# ACCESSIBILITY AND TRAVEL PATTERNS IN THREE NEW RAILWAY PRECINCTS


## ABSTRACT

This paper reports a research study that investigated the travel behaviour of residents in three case study station precincts located along a new railway in Perth, Western Australia. The precincts were selected for comparison, representing the different development opportunities ranging from planned transit-oriented development (TOD) to station precincts acting primarily as origin stations or transit interchanges. The relationship between accessibility measures and the actual travel patterns of residents in each station precinct are compared in order to consider the degree to which different station precinct designs have led residents to reduce their motorised travel and to substitute it with both public transport within the region, and walking or cycling within the local neighbourhood. We draw on two surveys: one, a household survey, including a travel diary, examining behaviours after the railway opened; the second, a detailed survey measuring both local and regional accessibility using a suite of over 30 measures of multi-modal accessibility.

The research findings show a positive relationship between improvements to accessibility by public transport and residents reducing car-based travel. Residents also increase the spatial reach of their travel and many converted from uni-modal to multi-modal travellers. At the local level (station precinct), however, we find an accessibility mismatch between infrastructure and proximity to facilities, whereby neighbourhoods with a high standard of infrastructure for walking and cycling do not have corresponding facilities that they may walk or cycle to and vice versa.


*Keywords: accessibility, travel patterns, factor analysis, transit-oriented development*

## INTRODUCTION

Access to essential goods and services is key in influencing residents' travel and location behaviours and distinguishes highly liveable areas from others. In Perth, for many decades, this accessibility has been achieved by car-based mobility. Since the late 80s, there has been an emergent policy seeking to offer alternatives to car travel. In addition to improvements to public transport (PT) infrastructure and services, there has been mounting support for a role for city planning in delivering more sustainable travel behaviours, including smart growth, new urbanism and transit-oriented development (TOD). These planning approaches suggest changes to accessibility at the city level (by improvements to public transport and proximity of development) and changes at the local level (by improving the infrastructure, amenity and development intensity and mix in order to facilitate more trips by walking and cycling).

The core question in this paper is whether these planning approaches, improving regional and local accessibility by more active travel modes, actually bring about travel behaviour change of residents. The purpose of this paper, therefore, is two-fold: to describe options to measure accessibility at a detailed spatial level in three TOD precincts and to explore the connections between these measures and the residents' travel. We apply multivariate analyses such as factor analysis, cluster analysis and analysis of variance to address the potential "causal chain" that explains the travel impacts along the TODs.

Using Perth, Western Australia as our case study, the research draws on two surveys: one, a household survey, including a travel diary, examining behaviours after the railway opened; the second, a detailed survey measuring both local and regional accessibility using a suite of over 30 measures of multi-modal accessibility. We investigate the relationships between travel and residents accessibility to both local and city-wide urban facilities. At the city level we apply impedance measures for the road and public transport networks to compare actual accessibility with travel. At the local level (or station precinct) we develop a multi-dimensional inventory and rating of the design features and local amenities that can be reached by public transport, walking, and cycling. The analysis is conducted along a 72km railway line opened between Perth and Mandurah (Figure 1).

## BUILDING ACCESSIBILITY MEASURES

Density, diversity of land uses and design (the "3Ds" suggested by Cervero & Kockelman, 1997) have been shown to impact on travel by reducing car dependence and increasing more sustainable transport modes. Frank & Pivo (1995) and Handy *et al.* (2005) found that when density increases and land uses are more diverse, people drive less (or at least the single car occupancy decreases). Ewing & Cervero (2001) expanded the '3Ds' to incorporate destinations and distance, with the same common theme, of encouraging healthier lifestyles and decreased car driving. The planning response has seen TOD, the "New Urbanist" or "Compact City" principles and the "Smarter communities" introduced in many cities throughout Australia and the US. The approaches aim to provide positive changes in the communities as a result of high levels of sustainable transport access to urban facilities, including: short distances between activity locations and potential of increased use of public transport alternatives. Where activity opportunity intensities are high and the land use mix appropriate, fewer separate locations are needed to fulfil the daily activity needs (Khattak & Rodriguez, 2005; Chen & McKnight, 2007). Where land use change comes with improved accessibility to public transport or other non-motorised alternatives of transport, there is potential for travel behaviour change.

TOD is expected to improve both local and regional access: at the regional (city)- level by networking station precincts across the region; at the local level by both improving the quality and amenity of cycling and pedestrian facilities and the variety and mix of neighbourhood services, clustered around the station. Positive results of TOD on more sustainable transport use have been found in USA and Europe (Lund, 2006; Aguilera *et al.*, 2009), and more recently in China (Cervero & Day, 2008). This is clearly in contrast with the demonstrated negative impacts of sprawl (see for example Newman & Kenworthy, 1999; Ewing *et al.*, 2002; or Travisi *et al.*, 2010), which were conducive to increased travel and environmental costs.

Ideas about accessibility planning have, most recently, been framed within the context of achieving more sustainable travel. In order to assess TOD's efficiency, there is a need to develop and evaluate measures of accessibility at both local and regional levels. At the local level, or neighbourhood, the urban design tradition is strong on directing design features that provide a physical environment to encourage accessibility for walking and cycling. Appleyard & Lintel (1972), Gehl (1987), Tibbalds (2001), Jacobs (2001), Barton *et al.* (2003) all argue for particular qualities of city space based on designing at a human-scale – reducing distance between buildings, activities and across the street in order to maximise the opportunity for contact and observation. It is not just the physical distance that is important, but also the quality of the experience: the design of buildings and orientation to the street and mix of uses to serve daily activity needs.

In Perth, the State's Liveable Neighbourhoods Planning Design Code (2001) draws on this urban design tradition and provides a detailed set of planning considerations for local accessibility, including detail about street cross section design, street networks, pedestrian access, provision of footpaths, cycle paths, amenity, traffic volumes and speeds, etc. They are consistent with previous scholarly work that has identified specific objective and subjective, quantitative and qualitative characteristics of the neighbourhood that need to be considered in accessibility evaluation. If objective factors include closeness to various activity locations, street design/layout, and facilities for cycling, parking and public transport, more subjective aspects refer to the quality of facilities, atmosphere or scenery, or range and variety of opportunities (Handy & Clifton, 2001).

Few empirical studies have captured the level of detail in measuring local accessibility expressed in this urban design tradition and evidenced in Perth's planning code. Handy & Clifton (2001) and Handy *et al.* (2005) come closest, but most research includes relatively simple measures of proximity by walking. Given the level of planning direction for urban design encompassing local accessibility, we developed a set of 35 local accessibility measures including: road type and traffic, street design features, slope, footpaths and pedestrian crossings, amenity/trees canopy, walking, cycling and public transport facilities, as well as distances to the local primary school, secondary school, shops, and park. This level of detailed measurement enables some empirical assessment of the value of policy measures put forward in planning practice.

