

## Comparison of perceived and measured accessibility between different age groups and travel modes at Greenwood Station, Perth, Australia

Mark Ryan<sup>1</sup>, Ting (Grace) Lin<sup>1</sup>, Jianhong (Cecilia) Xia<sup>1</sup> and Todd Robinson<sup>1</sup>

<sup>1</sup>Department of Spatial Sciences, Curtin University, Australia.

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Although there has been a significant focus on evaluating accessibility to facilities, the differences between age groups and/or mode of access to train stations is less clear. This paper compares perceived and measured accessibility to train stations among three age groups: young adults (18-24), middle aged adults (25-59) and elderly adults (60+) and three travel modes, Park and Ride (PnR), Bus and Ride (BnR) and Walk and Ride (WnR). The study focuses on the Greenwood railway station, Perth, Australia. Measured accessibility was lower than perceived accessibility for all three age groups. Both perceived and measured accessibility to train stations were lower for the elderly than the other groups. The catchment area of elderly PnR users was also the smallest. Middle aged adults evaluated accessibility (perceived) by WnR the highest. Young adults were found to have a larger PnR catchment area than other groups. Inadequate accessibility to Greenwood Station for different age groups and by different travel modes were identified, which can be used as a decision-making aid by practitioners and station managers for improving accessibility for these cohorts. The techniques used are directly transferable to the study of other stations.

**Keywords:** *accessibility measures, composite index, measured accessibility, perceived accessibility, transport planning*

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### 1. Introduction

Railway transport constitutes a sizeable share of daily travel made by Australian travellers. In Perth's transport infrastructure plan for the next 20 years, nearly 80% of a planned \$2.9 billion budget provided by government is allocated to establishing a light rail network and extending the existing heavy rail network to make it more accessible for the majority of the expanding population (Department of Transport 2011). Accessibility is defined as the ease of reaching a location (El-Geneidy & Levinson 2006) by a desired mode (e.g. Bus and Ride - BnR, Park and Ride - PnR and Walk and Ride - WnR), at a desired time Bhat et al. (2000). Its quantification plays a vital role in decision and policy making.

Two types of accessibility are considered based on the definition above: perceived accessibility and measured accessibility. Perceived accessibility is subjective and measures an individual's perception on how easy it is to reach opportunities based on their own experiences (Fone, Christie & Lester 2006). Measured accessibility is generally an objective measure but it can be a combination of objective and subjective measures and it can be defined as the ease of reaching and using opportunities or services from a location. Various accessibility measures are available to this end and are briefly reviewed below.

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<sup>1</sup> A: Kent St, Bentley, Western Australia, 6102 T: +61 8 9266 7563 F: +61 8 9266 2703 E: mark\_ryan.au@outlook.com

Many studies have been conducted evaluating accessibility in general terms since it was first developed by Hansen (1959). However, only a limited number of studies examine the diversity of accessibility needs to train stations for different groups of people and between travel modes even though it is well documented that these needs vary amongst the different cohorts (see below). Therefore, this paper aims to compare perceived and measured accessibility to train stations between different modes (WnR, BnR, PnR) and between different age groups (Young (18-24); Middle aged (25-59); and elderly adults (60+)) spatially. Age classes were developed based on the consideration that higher levels of adults aged between 18-24 are students rather than working professionals and adults over 60 are eligible to receive a Seniors card in Western Australia to encourage them to live an active retirement. Specifically, we focus on one train station to examine the differences between perceived and measured accessibility and examine if these measures differ between age groups and/or travel modes. Results can be used to inform policy makers of the specific requirements for different cohorts of passengers.

## 2. Literature review

### 2.1 Accessibility measures

A large number of accessibility measures exist (Baradaran & Ramjerdi 2001; Dalvi & Martin 1976; El-Geneidy & Levinson 2006), which can be summarised into five categories (Baradaran & Ramjerdi 2001). A comparison of the advantages and disadvantages of these accessibility measures are shown in Table 1.

### 2.2 Characteristics of travel behaviour between various age groups

Travel behaviour (e.g. travel time, mode or purpose) is influenced by various factors such as age and employment status (Figueroa, Nielsen & Siren 2014) and these factors may have varying importance or applicability to different age cohorts.

#### *Travel time*

Data from the Bureau of Transport Statistics (2012) (Sydney, Australia) shows that during peak periods 3.1% of passengers are aged 65. However, this increases to around 11.0% during off peak periods. This contrasts with 17.7% of passengers aged 18-24 and 64.9% of passengers aged 25-64 using the trains during peak periods. According to Prasertsapakij and Nitivattananon (2012), about 85% of elderly adults in their study travel in off-peak periods possibly due to the perceived unsafe conditions posed by excessive crowds in Bangkok.

#### *Travel mode*

Previous research shows that many elderly adults will have to adjust their travel mode due to their declining driving ability and potential financial constraints, which are likely to become more amplified the longer they are retired (Burkhardt, 1999). Investigations have also revealed that older people have more free time to use public transport. Besides using public transport, walking is also a popular travel mode if there are no health or mobility constraints (Zhang et al., 2007). It was also identified that young people are driving less because of lower vehicle ownership, lower licence-holding rate and economic, social influences (Raimond & Milthrope 2010; Simons et al. 2014).

