during the green phase only.	$\frac{R^2}{2T}$

Table 3: Comparison of average measured delay and average modelled delay.

Crossing	Measured average delay (s)	Modelled average delay (s)	
		Scenario 2	Scenario 3
Elizabeth Street, Central	30	28	38
John Street, Lidcombe	23	25	34

3.4 Network representation

OpenStreetMap (OSM) represents roads and footpaths as a set of vertices and edges. Pedestrians are modelled as being able to traverse the graph by walking along edges. In dense, urban areas, OSM distinguishes between footpaths and vehicle edges. Elsewhere, in most suburban or residential areas, OSM only has one vehicle link along the centreline to represent each road which needs to be adapted to the footpath network.

The OSM network is edited to accurately represent the walking network within a 500m radius of each studied station. This includes removing edges such as motorways, roads without footpaths, restricted access areas, busways and trunk roads which cannot be used by pedestrians. The network modifications also require the addition of pedestrian crossings missing from OSM. The delays calculated are applied onto signalised crossings by reducing the walking speed along the edges representing these crossings.

While the service areas extend far beyond 500m, it is assumed that the differences in walking speeds among the population would lead to vastly different delays with increasing walking distance. Beyond this distance, it is assumed that signals impose no delay.

3.5 Pedestrian access to stations

The service area or drawing catchment of the stations is defined by a fixed walking time budget ranging between 1-20 minutes applied along the OpenStreetMap (OSM) network. It is assumed that all pedestrians walk at 5km/h when unimpeded by traffic lights. Notably, this analysis does not consider the effect of environmental elements such as hills, stairs, elevators and ramps on walking speed.

The network is used to access opportunities or destinations embedded in the land use. Working at the building scale, the height, area and centroid of buildings within the maximum possible walking distance of the selected train stations were sourced from satellite imagery provided by Geoscape and filtered to remove erroneous entries. The building centroids are connected to the pedestrian network by a shortest distance link, which may not be representative of actual footpaths. It is assumed that this will have a negligible impact on access/egress time. The advantage of such a method compared to one that applies a buffer on the base OSM links is it avoids situations where the buffer is either too wide and includes

buildings that are not directly accessible, or the buffer is too narrow and excludes buildings that should be accessible.

The number of residents in each mesh block (a census area designation representing approximately 30-60 households) is sourced from 2021 Australian Census data. This population is apportioned into individual building centroids weighted by the volume of each building and building volume is approximated by the product of the building height and area. The number of jobs in each destination zone (each an aggregation of mesh blocks) is sourced from 2016 Census data, and the jobs in each destination zone are similarly apportioned into the building centroids in each destination zone.

The access of a given station is derived by determining the shortest path from the station centroid to each building within 20 minutes walking distance. The "x-minute" population access of a station is defined as the total population among buildings with access time less than or equal to x minutes. In situations where the same building is located within 20 minutes walking distance of two or more stations, the building populations are assigned to the station with shortest walking time to avoid double counting.

3.6 Train ridership

While access captures the potential utility of a train station, train ridership is a more appropriate measure of how much of this potential is realised. Method of Travel to Work (MoTW) data from the 2016 Census is used to determine train ridership under the three scenarios. 2016 Census data was chosen over the 2021 Census as the COVID-19 pandemic and associated lockdown severely reduced train mode choice during 2021 and does not reflect usual trends. The scope of the data and analysis is limited to journeys to work, so trips made by train for other purposes are not captured. Also, all train trips in the Census MoTW data are assumed to involve walking from home to the station and from the destination station to work. For simplicity, the mode recorded in the Census data is assumed to remain the same, and does not increase in response to reduced access or egress time in a different scenario.

Trip origins, i.e. residential dwellings, for Travel to Work data are recorded at the mesh block level, while trip destinations, i.e. workplaces, are recorded at the destination zone level which are aggregates of mesh blocks. Therefore, residential ridership is determined as the number of Travel to Work boardings within a station’s catchment, while job ridership is determined as the number of alighting passengers from Travel to Work data. The number of train users in each mesh block or destination zone is apportioned to the buildings weighted by their volume. In a similar manner to measuring access, the workers and jobs are assigned to the station with shortest walking time. This method does not consider the relative attractiveness of the stations due to their connectivity in the Sydney Trains network.

4. Results

This study aims to determine the effect of signalised intersections on walking access and train ridership. Figure 2 shows the isochrones for Parramatta station, which are characterised by branches along the street network and short stems from the street network to each building. The coverage decreases when accounting for signal delay as shown in the difference between scenario 1 and scenario 3 for each time threshold.