At the regional, or city level, access is most commonly measured using a spatial separation function. Our review of approaches to accessibility measurement found a diversity of approaches, many framed around accessibility by car, rather than by public transport and led to the conclusion that there was no single perfect accessibility measure (see Curtis & Scheurer, 2010). This resulted in the development of our own measures, in particular focusing on adaption of accessibility methodologies to public transport networks across the metropolitan region and placing emphasis on the distribution of land use activities. The SNAMUTS accessibility tool derives an impediment measure that uses average travel time along a route segment weighted by the frequency of the service. While SNAMUTS has a set of seven indicators, highlighting centrality, connectivity and network performance from several angles, in this research paper we apply only one: 'Closeness centrality', which measures the average minimum cumulative impediment (travel time weighted by service frequency) for all network paths, from each node to reach any other node on the network. This indicator provides the best comparison with accessibility by car (using distance and travel time as the measure).

## DATA AND METHODOLOGY

The emerging TOD precincts along Perth's new railway line presented differing development opportunities and patronage potential. At one end of the spectrum is the precinct which acts primarily as an origin station or transit interchange, the focus here is on achieving a high level of accessibility by car and feeder bus, with little attempt to plan for land uses designed to act as a trip attractor. At the other extreme is the precinct designed around the traditional TOD concept, here the emphasis being on creating a land use mix and residential density, which will serve as a strong trip attractor, with access mainly by foot rather than car. The rationale for the selection of our precincts was to represent various design choices of interest to land use and transport planners. To this effect we selected three precincts: Bull Creek, Cockburn Central, and Wellard (Figure 1).

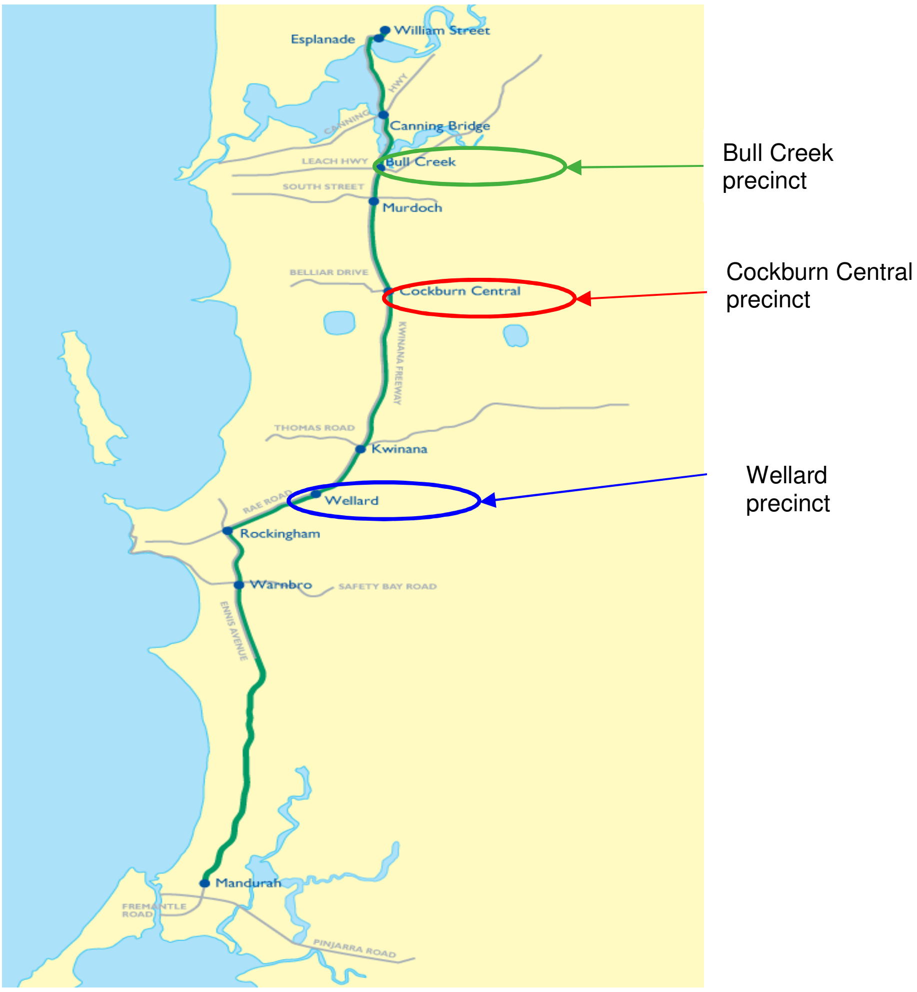
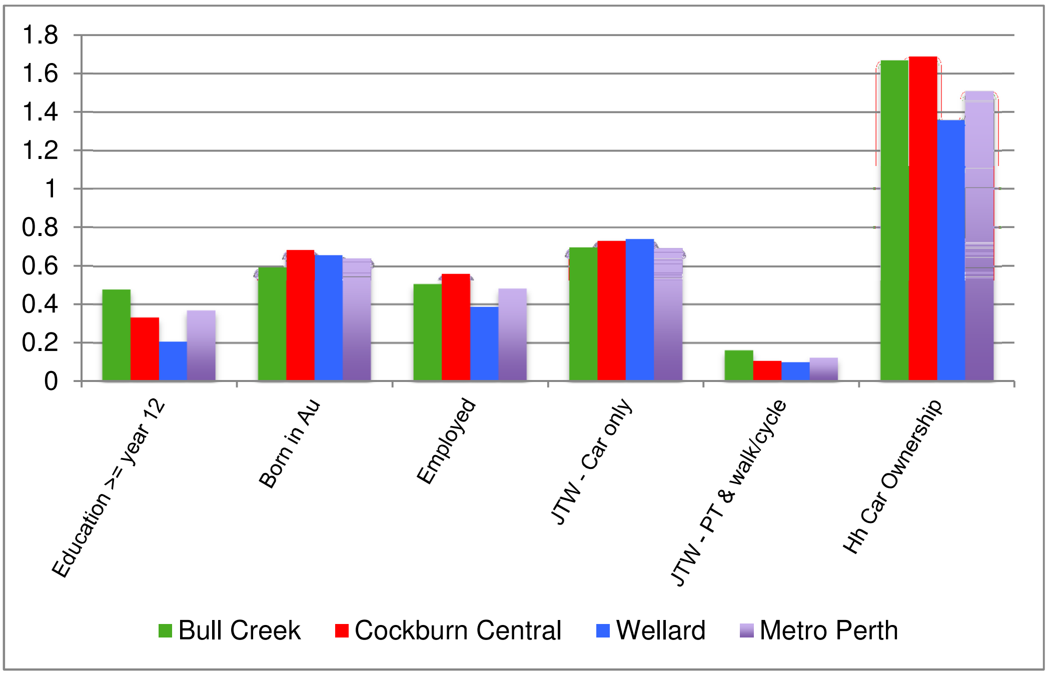



Figure 1: Railway corridor and study area

The primary focus at Bull Creek is the transit interchange. The station is located at the intersection of a primary arterial road and a freeway and is 12km from Perth city centre. The freeway reserve, at its narrowest point is approximately 100m wide, although at the off ramps this distance increases to approximately 500m, effectively constraining the opportunity for development of a pedestrian-scale precinct in close proximity of the station. At present there are no plans to promote mixed-use development. The station caters for a high volume of car access (610 car parking bays) and a feeder bus system along the arterial road serving the surrounding suburbs. At Wellard Station (39km from the city) the design objective is to mirror both TOD and 'new urbanism' principles with a mixed-use 'main street' (including 4,070m$^2$ of retail space) centred on the station surrounded by higher density residential development. The street network is designed to provide a high quality pedestrian environment. Finally, the Cockburn Central precinct (19km from the city) features aspects of both the Wellard and Bull Creek precincts. It provides for high car access (414 'park-and-ride' car bays and an estimated 928 car parks for the exclusive use of commercial premises). The precinct is dissected by a freeway reserve. Like Wellard, a mixed-use town centre is being developed centred on the station, with a range of recreational, commercial, entertainment and cultural facilities including residential apartments. There is also a suburban shopping centre located nearby.