#### *Travel purposes*

Employment status directly shapes travel purposes and since many elderly adults are retired, their travel purposes are different from other members of the population. The literature suggests that the travel purposes of elderly adults have gradually transferred from survival to activities such as shopping, familial affairs and recreation (Collia, Sharp & Giesbrecht 2003; Zhang et al.

2007). Young adults are mainly involved in activities such as further/higher education, full/part-time employment and recreation/social activities (Currie, Stanley & Ttanley 2007).

**Table 1. A summary of advantages, disadvantages and theory of commonly used accessibility measures.**

Measure	Description	Advantages	Disadvantages	Example Studies
Spatial separation	Measured by one or more of travel time, cost, or distance, for example.	Easy to understand. Easy to calculate. Requires less data than other indicators.	Does not take into account variability of attractiveness of destination. Does not take into account value of time. Does not consider behaviour of travellers.	(Burns & Golob 1976; Pooler 1995)
Gravity	Based on spatial opportunities where closer opportunities are more attractive, can use travel distance or time.	Easy to understand. Easy to calculate. Able to differentiate between different locations.	Need to develop an impedance measure. Combining different modes difficult.	(Erlander & Stewart 1990; Levinson 1998)
Constraints-based	Takes into account space and time constraints facing an individual as limiting variables in accessibility.	Considers temporal dimensions. Accounts for time constraints.	Require detailed surveys to catch required information. Assumes constant speed in all directions. Activity schedules are normally incomplete. Not good for large groups due to data requirements.	(Kwan 1998; Miller 1999; Miller & Wu 2000)
Utility	Similar to the gravity measure but takes into account user preferences which may affect the accessibility of a location	Incorporate individual preferences. Adheres to travel behaviour theories.	Most complex and data intensive.	(Ben-Akiva, Moshe & Bierlaire 1999; Ben-Akiva, M. & Lerman 1979)
Composite	Combines two or more measures into one and is also beyond the scale of the four categories above	Flexible. Consistent.	Vary depending on the individual measures.	(Al Mamun & Lownes 2011; Miller & Wu 2000)

### *Physical travel abilities*

In general, as age progresses, people tend to experience lower levels of physical activity, reduced independence and greater health risks (Kockelman 1997). Carey (2005) reported that the average walking speed was around 0.5 ft/second slower for older pedestrians than younger pedestrians

and that the difference is magnified when climbing stairs. Similar results were also found by Bohannon (1997).

### 2.3 Variables affecting accessibility to train station

Variables affecting accessibility to train stations can be categorised into three types: 1) User-specific variables, such as affordability (Halden 2011), mobility (Hess 2009), time, budget and other general individual needs or purposes (Geurs & van Wee 2004); 2) station-specific variables such as service and facility quality (Debrezion, Pels & Rietveld 2009), land use (Levinson 1998) and intermodal connectivity (Kwan 1998); and 3) travel-specific variables such as travel time, distance, cost, travel reliability (Hensher & Stopher 1979), time of day and road network connectivity (Geurs & van Wee 2004). Some of these variables are travel mode specific, for example, parking capacity around a train station is only applicable to the park and ride travel mode. Intermodal connectivity is meaningful for BnR and PnR travel modes but is relatively unimportant for the WnR travel mode.

## 3. Methods

### 3.1 Study area

Figure 1 shows Perth's train system, which consists of 5 lines (Armadale, Fremantle, Joondalup, Midland and Mandurah) and one spur line (Thornton) all running from a central station Perth, with 70 train stations (Olaru et al. 2014). Greenwood train station is situated on the Joondalup Line (Figure 1) and is located at the boundaries of the suburbs of Greenwood, Kingsley, Padbury and Duncraig. The combined population, land area and population density for these suburbs was 46186, 2684 hectares and 17.21 persons per hectare in 2011 (*Welcome to the City of Joondalup Community Profile* n.d.). The Joondalup line was completed in 1992 with extensions to Currabine in March 1993 and Clarkson in October 2004 while Greenwood Station was opened in January 2005 (*Our History* 2015). Greenwood station is situated in the median strip of the Mitchell Freeway and is serviced only by trains that stop at all stations on the line running from Perth to Currabine.

### 3.2 Data collection methods

Data were collected by a series of intercept surveys at Greenwood Station, conducted over nine days during 2012-2013 and provided information on commuters' origins and their perceived accessibility rating of the station. In total, 128 respondents were asked to rate the overall access to this train station in consideration of their travel mode at one of five levels: from inaccessible to extremely accessible and summary statistics are shown in Table 2.

In total, 128 respondents were asked to rate the overall access to this train station in consideration of their travel mode at one of five levels: from inaccessible (1) to extremely accessible (5) and summary statistics are shown in Table 2 for the three age groups.

**Table 2. Summary of the perceived accessibility at Greenwood Station. Perceived accessibility ranges from 1 (inaccessible) to 5 (extremely accessible).**

Age groups	N	Mean	Std. Deviation
Young	19	2.89	0.57
Middle	89	2.97	0.73
Old	20	2.45	0.94
Total	128	2.88	0.76

### 3.3 Study framework

Figure 2 shows the framework of the study. Statistical tests (see below) were used to compare the accessibility differences between three age groups (step 1). Variables affecting accessibility were then identified (step 2). Based on these variables, the accessibility to the target station was measured for WnR, BnR and PnR respectively (step 3) and finally the perceived and measured accessibility was compared between three age groups (step 4).