Figure 2: Scenario 1 and scenario 3 isochrones for 5-, 10- and 15-minutes walking from Parramatta station. Signalised intersections reduce the accessible area as seen in the reduced coverage of the scenario 3 isochrones compared to scenario 1.

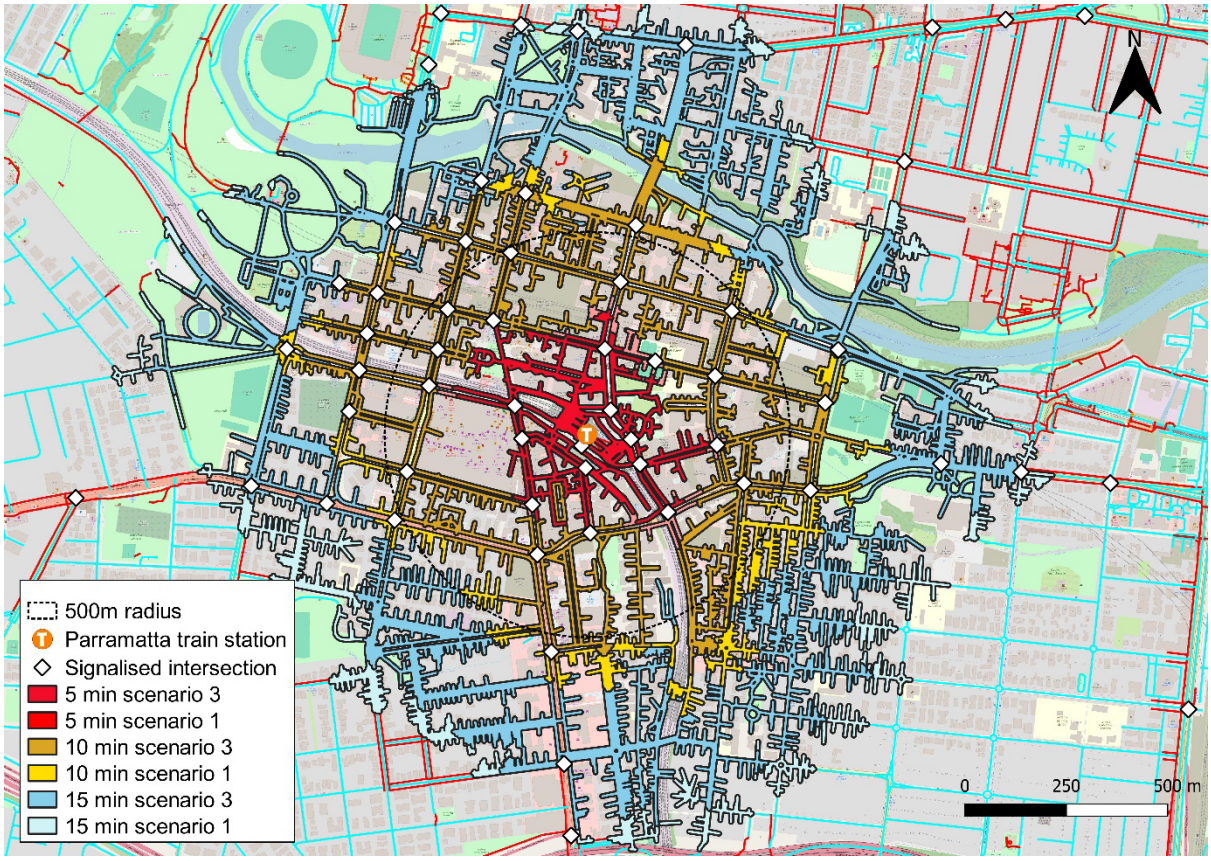


Table 4 compares the 20-minute residential population access across each scenario for the surveyed stations while Table 5 compares the average access time among train riders across the scenarios. Among the surveyed stations, signalised intersections cause up to a 9.4% reduction in residential population access and up to a 9.9% increase in average access time among riders.

Table 4: 20-minute residential population access for all scenarios.

	Residential population access	Access relative to scenario 1	
Station	Scenario 1	Scenario 2	Scenario 3
Central	34589	-432 (-1.2%)	-754 (-2.2%)
Parramatta	32456	-1859 (-5.7%)	-3066 (-9.4%)
Ashfield	29440	-729 (-2.5%)	-945 (-3.2%)
Auburn	25571	-404 (-1.6%)	-520 (-2.0%)
Strathfield	23547	-187 (-0.8%)	-479 (-2.0%)
Burwood	20013	-1065 (-5.3%)	-1183 (-5.9%)
Lidcombe	19483	-1231 (-6.3%)	-1647 (-8.5%)
Town Hall	16320	-529 (-3.2%)	-810 (-5.0%)

Table 5: Average access time among train boarders within 20 minutes' walk.