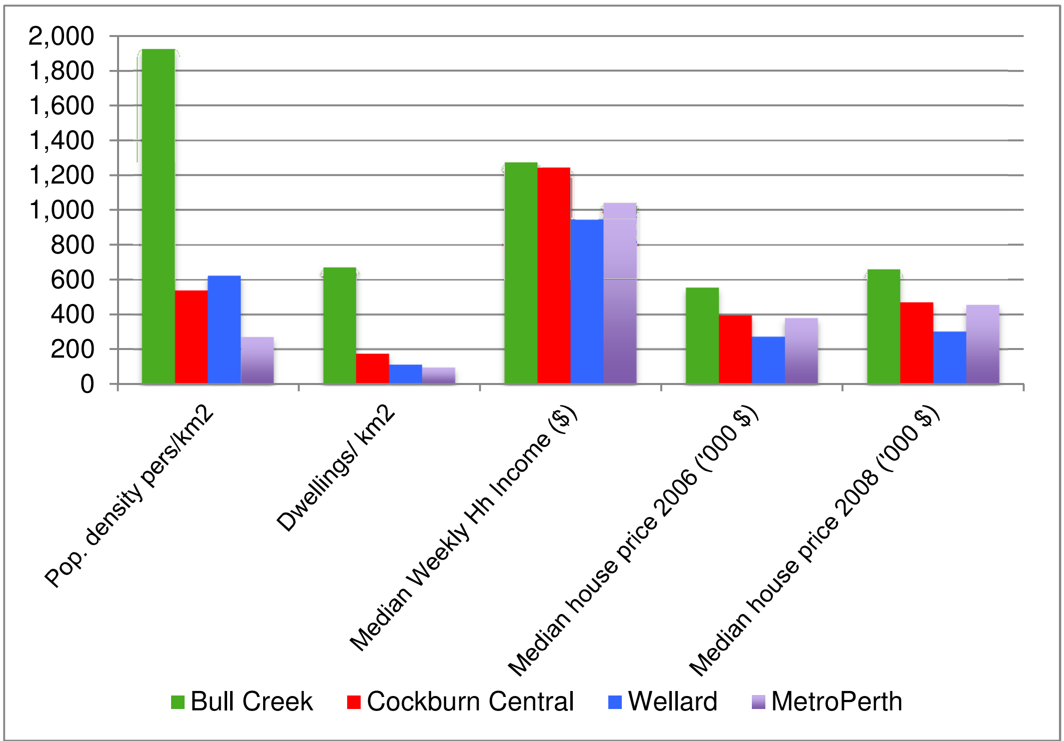
The limits of the station precincts were established at a five-minute drive around the railway station, considering the distance between adjacent stations and also known travel behaviour thresholds. Isochrones of actual 5, 10, and 15 minute walking distance were also drawn to identify population groups that may have different propensities to use public transport post railway opening, depending on their proximity to the railway station.

Figure 2 confirms the significant heterogeneity in the precincts in terms of socio-economic status.




a) Socio-demographics and Journey to Work (JTW)

Note: Education, ethnicity, employment, travel by car, PT, active transport in %, car ownership in cars/hh.




b) Densities, household income, and house prices

Figure 2: Profile of precincts compared to metropolitan Perth

Bull Creek residents have the highest income and level of education, but a significant proportion of them are retired or skilled immigrants, Cockburn Central is an emergent area with high employment, primarily in the resources area, whilst Wellard, has the lowest employment and income and the largest use of car for commuting.

## Data Collected – Survey 1 (Household survey)

The first data source is a quasi-longitudinal household survey, which was conducted over four years (2006-2009). We collected data for household and individual characteristics, car ownership, travel behaviour, location, physical activity and mobility restrictions in the surveys (Table 1). Here we focus on the "established" travel behaviour (trip diaries).

Table 1: Household Survey Information collected

| | |
|---|---|
| Household (hh): | Size, type of dwelling and tenancy, when moved to the residence, number of cars, bicycles, scooters, motorcycles, parking bays (income and contact details asked at the end of the interview). |
| Hh vehicles: | Type, make, age, fuel, costs amount and who bears them. |
| Hh members: | Age, gender, education, work/education place, number of weekly hours involved in work and voluntary work, flexibility of work program, types of driving licenses possessed, mobility restrictions due to physical condition (or imposed by parents on their children), physical activity, height and weight. |
| Travel diaries: | Collected as daily logs of all trips made by each hh member on the specified Wednesday (origin, destination of locations, departure and arrival time, purpose/activity, mode of travel, route, party size, out-of-pocket cost, parking, transfers). The activities in which the individuals were engaged were recorded in five main categories: work/study, shopping (for groceries or for other), personal business (personal care, banking, institutional appointments, etc.), recreational (spectating or participating in sporting events, cultural/public events, visiting friends/receiving visitors, eating out, sightseeing, |

| | |
|---|---|
| | fitness/exercise), pick-up/drop-off or accompanying someone, plus returning home. The trip diaries recorded separately transfers between travel modes and waiting times. The trip diaries were manually geo-coded after data collection. |

The study started with more than 1,000 households interviewed in 2006 and panel attrition resulted in about 500 households in the fourth and last survey in 2009. In this paper we report only on the 2006 and 2009 data – before and after railway opening.