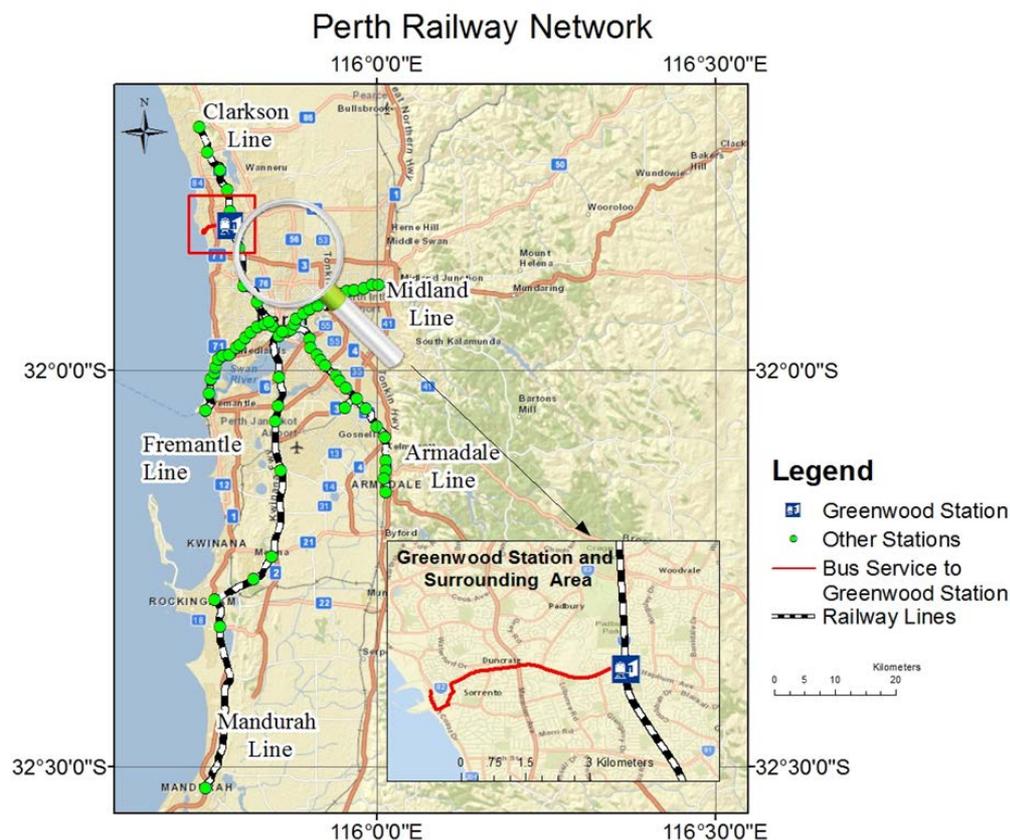


Figure 1. Study Area showing the location of Greenwood station on the Joondalup line in the context of Perth's train line network.

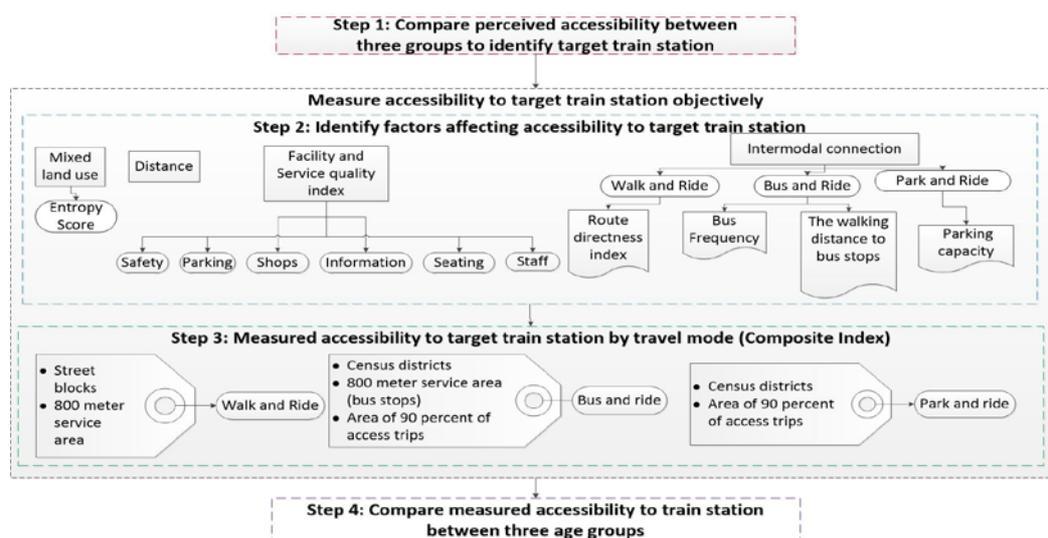


Figure 2. The framework of commuters' accessibility to a railway station.

#### Statistical tests

As perceived accessibility is of the ordinal data type or a rank, non-normal, and of a small sample size a nonparametric Kruskal-Wallis test was used to identify whether there were any statistically significant differences between perceived accessibility between the three age groups (Mumby 2002).

#### Accessibility variables

- Route Directness Index ( $d(r)$ )

According to Dalton et al. (2015), route directness is the ratio of route distance to straight line distance between two locations. A ratio of 1 indicates a direct route and hence an index closer to 1 indicates the most accessible route possible. Route directness was calculated for WnR, PnR and BnR respectively. The route directness index was calculated based on the street block within an 800m buffer of a station for WnR. While for PnR and BnR, the census district area is the basis for the origin of the trip and the catchment area encompasses 90% of the origins used by passengers by these two travel modes. Google Direction API and ArcGIS were used to conduct the calculation.