Station	Average access time among train boarders Scenario 1 (mins)	Access time relative to scenario 1 Scenario 2 (mins)	Scenario 3 (mins)
Central	12.75	+0.32 (+2.5%)	+0.44 (+3.5%)
Parramatta	11.15	+0.58 (+5.2%)	+0.97 (+8.7%)
Ashfield	11.92	+0.31 (+2.6%)	+0.41 (+3.4%)
Auburn	8.11	+0.45 (+5.5%)	+0.62 (+7.6%)
Strathfield	10.16	+0.27 (+2.7%)	+0.42 (+4.1%)
Burwood	9.38	+0.69 (+7.4%)	+0.93 (+9.9%)
Lidcombe	11.16	+0.66 (+5.9%)	+0.87 (+7.8%)
Town Hall	7.96	+0.72 (+9.0%)	+0.97 (+12.2%)

Figure 3 and Figure 4 compare walking access and train ridership across the surveyed stations at 5-minute intervals. The difference between the Figures is due to some stations being surrounded by residential land uses while others are mostly surrounded by commercial and retail uses. Most of the losses in job access and ridership due to signal delay occur in the 5 minute range, with negligible losses for longer walking times. This is in contrast to residential access and ridership, which experience losses across all four time budgets. Since jobs in the CBD tend to be clustered more densely than residential populations in suburban areas, a small increase in reachable area translates to far greater increase in job access. However, the close proximity between CBD stations and the high density of jobs around each station means there are few jobs beyond 10 minutes walking of any particular CBD station. Therefore, reducing delay by ignoring signalised crossings does not translate to reaching more distant employment opportunities, only to reaching nearby opportunities slightly faster.

Figure 3: Residential population access and train ridership under each scenario, sorted by decreasing population access. Stations with high population access such as Central and Auburn do not necessarily have proportionally high train ridership. Also, the loss of access and ridership due to signalised crossings does not accumulate with increasing time budget.