## Data Collected – Survey 2 (Regional and local accessibility)

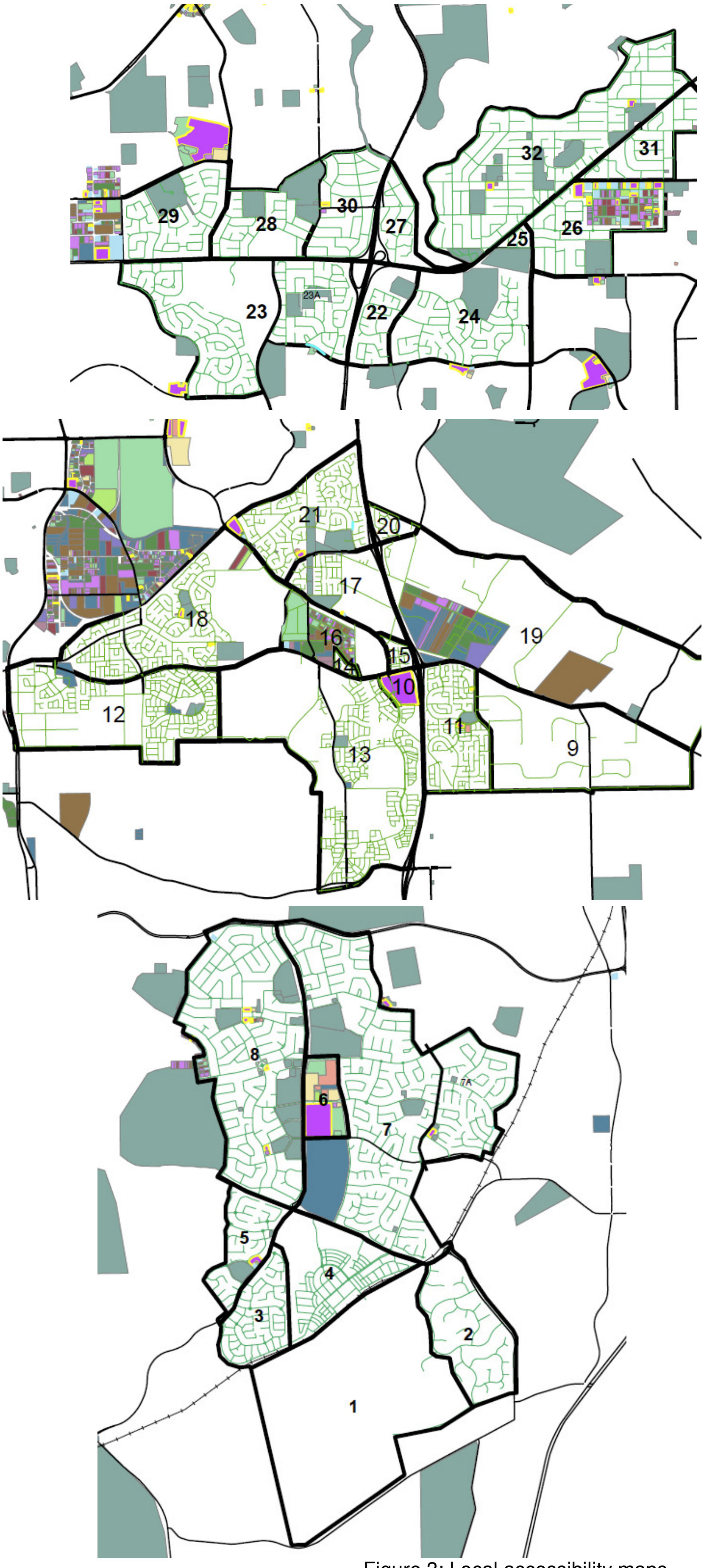
Accessibility is evaluated at two levels: regional (city-wide) and local (neighbourhood). As indicated, the regional accessibility measure is determined by the transport network and its services to reach destinations, with greater accessibility by car and by PT corresponding to lower values (Table 2). Bull Creek has the highest access and Wellard the lowest. This is mainly due to their geographical location in regard to Perth CBD and in the case of public transport a product of a radial rail network centred on Perth city. All three precincts witnessed substantial improvements in public transport following the opening of the rail corridor (in fact for the city as a whole Bull Creek's regional accessibility became second to the Perth city). Moreover, the metrics dropped significantly in all three precincts immediately after the railway opening, but policy measures of a 3% cut in services (taken in 2008 as a result of the in-coming liberal government economic policy aimed at cutting the cost of government), meant reduction of the frequency of public transport services and the access measures worsened (not shown here). Table 2 also shows no significant changes in the road distance access as a result of the new railway corridor. Anecdotal evidence suggests significant deterioration of the time access on the road network between 2006 and 2009 (especially peak time), however data on traffic congestion was not available for this analysis.

Table 2: City-wide access by precinct

| Access variable | Bull Creek | Cockburn Central | Wellard | Bull Creek | Cockburn Central | Wellard |
|---|---|---|---|---|---|---|
| | Before railway opening | | | After railway opening | | |
| City-wide road distance accessibility (km) | 24.1 | 30.2 | 39.9 | 24.1 | 28.9 | 38.3 |
| City-wide public transport time accessibility (non-dimensional) ** | 45 | 70 | 112.9 | 38.1 | 46.9 | 99.2 |

** Details in Scheurer & Curtis (2008) and Curtis & Olaru (2010)

At the local level our interest was to capture in detail the ease of movement within the precincts when using public transport, walking, or cycling (see section above for rationale). The data was compiled from various sources: GIS data for proximity measures provided by Department of Transport WA, traffic volume and public transport routes and schedules provided by Public Transport Authority WA, and field work for amenity and walking, cycling, and public transport facilities. The three precincts were split into sub-zones of accessibility (32 zones in total for all three precincts), defined by natural boundaries, major arterials, internal road layout and the distribution of land-uses. Figure 3 presents these sub-zones and Tables 3 to 6 in the following section describe in more detail the local access indicators.
The different colours in Figure 3 indicate various land uses in the precincts.




a) Bull Creek local accessibility zones

b) Cockburn Central accessibility zones

c) Wellard local accessibility zones

Figure 3: Local accessibility maps

# RESULTS

## Sample characteristics

The selected socio-demographics confirm the distinctive profile of the precincts, but do not indicate considerable changes in their 'social fabric' after railway opening (Table 3).

Table 3: Descriptive statistics by precinct (socio-demographics)

| Variable | Bull Creek | Cockburn Central | Wellard | Bull Creek | Cockburn Central | Wellard |
|---|---|---|---|---|---|---|
| | Before railway opening 2006 | | | After railway opening 2009 | | |
| Family size | 2.85 | 3.0 | 2.76 | 2.79 | 2.92 | 2.59 |
| # bedrooms | 3.63 | 3.73 | 2.75 | 3.68 | 3.70 | 3.13 |
| Weekly working hrs/person | 31.2 | 30.7 | 28.7 | 32.5 | 31.4 | 31.9 |
| Car availability | 1.95 | 1.94 | 1.83 | 1.86 | 1.98 | 1.69 |
| Parking space | 2.86 | 3.14 | 3.15 | 3.02 | 3.13 | 3.18 |
| # bicycles adults/hh | 1.26 | 0.92 | 0.72 | 1.21 | 0.98 | 1.13 |
| # bicycles children/hh | 0.47 | 0.70 | 0.64 | 0.59 | 0.76 | 0.87 |
| N households | 317 | 369 | 348 | 201 | 161 | 137 |