- Distance ( $D$ )

This is the network distance between the origin and the station.

- Facility and Service Qualities ( $Q_i$ )

The facility and service qualities of a train station were measured by 14 surveyed items. Respondents were asked to rate the overall importance of these items (1 = Not at all important to 7 = Extremely important). In addition, they also rated their satisfaction to these variables (1 = Poorest to 7 = Excellent). A facility and service quality index ( $Q_i$ ) was then calculated using the formula (1):

$$Q_{qi} = \frac{\sum_{k=1}^m (\sum_{j=1}^n (q_{jkqi} * w_{jkqi}))}{m * n * 7 * 7} \quad (1)$$

where:

$q_{jkgi}$  is the value of surveyed item  $j$  evaluated by respondent  $k$  in age group  $g$  at the station  $i$

$w_{jkgi}$  is the weight of surveyed item  $j$  evaluated by respondent  $k$  in age group  $g$  at the station  $i$

$n$  is the number of the surveyed item  $j$

$m$  is the number of respondent  $k$  in age group  $g$  evaluating the item  $j$

- Land Use Index (H)

The diversity of land uses surrounding train stations can play an important role in attracting commuters to use public transportation (Kockelman 1997). It was measured by an entropy score known as the mixed land use index (Brown et al. 2009):

$$Landusemix = -A/(\ln(N)) \quad (2)$$

$$A = \sum_{i=1}^7 (b_i/a) \times \ln(b_i/a) \quad (3)$$

where:

$b_1 = Area_{Shop/Retail}$ ;  $b_2 = Area_{Education}$ ;  $b_3 = Area_{Health/Welfare \& \text{Community Services}}$ ;  $b_4 = Area_{Residential}$ ;

$b_5 = Area_{Office/Business}$ ;  $b_6 = Area_{Entertainment, Culture \& Recreation}$ ;  $b_7 = Area_{Other}$

$a$  = total area (m<sup>2</sup>) of land for all land uses present in buffer

$N$  = number of land uses within buffer >0

- Parking capacity (N(p)) and bus frequency (F(b))

According to Duncan and Christensen (2013), the provision of PnR is one of the strongest predictors of station use. Kuby, Barranda and Upchurch (2004) found that increasing the number of PnR spaces and BnR connections and frequency can markedly increase weekday boarding's respectively. Bus frequency is defined as the average of the number of buses that arrive at a train station per hour on a weekday between 7:00am and 6:00pm. The PnR parking capacity at the station is defined as the number of parking bays for PnR purposes (N(p)). In addition, street parking availability near the station (NO(p)) was a binary variable (1 = parking available, 0 = unavailable).

- Scaling

Scaling into five levels from very poor to very high (see Table 3) was required to combine the variables into one index as the variables were in different units. The equal interval and standard deviation were used to this end. For example, mixed land use index was classified into five equal interval categories between 0 and 1. As the travel distance for PnR users varies across the stations it was converted into the cumulative probability of travel distance. The cumulative probability of the travel distance is consistent for all the stations and, therefore more suitable for comparison purposes. The details of scaling can be seen in Figure 3.

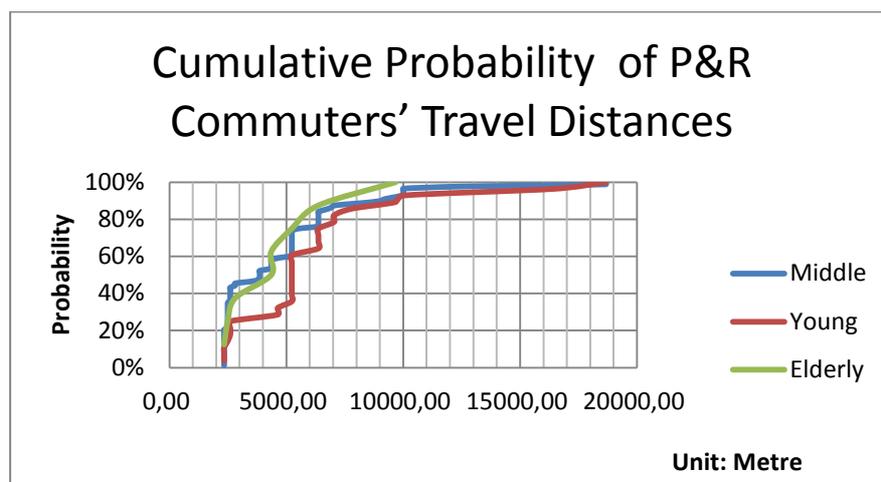


Figure 3. Cumulative Probability of Travel Distances to Greenwood Station.

Table 3. Assignment of variables to a common class scale.