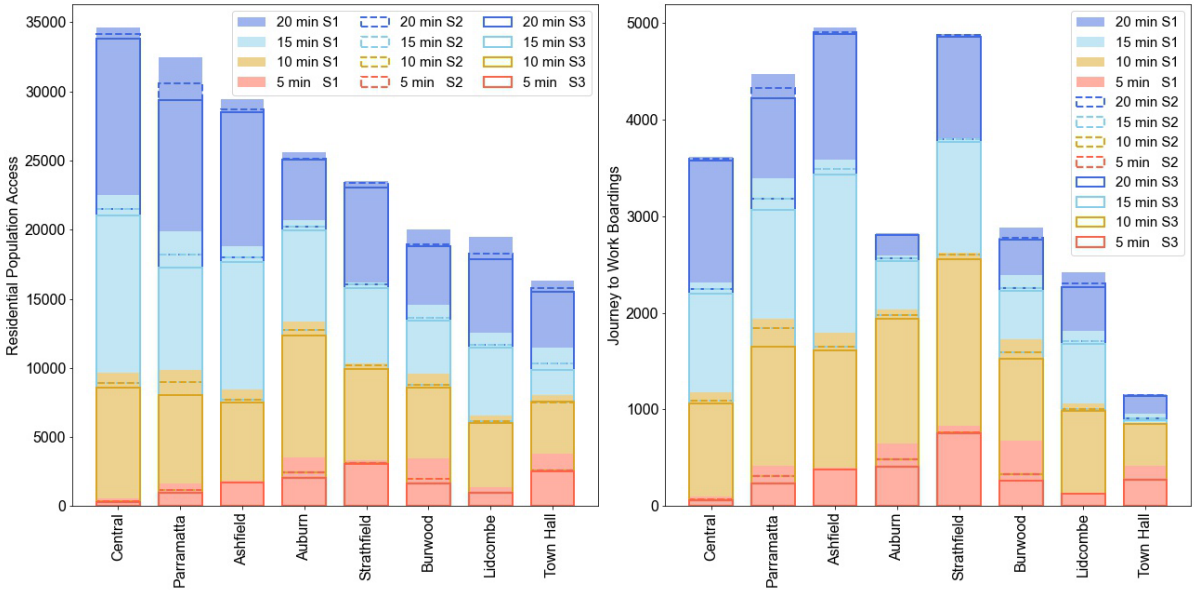
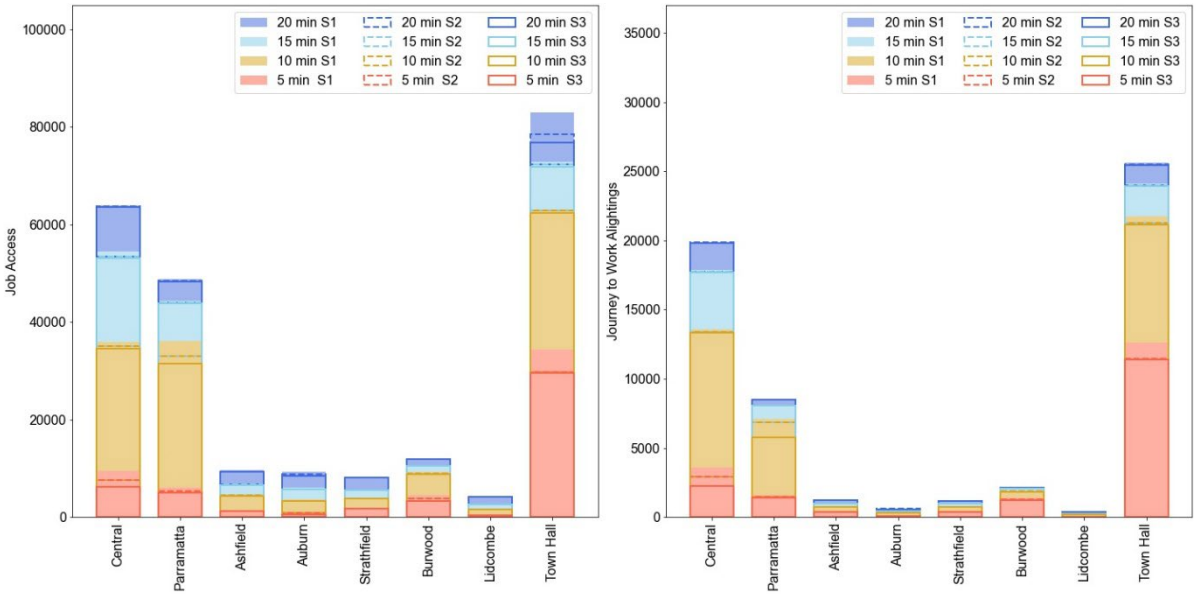


Figure 4: Job access and train ridership under each scenario. Walking access to employment opportunities is concentrated in the CBD stations and Parramatta. Signalised intersections have some impact on 5-minute access and ridership across these stations, with negligible impact beyond this threshold.



5. Discussion

Given an investment in rail and the service cost of operating a station, it is imperative to maximise ridership. Much attention has been paid to the factors that determine how far and under what conditions a potential transit rider is willing to walk to the station. The state of best practice relying on network distances generally does not account for the delay caused by intersections, which increases average access time by 2.5% to 9.0% (16 to 42 seconds) in scenario 2 and by 3.4% to 12.2% (25 to 58 seconds) in scenario 3. This analysis has considered the population and jobs enclosed within a fixed travel time budget service area under three scenarios of intersection delay.

5.1 Residential population access and ridership

The analysis presented in this study has demonstrated that signalised intersections impact walking access from train stations to residential populations in Sydney. Comparing the baseline (scenario 1) to the test scenarios, signalised intersections reduce the service area of stations by reducing the effective access/egress walking-time budget. Stations most impacted by signalised intersections typically have an intersection immediately outside the station (e.g. John Street, Lidcombe) which impedes all paths. Under scenario 2, Lidcombe and Burwood station experience worse 5-minute access reduction (-32% and -42%) compared to Strathfield (-7%) due to the presence of intersections immediately adjacent to the former two stations. Since probability of transit mode share decreases as access time increases (Ha et al., 2020), this substantial impact on the most local population could heavily impact the number of boardings. Also, Figure 3 shows that the difference between the scenarios in both residential access and Journey to Work boardings does not accumulate with increasing walking time. Given that there are more alternative routes further from a station, more distant signalised intersection have a reduced impact on pedestrian access. This suggests that access improvements including better signal timings and footpath connections will be most effective adjacent to the station.

5.2 Job access and ridership

Train stations that offer high residential population access, such as the suburban stations, tend to offer low employment access. Conversely, Town Hall serves relatively low residential populations but has much higher job access. Hence, job access is a necessary metric to measure the impact of signalised intersections on walking. Given that it takes less time to access job opportunities than residential populations, walking access to residential populations is more impacted by signalised intersections than access to jobs. This suggests that improvements to walking access should target signalised crossings in residential areas instead.