A comprehensive audit of local access used 35 characteristics or measures (see discussion p.5). To summarise these local accessibility measurements factor analysis was performed. The reasoning for this is that each single measure is unlikely to be very informative about the level of access by a mode; also many indicators go hand-in-hand (because of the design practices or agglomeration economies) or complement each other. By using factor analysis we created composites/summaries/constructs likely to mirror the accessibility requirements residents consider. Each construct has a measure of reliability, so instead of the 35 individual local accessibility measures, we use a reduced number of measures (based on their commonality) beneficial for model complexity. The factor analysis provides loadings, which reflect the strength of relationship between the construct and the individual measure and show how consistent the items are within a construct. Some items are strongly related to the construct, others are weak. Loadings show the relative importance/contribution of the items within the construct based on the objective planning practices applied in these zones. In addition, these summaries are continuous variables, providing an advantage in modelling over binary or ordinal variables, which require special approaches.
Following an exploratory stage, our confirmatory factor analysis (CFA) has shown a number of seven uni-dimensional constructs. Six of them have reliabilities above 0.65, with only one exception - of the construct of bicycle facilities. Table 4 presents the factor loadings for these constructs. We notice that the public transport level of service factors, the comfort and convenience of pedestrian facilities and the impedance (distance) all have loadings above 0.7, confirming the appropriateness of using construct measures to evaluate the impacts of access in the TOD developments on travel behaviour. In relative terms, walking and cycling to shops (0.869 and 0.843) and recreation spaces (0.92 and 0.658) seems to have higher contribution to the constructs than access to schools (lower values for loadings); the width of

footpaths (0.974) and the surface quality (0.956) are determinant for the easiness of walking; and the presence of benches and shelters (0.884) along with more frequent bus services to shops (0.906) and schools (0.883) are vital to public transport users as they affect the quality of waiting time. This represents a prime indication for planning practice of essential accessibility elements that have to be incorporated in the overall access.

Table 4: Measures of local accessibility – factor loadings

| Construct – variance explained | Items | Factor loadings |
|---|---|---|
| Walking distance to neighbourhood facilities – 0.684 | Walking distance to the park | **0.920** |
| | Walking distance to basic shop | **0.869** |
| | Walking distance to the nearest high school | 0.782 |
| | Walking distance to the nearest primary school | 0.723 |
| Walking facilities /Footpaths – 0.883 | Width of the footpaths | **0.974** |
| | Surface quality | **0.956** |
| | Presence footpaths (one or both sides) | **0.887** |
| | Tree canopy | **0.815** |
| Street design/geometry – 0.577 | Distance in m from kerb to kerb | 0.799 |
| | Street crossing b | 0.767 |
| | Street crossing a | 0.676 |
| | Active frontage | 0.661 |
| Cycling distance to neighbourhood facilities – 0.588 | Cycling distance to basic shop | 0.843 |
| | Cycling distance to the park | 0.658 |
| | Cycling distance to the nearest high school | 0.614 |
| | Cycling distance to the nearest primary school | 0.571 |
| Bicycle facilities – 0.378 | Terrain | 0.738 |
| | Bike parking at the shops | -0.712 |
| | Off-road designated bike paths | 0.283 |
| PT amenities – 0.758 | Bus stop sets | 0.884 |
| | Bus stop shelter | 0.884 |
| | Bus stop | 0.856 |
| | Bus stop information | 0.667 |
| PT local services - 0.846 | Frequency bus services to shopping centre | 0.906 |
| | Bus route to primary school | 0.895 |
| | Frequency bus services to primary school | 0.883 |
| | Bus route to shopping centre | 0.881 |

The factor scores were then further applied to characterise the local accessibility features for the 32 access zones in the three precincts. Figure 4 shows the standardised local access values for each of the local access zones displayed in Figure 3. Negative values indicate a lower level of combined access or facilities, whilst a positive value indicates that the zone has a higher access and quality of services. A number of areas display a certain degree of incongruity between design features or walking and cycling facilities and the availability of urban facilities (such as shopping, health, recreational, or educational establishments). In these zones the indicators of amenities or proximity frequently have a positive value, whereas the available facilities display a negative values, as highlighted in the radar charts below.

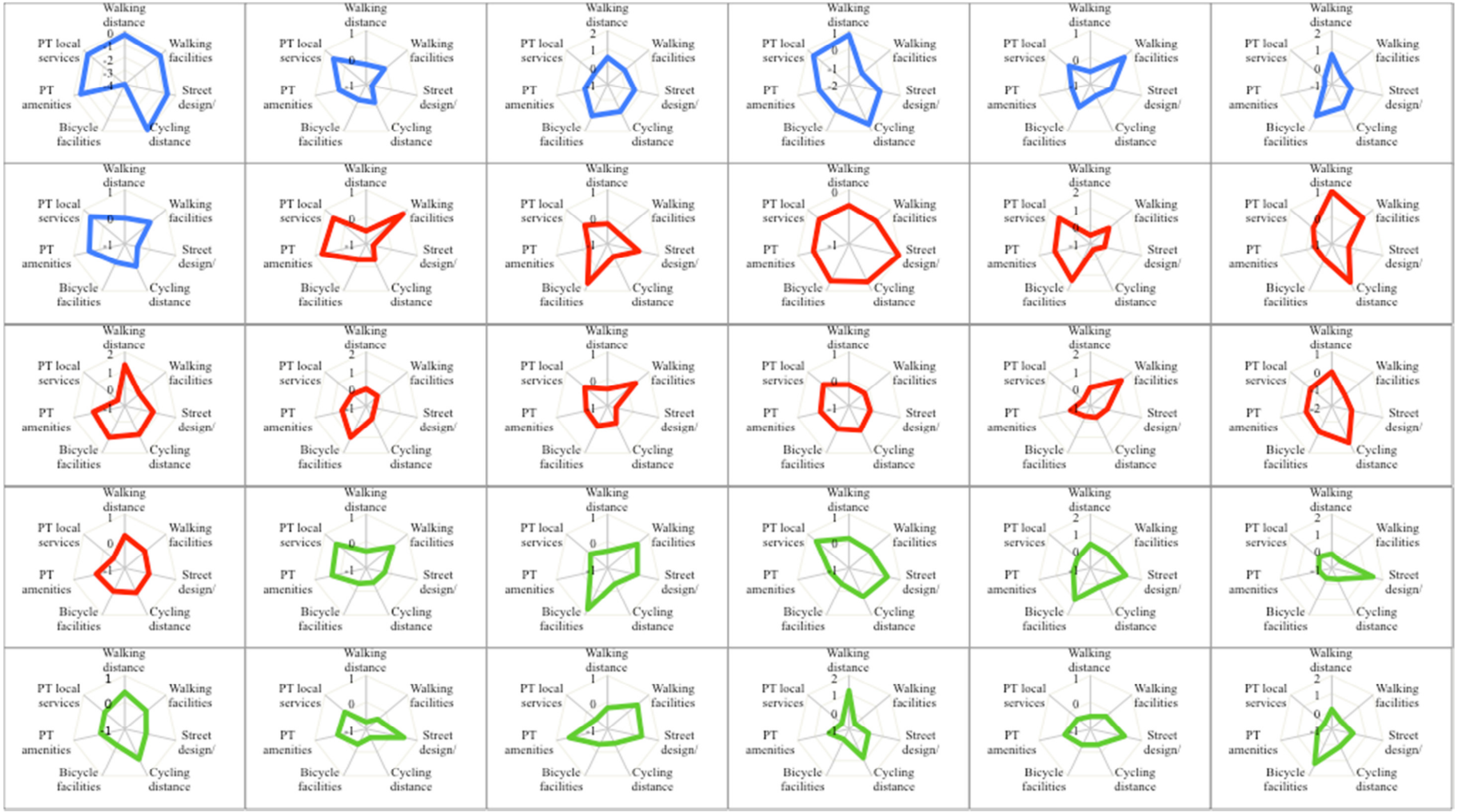


Figure 4: Local accessibility by zone (left to right and top-down, zones 2 to 9, and 11 to 31); Colour code: Wellard – blue, Cockburn Central - red, and Bull Creek - green.