Class	Mixed land use index	Distance (WnR)	Distance (PnR cumulative probability)	Service quality	Route directness	Short-term Parking bays	Long-term Parking bays	Bus frequency
Very High	0.8-1	0-200	0-20%	0.8-1	1-1.5	32 over	1100 over	659 over
High	0.6-0.8	201-400	20.1%-40%	0.6-0.8	1.51-2	25-32	852-1100	493-659
Medium	0.4-0.6	401-600	40.1%-60%	0.4-0.6	2.01-2.5	17-24	471-851	326-492
Poor	0.2-0.4	601-800	60.1%-80%	0.2-0.4	2.51-3	9-16	87-470	159-325
Very Poor	0-0.2	800over	80.1%-100%	0-0.2	3.01over	0-8	0-86	0-158

#### Accessibility measures

The composite measure was used to measure accessibility to train stations as it is less data-intensive, more structured, comprehensive and flexible enough to combine different variables and measures into one single index (Peterson et al. 2010). Multiple variables affecting the ease of access and use of train stations are evaluated and weighted to evaluate accessibility systematically. Respondents rated the importance of the variables in terms of their travel modes used and the Analytic Hierarchy Process (AHP) was used to generate the weight for each variable. The AHP method, initially proposed by Saaty and Vargas (1979), compares the variables using a pair wise comparison matrix and derives the weights and priorities of variables based on their relative importance.

The mathematical form of accessibility measure for each travel mode is explained as follows:

- WnR

Based on literature and survey results the catchment area for WnR is an 800m buffer around the station  $j$ . The catchment area was divided into street blocks and the accessibility  $A_{ijwalk}$  to the train station  $j$  from each block  $i$  within the 800m buffer was estimated by using the formula:

$$A_{ijwalk} = W_{Q_{jwork}} Q_{jwalk} + W_{H_j} H_j + W_{d(r)_{ij}} d(r)_{ij} + W_{D_{ij}} D_{ij} \quad (4)$$

where  $Q_{jwalk}$  is calculated from the mean values of all variables in the facility and service quality survey except for parking,  $H_j$  is the land use index,  $d(r)$  is the route directness index and  $D$  is the distance.  $W_{jwalk}$ ,  $W_{H_j}$ ,  $W_{d(r)}$  and  $W_D$  are the weights of these variables taken from Table 6.

- PnR

The catchment area for PnR was delineated by capturing 90% of all access trips to a station  $j$ . The accessibility to a station  $j$  from each census district  $i$  within the catchment area was estimated by:

$$A_{ijPnR} = W_{N(p)}N(p)_j + W_{NO(p)}NO(p)_j + W_{Q_{jPnR}}Q_{jPnR} + W_{H_j}H_j + W_{d(r)}d(r)_{ij} + W_{D_{ij}} \quad (5)$$

where  $Q_{jPnR}$  is calculated from the mean values of all variables in the facility and service quality survey,  $N(p)$  is the parking capacity at the station and  $NO(p)$  is the street parking availability near the station and is a binary variable (1 = parking available, 0 = unavailable).

$W_{PnR}$ ,  $W_{N(p)}$  and  $W_{NO(p)}$  are the weights of these factors taken from Table 6 with all other parameters as defined in equation 4.

- BnR

The BnR catchment area captured 90% of all access trips by BnR to a station  $j$  within an 800m service area buffer around bus stops. The accessibility to a station  $j$  from each census district  $i$  within the catchment area was estimated by:

$$A_{ijBnR} = W_{Q_{jBnR}}Q_{jBnR} + W_{H_j}H_j + W_{F(b)}F(b)_{ij} + W_{D_{ijwalk}}D_{ijwalk} + W_{D_{ijbus}}D_{ijbus} \quad (6)$$

where  $Q_{jBnR}$  is calculated from the mean values of all variables in the facility and service quality survey except for parking,  $F(b)$  is the average of the number of buses that arrive at a train station per hour on a weekday between 7:00am and 6:00pm,  $D_{walk}$  is the walking distance between the origin and the nearest stop to the rail station and  $D_{bus}$  is the bus distance between the nearest bus stop to the origin and rail station.  $W_{QBnR}$ ,  $W_{F(b)}$ ,  $W_{D_{walk}}$  and  $W_{D_{bus}}$  are the weights of these factors taken from Table 6 with all other parameters as defined in equation 4.

## 4. Results

### 4.1 Perceived accessibility

There was a statistically significant difference in the perceived accessibility between the elderly and other two age groups ( $p = 0.05$ ), with the former indicating Greenwood station to have a considerably lower level of access to them (Table 4).

**Table 4. Summary of mean ranks based on a Kruskal-Wallis test for Greenwood Station. Different subscripts denote significantly different mean ranks between the age groups.**

Age groups	N	Mean Rank
Young	19	64.92 <sup>a</sup>
Middle	89	68.24 <sup>a</sup>
Elderly	20	47.45 <sup>b</sup>

### 4.2 Measured accessibility

#### Service quality index

The service quality was measured using equation 1 and results are illustrated in Figure 4. Overall, lack of shopping services around stations is a major issue for all respondents (Figure 4). The elderly adults tended to rate the service qualities better than the other two age groups. However, lack of staff and parking availability was rated lower compared to the other two groups. For middle aged respondents, seat availability on trains was considered an important

issue, especially during peak hour travelling. In comparison to the other two groups, train frequency was rated slightly lower by young respondents, but considered most services more favourably than the other age groups.