5.3 Recommendations and implications

Measures can be introduced to improve walking access by reducing the delay on pedestrians accessing train stations. During low car traffic, some intersections could be treated as unsignalised intersections that allow pedestrians to choose a gap in traffic. Alternatively, signalised crossings in Sydney could reactivate the green signal mid-phase if the button is pressed during the coordinated vehicle phase. Such features have implications on vehicle traffic flow and pedestrian safety which should be examined further. For stations that experience less frequent train services and therefore experience higher variability in pedestrian arrivals, the signalling of intersections adjacent to the station entrances can be altered to minimise delay on train users.

At some train stations, alighting passengers depart the station in a platoon with a substantial crowd of pedestrians reaching a key signalised intersection within a short interval. The analysis above indicates that timing the signal to match the train arrival in that case could increase the drawing catchment of the station. In other cases, the number of train arrivals or the density of intersections are too high to isolate a single coordination that would be effective. In that case, removing signalisation in favour of zebra crossings and prioritising pedestrian movements in the broader station precinct though footpath design or removing signal actuation would be the best approach for maximising the catchment. One example of this is the removal of car traffic along the Deane Street crossing near Burwood station as shown in Figure 5.

Figure 5: Google Street View images of Deane Street before (left) and after (right) the Precinct Transformation in June 2023. Concrete barriers were installed to prevent car traffic from entering from Deane Street. The entrance to Burwood station is located at the top right of each image (Google Maps 2024).

Beyond access implications, improving the signal phasing of signalised intersection by increasing the length of the green phase and flashing red phase for pedestrians would improve pedestrian safety. The current green signal length at most crossings in Sydney is not sufficient for pedestrians to complete their crossing, which leads to conflicts with pedestrians and higher risk of collisions.

While the average delay of train riders at the analysed stations was under 60 seconds in scenario 2, that still represents 10% of a typical access time. It is known that environmental factors around transit stations correlate with walking accessibility, which in turn influences transit ridership (Cui et al., 2022) . Through this study, signalised intersections have been shown to have a negative impact on walking access measured in terms of the covered population within a given walking time threshold.

6. Conclusion

The findings presented in this study have demonstrated that pedestrians accessing transit experience substantial delays at signalised intersections. They reduce the number of potential riders, especially when considering the smallest drawing catchments. When forecasting ridership or intervening to increase station access, the impact of the signals should be considered rather than distance-based walking catchments.

6.1 Limitations and future outlook

Phase timing measurements in this study were only taken of intersections within 500m of the surveyed stations and each crossing contributed delay independently. It is possible that adjacent intersections or adjacent crossings at the same intersection are coordinated (or anti-coordinated) leading to correlations in the delays along particular routes. Also, pedestrians with larger walking distances who encounter intersections outside of this perimeter would experience further delays along their journey which have not been captured in this study. Future work could consider using SCATS data to both reduce data collection time and capture the impact of all signalised intersections within the 20-minute walking catchment.

The impact of unsignalised crossings was not included within the scope of this study, which depend on the intersection control method, pedestrians' gap selection behaviour, traffic volumes and drivers' tendency to give way. These nuances could be treated in future work to capture pedestrian access more accurately for stations with high vehicle traffic volume and greater density of unsignalised crossings.

Unintended pedestrian behaviour such as crossing against a solid red light were omitted from this analysis. However, there was minimal difference in access between scenario 2 and scenario 3, which suggests that pedestrian behaviour does not play a significant role. The analysis conducted so far has determined pedestrian access assuming average delays at intersections and uniform walking speed. An alternative approach could examine the worst-case scenario where pedestrians are required to wait the maximum time at each intersection as an additional scenario. This scenario corresponds to the time budget that a potential transit rider would need to plan for. Future work could disaggregate the analysis, producing stochastic pedestrian departures to simulate the distribution of expected delays and use 80th percentile delays as a proxy for planning decisions.

The work presented in this study is limited to predicting ridership for trips to work only, which underestimates the true train ridership. Future work should investigate other trip purposes to determine if the correlation between train mode choice and intersection delay remains. Finally, the population and employment data used in this study are sourced from the 2021 and 2016 Census which do not distinguish between walking trips to train stations and others. Also, given the changes in working arrangements following the COVID-19 pandemic, studies would benefit from analysing this topic using updated data that specifies which part of the trip involve walking. It remains to be seen how signalised intersections influence the perceived accessibility of walking to transit.

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