Note: Zone 1 is a reserve and zone 10 is the local town centre, without residential use and therefore not included in the analysis.

The matrix of radar charts demonstrates the heterogeneity within the precincts and assists us in identifying neighbourhoods with deficiencies in accessibility and suggests possible solutions. An example of this planning inconsistency may be the industrial area in Jandakot, opposite to the Cockburn Central railway station (zone 19), where the access to local facilities is nil; another one is the Wellard suburb, with good walking and cycling access, but no retail, recreation, community services available on the Main Street Complex (zone 4).
Table 5 presents correlations between the seven complex measures of local access. These results further attest to the mismatch between the provision of facilities or opportunities for local activities and the network features enabling more sustainable transport (walking, cycling, public transport) e.g., the insignificant correlations (p>=0.05) between the walking distance to facilities and the pedestrian orientation of the zones and the street design, or between the bicycle facilities and cycling distance to local amenities. Ideally, the matrix would include significant positive associations, such as between the PT amenities and local services, but in the case of the three precincts there are numerous ‘anomalies’. As suggested, this has implications for planners, who can use this type of information and analysis to find gaps in the availability and quality of urban services at the neighbourhood level.

Table 5: Correlations between local access constructs (Pearson correlation and p-value)

| | **Walking distance to facilities** | **Walking facilities/ footpaths** | **Street design/ geometry** | **Cycling distance to facilities** | **Bicycle facilities** | **PT amenities** | **PT local services** |
|---|---|---|---|---|---|---|---|
| Walking distance to facilities | 1 | | | | | | |
| Walking facilities/footpaths | -0.146 | 1 | | | | | |
| | (0.074) | | | | | | |
| Street design/ geometry | -0.103 | ***0.509*** | 1 | | | | |
| | (0.215) | *(0)* | | | | | |
| Cycling distance to facilities | ***0.921*** | -0.149 | -0.121 | 1 | | | |
| | ***(0)*** | (0.067) | (0.145) | | | | |
| Bicycle facilities | 0.083 | 0.132 | 0.111 | 0.037 | 1 | | |
| | (0.307) | (0.106) | (0.179) | (0.652) | | | |
| PT amenities | -0.146 | ***0.548*** | ***0.577*** | -0.131 | 0.132 | 1 | |
| | (0.074) | *(0)* | *(0)* | (0.109) | (0.105) | | |
| PT local services | -0.128 | ***0.448*** | ***0.455*** | -0.105 | 0.125 | ***0.609*** | 1 |
| | (0.117) | *(0)* | *(0)* | (0.199) | (0.125) | *(0)* | |
| N | 152 | 151 | 147 | 152 | 152 | 152 | 152 |

Note: The matrix being symmetric, only half is presented.

When aggregated at the precinct level[1] (Table 6), we observe that Bull Creek has better distribution of local shops, parks, and schools that are accessible by walking and cycling, and superior cycling facilities. Wellard displays the best street geometry/design out of the three

1 The aggregation takes into account the number of households in each local access zone, reducing the potential bias towards large size areas and reflecting the fact that accessibility is measured for households residing in the area.

precincts, attesting to its intended traditional TOD design, although local shops are yet to be constructed. Cockburn Central appears to be served by superior public transport amenities and to offer good bus services to local urban facilities (likely the result of one major shopping precinct which includes a bus station).

Table 6: Aggregated local access by precinct (weighted by number of households in each zone)

| Access variable | Bull Creek | Cockburn Central | Wellard |
|---|---|---|---|
| Walking distance to facilities | *0.273* | -0.203 | -0.043 |
| Walking facilities | -0.085 | -0.110 | -0.052 |
| Street geometry/design | -0.041 | -0.190 | *0.293* |
| Cycling distance to facilities | *0.200* | -0.238 | -0.037 |
| Bicycle facilities | *0.417* | 0.254 | 0.294 |
| PT amenities | -0.087 | *0.158* | -0.078 |
| PT services to local facilities | 0.175 | 0.186 | -0.186 |

Cluster analysis assisted us to classify areas with similar local access features into groups without preconceptions of their defining attributes. Euclidean distances measures between the access zones were used to group the zones that are more similar with one another in the same cluster/group. The relatively homogenous resulting clusters were further used in comparing travel behaviour with the composite of access score. In each precinct we distinguished between zones with lower (Cluster 1) and higher access (Cluster 2) for pedestrian, cycling, and public transport features. The evidence suggests that the local access metrics were significantly different between the two clusters (at 0.05 level), with the exception of the street layout and cycling distance to the nearest high school.

Table 7: Clusters of high and low local access

| Access zone | Walking distance to facilities | Walking facilities | Street design/ geometry | Cycling distance to facilities | Bicycle facilities | PT amenities | PT local services | Clusters walking access | Clusters cycling access | Cluster PT access |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | -0.30 | -0.56 | -0.64 | -0.08 | -3.99 | -0.55 | -0.47 | *low* | *low* | *low* |
| 3 | -0.25 | -0.11 | -0.78 | -0.21 | -0.34 | 0.03 | 0.56 | low | low | high |
| 4 | 0.50 | 0.24 | 0.60 | 0.77 | 1.02 | 0.28 | -0.04 | high | high | high |
| 5 | 0.76 | -1.02 | -0.19 | 0.58 | -0.34 | -0.26 | 0.56 | low | high | low |
| 6 | -0.51 | 0.65 | -0.18 | -0.48 | -0.02 | -0.26 | 0.05 | *low* | *low* | *low* |
| 7 | 0.70 | -0.29 | 0.14 | 0.43 | 1.02 | -0.55 | -0.47 | low | high | low |
| 8 | -0.07 | 0.23 | -0.51 | -0.03 | -0.21 | 0.37 | 0.64 | *low* | *low* | *low* |
| 9 | -0.56 | 0.80 | -0.73 | -0.29 | -0.34 | 0.72 | 0.55 | *low* | *low* | *low* |
| 11 | -0.27 | -0.47 | 0.23 | -0.45 | 0.68 | -0.26 | 0.12 | low | high | low |
| 12 | -0.28 | -0.33 | -0.02 | -0.19 | -0.22 | -0.32 | -0.29 | *low* | *low* | *low* |
| 13 | -0.52 | 0.35 | -0.13 | -0.57 | 1.34 | 1.06 | 1.27 | high | high | high |
| 14 | 0.97 | 0.51 | -0.36 | 0.64 | -0.34 | -0.32 | -0.12 | high | high | low |
| 15 | 1.30 | 0.07 | 0.68 | 0.87 | 1.02 | 0.77 | -0.47 | low | high | high |
| 16 | -0.05 | -0.17 | -0.50 | -0.19 | 1.02 | 0.40 | 0.05 | low | high | high |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 | -0.36 | 0.37 | -0.68 | -0.25 | -0.12 | -0.16 | 0.06 | *low* | *low* | *low* |
| 18 | -0.20 | -0.25 | -0.15 | 0.06 | -0.04 | 0.08 | 0.22 | low | high | low |
| 19 | 0.03 | 1.26 | -0.03 | -0.21 | -0.34 | 0.11 | -0.47 | high | low | low |
| 20 | -0.11 | -1.02 | -0.8 | 0.35 | -0.34 | -0.55 | -0.47 | low | high | low |
| 21 | 0.24 | -0.02 | -0.03 | 0.06 | -0.02 | 0.11 | -0.47 | low | high | high |
| 22 | -0.40 | 0.30 | -0.27 | -0.40 | -0.34 | 0.32 | 0.47 | low | low | high |
| 23 | -0.38 | 0.44 | 0.18 | -0.32 | 0.75 | -0.32 | -0.17 | low | high | low |
| 24 | 0.10 | 0.04 | 0.50 | 0.21 | -0.34 | -0.26 | 0.58 | high | high | low |
| 25 | 0.32 | 0.24 | 1.07 | 0.16 | 1.02 | -0.03 | -0.1 | high | high | low |
| 26 | -0.26 | -0.41 | 1.45 | -0.28 | -0.34 | -0.26 | -0.04 | high | low | low |
| 27 | 0.38 | 0.05 | -0.14 | 0.28 | -0.34 | -0.08 | -0.02 | high | high | low |
| 28 | -0.73 | -0.41 | 0.48 | -0.60 | -0.34 | 0.11 | 0 | high | low | low |
| 29 | -0.22 | 0.46 | 0.35 | -0.37 | -0.34 | 0.50 | -0.47 | low | low | high |
| 30 | 1.14 | -0.56 | 0.16 | 0.84 | -0.34 | 0.11 | -0.47 | high | high | low |
| 31 | -0.53 | -0.24 | 0.34 | -0.31 | -0.34 | -0.02 | -0.43 | low | low | low |
| 32 | 0.07 | -0.33 | 0.26 | 0.09 | 1.18 | -0.22 | -0.47 | high | high | low |