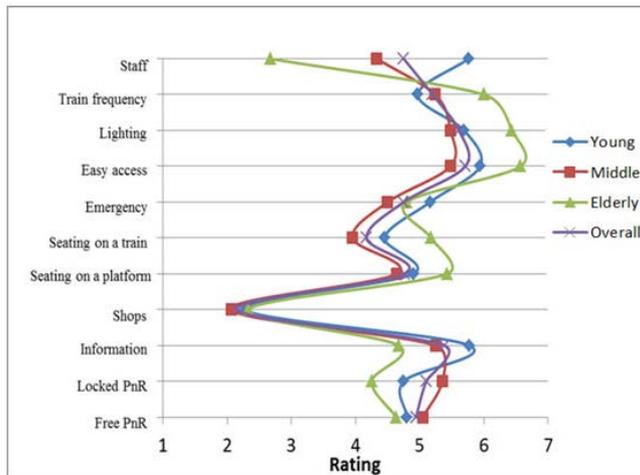


Figure 4. Service Quality of Greenwood Station

#### The mixed land use index

Figure 5a shows land use within 800m of Greenwood station. The mixed land use index was calculated using equation 2 and returned a value of 0.19 indicating low land use diversity around the station.

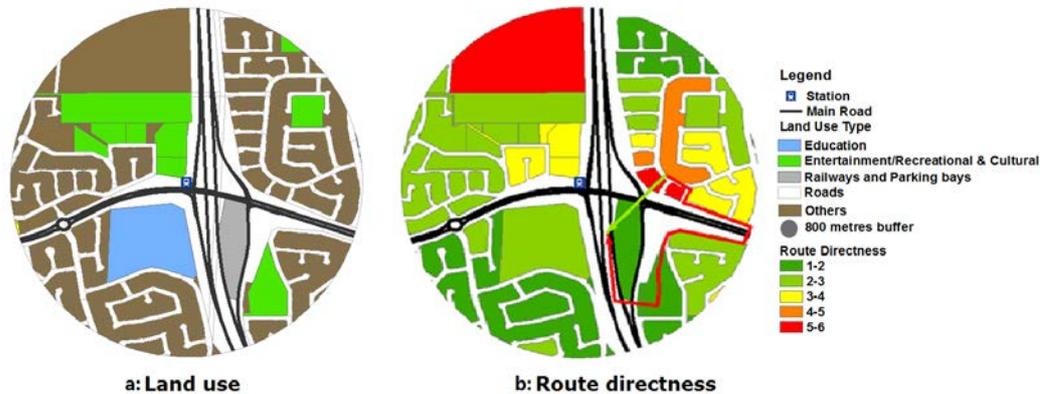


Figure 5. Land Use in the vicinity of Greenwood Station (a) and Route Directness for WnR (b).

#### Route directness index

The route directness index was distributed heterogeneously across the study area for the WnR mode (Figure 5b) and shows that accessibility can be extremely poor, even at relatively short Euclidean distances from the station. For example, the red line illustrates the shortest pedestrian path from one street block to the Greenwood Station platform. The green line shows the straight line between these two places. The ratio of these two lines (the route directness index) is 5.79. In some areas, especially near the northeast of the train line, the route directness index from a street block to Greenwood Station was up to 6, which means that a pedestrian has to walk six times further than the straight-line distance in order to access the station platform.

*Weights for accessibility variables*

The weighting of accessibility factors was used to indicate their relative importance in terms of station choice. The higher the weight, the more important the variables are considered to be for decision making and the more the variables contributed to the accessibility measure. The weights were organised, analysed and aggregated for each travel mode and age group using the AHP method (see Table 5). There was no statistically significant difference in the weights between the age groups for each travel mode. However, the distance between origin and train stations, bus frequency and parking capacity was considered to be relatively more important than other variables for WnR users, BnR users and PnR users, respectively. The land use mix was considered to be the least important variable by all age groups. The elderly adults evaluated the importance of these variables with the most variance compared to the other age groups.

*Measured accessibility to Greenwood Station*

The accessibility to Greenwood station was measured for WnR, PnR and BnR modes and three age groups using Equations 4-6 respectively. The variables for measuring accessibility were scaled into five unified categories (see Table 5). Figure 6 shows a map of measured accessibility for each age group for each travel mode. Generally, proximity provides a reasonable approximation of accessibility; however, this was not necessary the case for WnR with nearby areas to the north of the train line found to have very poor accessibility to Greenwood Station. Distributions of measured accessibility are similar between the three age groups travelling by WnR and BnR. However, the accessibility to Greenwood Station by PnR is different between the three groups as indicated by the different size and shape of their catchment area. Young adults have the largest catchment areas and better accessibility. Elderly Adults have the lowest PnR accessibility to train stations compared to the other age groups.

**Table 5. The weights of variables**

Mode	Description	Young	Middle	Elderly
WnR	the distance between origin $i$ and the rail station $j$	0.25	0.27	0.30
	the route directness index of the origin $i$ and the rail station $j$	0.25	0.27	0.27
	mixed land use within 800m buffer around the railway station $j$	0.25	0.23	0.20
	facility and service quality at railway station $j$	0.25	0.23	0.23
BnR	The bus frequency	0.22	0.22	0.22
	the walking distance between origin $i$ and the nearest stop to the rail station $j$	0.21	0.21	0.22
	the bus distance between origin $i$ nearest bus stop and rail station $j$	0.21	0.21	0.20
	mixed land use within 800m buffer around the railway station $j$	0.18	0.18	0.16
	facility and service quality at railway station $j$	0.18	0.18	0.19
PnR	parking capacity at the railway station $j$	0.19	0.19	0.21
	parking capacity off the railway station $j$	0.16	0.16	0.15
	the distance between origin $i$ and the rail station $j$	0.19	0.16	0.17
	the route directness index of the origin $i$ and the rail station $j$	0.16	0.19	0.17
	mixed land use within 800m buffer around the railway station $j$	0.15	0.15	0.14
	facility and service quality at railway station $j$	0.15	0.15	0.16