The clustering shows that in each precinct, there are areas of high access by one mode or another, but not necessarily by all modes. In fact only two zones have high access by all three active travel modes and six have low access in walking, cycling, and PT walking.

## Travel Behaviour

To explore the associations between travel behaviour and accessibility indicators we have undertaken a series of comparisons: i) changes in travel behaviour and destinations before and after the railway opening; and ii) differences in travel patterns by cluster of local accessibility. The first one provides insights into possible changes in travel due to the new railway line (city level access) and TODs and the latter looks into the travel behaviour at local level.

Table 8: Descriptive statistics by precinct (travel behaviour – averages and standard deviations)

| Variable | Bull Creek | Cockburn Central | Wellard | Total | Bull Creek | Cockburn Central | Wellard | Total |
|---|---|---|---|---|---|---|---|---|
| | Before railway opening (2006) | | | | After railway opening (2009) | | | |
| Daily travel distance (km) | 28.75 (25.11) | 34.21 (29.98) | 44.58 (40.26) | 31.39 (30.27) | 24.18 (23.44) | 26.09 (24.84) | 39.31 (43.97) | 28.84 (31.26) |
| Daily travel time (min) | 71.85 (48.41) | 73.32 (52.65) | 87.35 (70.70) | 76.96 (61.74) | 71.77 (53.06) | 68.02 (66.93) | 81.52 (85.56) | 73.11 (67.71) |
| N trips | 1,853 | 1,289 | 1,984 | 3,936 | 1,618 | 1.081 | 864 | 3,563 |
| # trips/day and person | 3.95 (2.40) | 3.78 (2.84) | 3.76 (2.54) | 3.85 (2.73) | 4.72 (3.07) | 3.63 (2.34) | 3.81 (2.95) | 4.12 (2.86) |
| % trips by mode: | | | | | | | | |
| - private motorised | 77.07 | 81.80 | 83.46 | 80.34 | 67.60 | 75.72 | 72.23 | 70.20 |
| - public transport | 6.29 | 5.20 | 4.19 | 5.54 | 11.04 | 6.79 | 12.08 | 11.24 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| - cycling & walking | 16.23 | 11.22 | 9.88 | 12.60 | 17.89 | 16.65 | 14.99 | 16.42 |
| Trips under 5km: | | | | | | | | |
| % private motorised | 63.60 | 66.45 | 82.84 | 69.23 | 61.39 | 66.93 | 61.88 | 63.30 |
| % walking and cycling | 27.90 | 24.89 | 14.71 | 24.58 | 29.72 | 28.18 | 22.80 | 27.52 |
| N persons | 913 | 1,095 | 967 | 2,975 | 484 | 414 | 284 | 1,182 |

Note: Cycling and walking trips combined both utilitarian and recreational activities.

We notice a significant drop in the use of motorised modes in all precincts and the corresponding increase in alternative modes such as walking-cycling and public transport. The increased access as a result of the corridor and TOD precincts is reflected in the reduced distances travelled daily, although the travel expenditures remained unchanged. This is because we witness a change in trip-making, many residents being converted from uni-modal to multimodal travellers (i.e., city-level access facilitated a larger number of legs in the trip chains).