*Comparison between perceived and measured accessibility*

Table 6 shows the differences between perceived and measured accessibility by different age groups and travel modes at Greenwood Station with perceived accessibility being calculated from the results in each row in Table 6 where perceived accessibility ranges from 1 (inaccessible) to 5 (extremely accessible). Generally, perceived accessibility is higher than measured accessibility. Both perceived and measured accessibility were lower for elderly adults than the other two groups. When the perceived accessibility is broken down into age groups and travel modes, elderly adults were less satisfied with all three travel modes. Young adults were relatively less satisfied with the WnR mode when compared to PnR. No young adult was captured from the survey using BnR and only two middle aged respondents used BnR services.

**Table 6. Comparison between perceived and measured accessibility**

Age Group	Mode	Perceived Accessibility					Average Perceived Accessibility	Measured Accessibility
		Inaccessible	Not very accessible	Usable but need work	Pretty accessible	Extremely accessible		
Young Adults	PnR	-	-	9.09%(1)*	72.73%(8)	18.18%(2)	4.09	2.41
	BnR	-	-	-	-	-	-	2.3
	WnR	-	-	50%(3)	33.33%(2)	16.67%(1)	3.67	2.11
Middle Aged Adults	PnR	-	-	22.5%(9)	65%(26)	12.5%(5)	3.9	2.41
	BnR	-	-	-	50%(1)	50%(1)	4.5	2.3
	WnR	-	-	21.05%(4)	31.59%(6)	47.36%(9)	4.29	2.12
Elderly Adults	PnR	-	-	45.46%(5)	27.27%(3)	27.27%(3)	3	2.22
	BnR	-	33.33%(1)	33.33%(1)	33.33%(1)	-	3	2.2
	WnR	-	50%(1)	-	50%(1)	-	3	2.13

\*Percentage of respondents (number of respondents)

## 5. Discussion and conclusion

The aim of this study was to compare differences of accessibility, based on data acquired at Greenwood Station, Perth, Australia, from three angles: 1) different evaluation methods (perceived and measured); 2) different age groups (young adults, middle aged adults and elderly adults); and 3) different travel modes (PnR, BnR and WnR).

Perceived accessibility has been used broadly to understand people's perception on accessibility to services (Sanchez et al. 2000; Scott et al. 2007; Thériault & Des Rosiers 2004). However perceptions on the ease of access can vary individually and change over time depending on respondents' departure time (Scott et al. 2007). As Prasertsubpakij and Nitivattananon (2012) stated, transit services tend to cater for typical users such as commuters. When transit users travel during off-peak hours, the perceived accessibility was evaluated to be lower by respondents due to decreased train and bus frequency and parking availability. In addition,

because we conducted our survey at train stations, the respondents are service users. Even though they could be unsatisfied with services, they were tolerant of the services, and may not have an ideally accessible station to compare it to. This may be the reason why the perceived accessibility was measured generally higher than measured accessibility. In this case, a household survey could be a better way to collect perceived accessibility information evaluated by potential train users.

The results of the study show that Greenwood Station was found to have a statistically significant difference in perceived accessibility with elderly adults rating the perceived accessibility lower than the other two groups. The measured accessibility was found to be lower than perceived accessibility and this was consistent for all three groups, although the general trend is similar to perceived accessibility with the accessibility value highest for middle aged adults and lowest for the elderly.

Differences in the rating of parking by elderly adults may be due to elderly adults over 60 in Western Australia, being eligible for free public transport from 9:00am to 3:00pm during weekdays. However, parking bays are usually fully occupied by around 7:30am. While the lower rating of train frequency by young adults may be due to their travelling during off-peak periods (average departure time is around 9:46am), although elderly adults also travel during off-peak hours (average departure time is around 11:33am) they do not rate the train frequency as low as young adults. This may be due to elderly adults having different travel purposes and expectations than young adults.

It is interesting to note that the middle aged adults consider route directness to be more important than the distance between an origin and a train station compared to young adults which led to the spatial variation of PnR measured accessibility between these two groups. Land use was considered to be the least important variable for measuring accessibility, which could be due to the low level of mixed land use development around Greenwood Station.

The major accessibility gaps identified from the survey at Greenwood Station are low bus frequency, poor intermodal connectivity between bus and train, low route directness of the network and lack of toilets, shelters, staff and parking, which are common problems of street layout and station design (Cervero & Day 2008). Some elderly adults complained about crossing busy streets and car parks in order to reach the train station. Therefore, some improvements can be made to fill in these accessibility gaps and increase walkability in local communities around the station (Owen et al. 2007). In addition, this paper identified spatial gaps of accessibility to Greenwood Station for different age groups and by different travel modes. This detailed information can also be used as a decision-making aid by practitioners and station managers for developing accessibility.

One limitation of this study is related to the route directness measure. Google Direction API was used to generate routes for the WnR mode in this study. However, from Figure 7, it can be seen that the measured accessibility is better in the far north eastern corner than near the station in the same quadrant. The reason for this is that the Google direction API did not recognise some paths and short cuts that pedestrians use in the real world and this has affected the results.

This paper only considered limited variables affecting accessibility to train stations. They are mainly survey-related factors. Other variables, such as, users' mobility, availability and cost of parking space in a PnR parking lot and distance between train stations, haven't been considered in this paper. Perth is a low population density city. Free parking before July, 2014 and low cost (\$2 per day) after July, 2014 has made PnR services very popular and in high demand. Shortage of parking at PnR parking lots has created massive neighbourhood spill overs in surrounding streets. Parking enforcement is needed to solve this problem. In the future study, these variables would be considered for measuring accessibility to train stations.

This study provides evidence that there are differences between perceived and measured accessibility to train stations by three different transit modes and between the three age groups at one station (Greenwood). The results of this study will be of importance to public transit policy makers, urban planners and researchers, particularly the Public Transport Authority, to understand current accessibility gaps and transit user's concerns about the accessibility of Greenwood Station. The major contribution of this study is the development of a systematic approach for identifying and tackling the barriers that prevent people, especially the elderly, from using public transport services. The method is reproducible and generalisable internationally to understand differences of accessibility to train stations, especially how different age groups perceive accessibility to train stations by different modes of arriving at them.

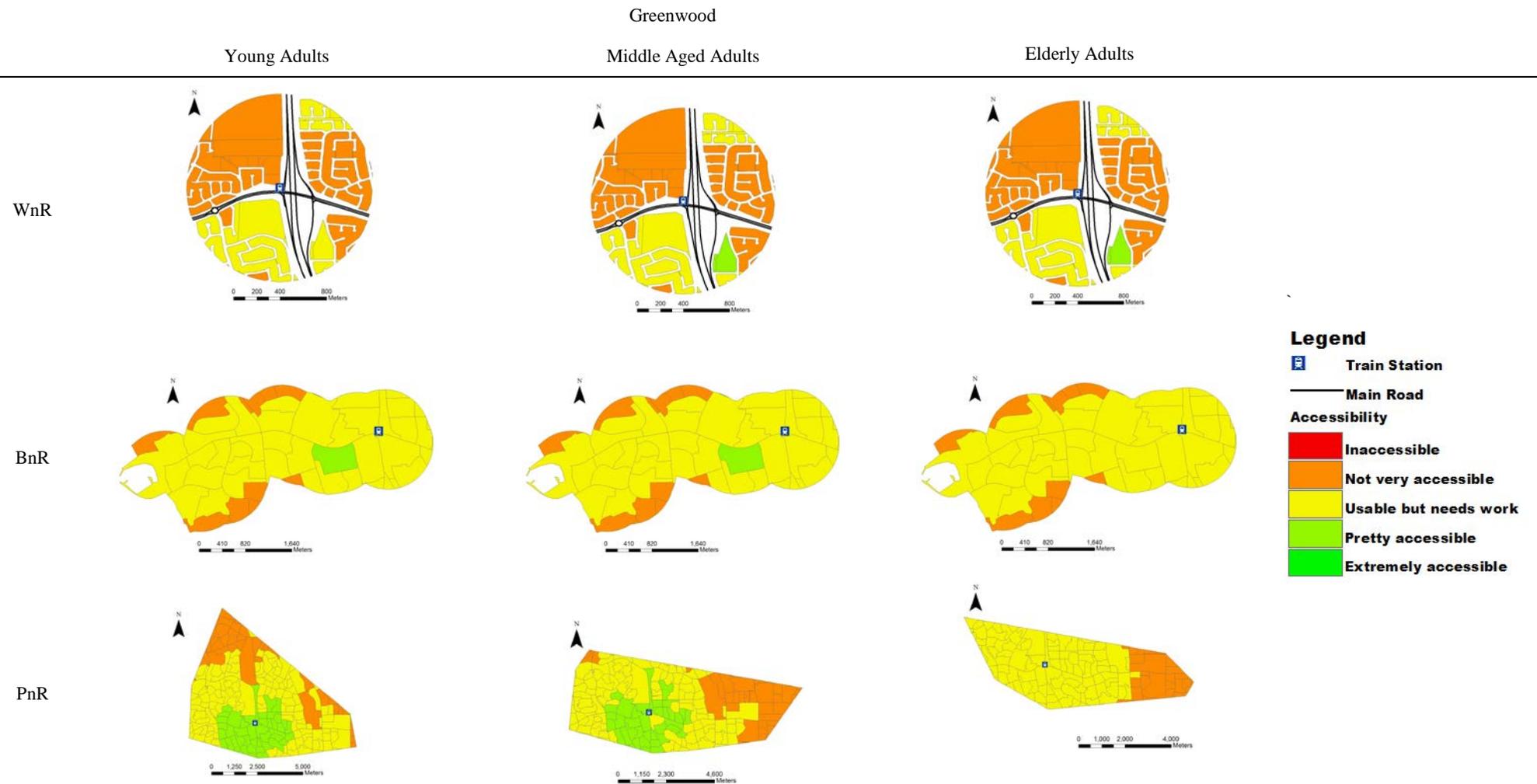


Figure 6. Map of measured accessibility for the different travel modes and age group

## Acknowledgements

This research was supported by an ARC Linkage grant (LP110201150). The authors would like to thank the people who willingly gave their time to participate in the study. We are very grateful to PTA (The Public Transport Authority) and DoP (The Department of Planning) for their ongoing support for this study. We would like to thank two reviewers for very helpful comments and suggestions. Special thanks are due to the data collection team. The views expressed in this article are those of the authors, and do not necessarily reflect the policies of any organisation.

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