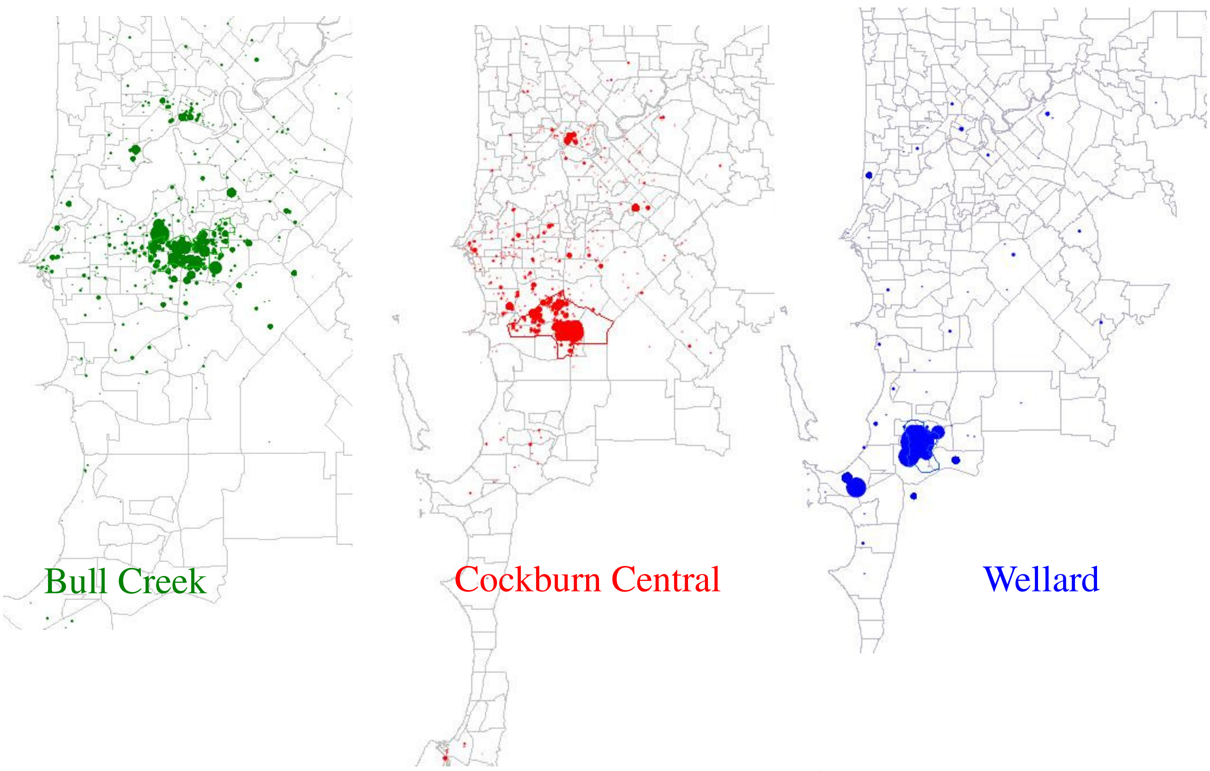



Figure 5: Main travel destinations – all journey purposes (before railway opening)

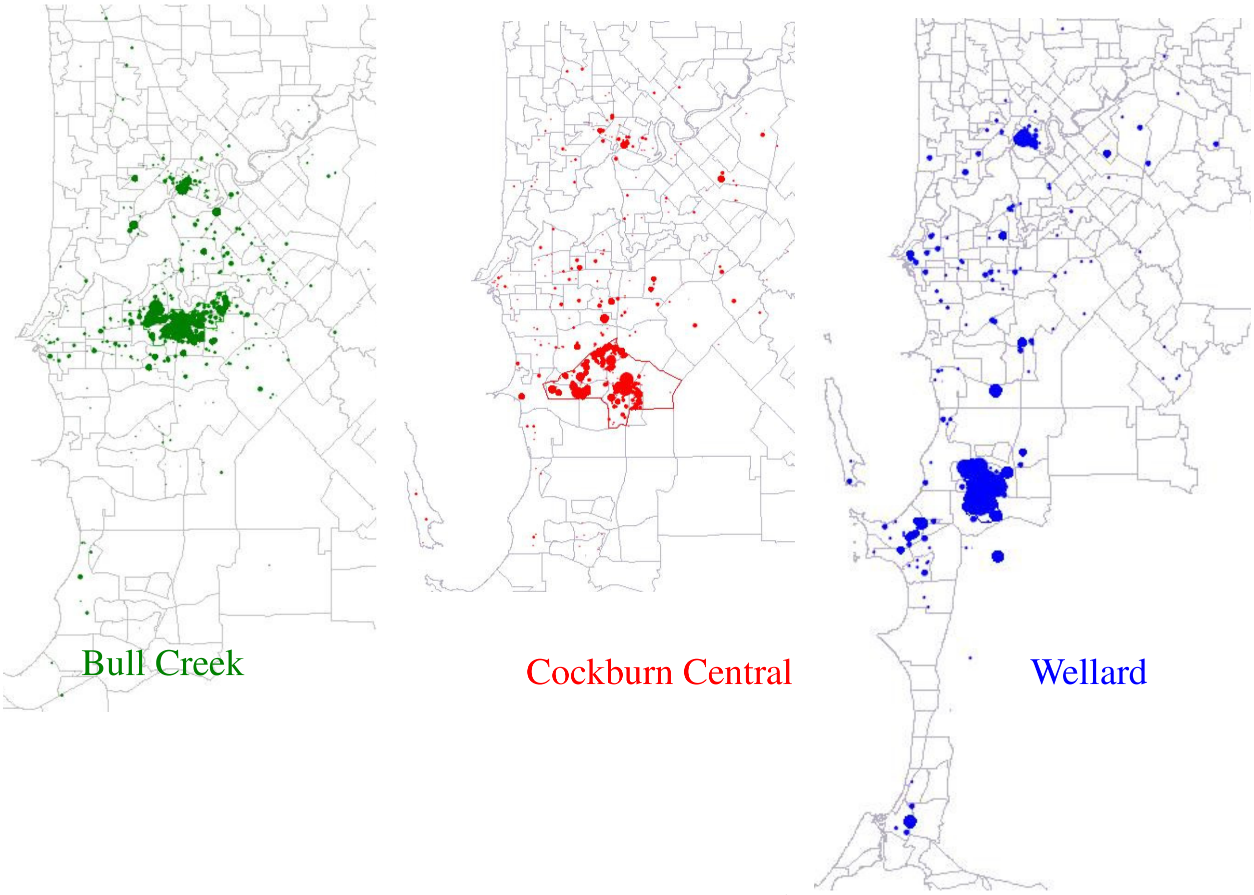



Figure 6: Main travel destinations – all journey purposes (after railway opening 2009)

Comparing Figures 5 and 6 shows significant changes in the travel destinations. In Bull Creek we note strong local focus with many destinations within 0-15kms radius, Perth CBD representing a strong magnet for trips generated in Bull Creek. Cockburn Central displays more dispersed destinations, but Perth CBD is reached easier than before, as well as Mandurah. Wellard displays the most scattered map of destinations, but again this is explained by the corridor accessibility, which becomes more attractive for residents. Increased accessibility at the city level means that residents along the corridor can now reach Perth and Mandurah city centres faster, which has significant implications for commuting. Interestingly, the shopping destinations have changed to a certain extent as a result of the opening and extension of the Cockburn Gateway Shopping Centre (including not only supermarkets, liquor stores, chemists, bank offices and food courts, but also electronics, furniture, florists, fitness centres). Residents in the Cockburn Central and Wellard precincts now shop at Gateway instead of Garden City and Kwinana Hub, the closest retail areas to each precinct respectively, prior to the TOD developments. The percentage of trips made within the precinct (self-contained) increased in relation to the extent of TOD design (i.e. Wellard shows greatest local trips while Bull Creek the least) and there is more sustainable travel (walking and cycling) in all three precincts.
Table 9 contrasts the two clusters of access in each precinct in their travel, using multiple analysis of variance (MANOVA). The purpose is to test if travel behaviour indicators are the same between the lower and higher access clusters at household, individual, and trip level.

Table 9: Travel behaviour by local accessibility (Cluster 1 – low, Cluster 2 – high access)

| Variable | Walking access | | Cycling access | | Public transport (PT) access | |
|---|---|---|---|---|---|---|
| | Cluster 1 | Cluster 2 | Cluster 1 | Cluster 2 | Cluster 1 | Cluster 2 |
| **Household level** | | | | | | |
| Daily travel distance (km) | *69.06* | *53.74* | *61.76* | *64.58* | 63.41 | 64.56 |
| Daily travel time (min) | *148.89* | *168.26* | *154.19* | *164.74* | *158.80* | *168.84* |
| N trips | 9.19 | 8.92 | 8.85 | 9.2 | 8.98 | 9.41 |
| N motorised trips | *6.37* | *5.72* | 6.25 | 6.11 | *6.00* | *6.52* |
| N trips walking & cycling | *1.72* | *2.07* | 1.73 | 1.9 | *1.8* | *1.96* |
| N trips by PT | 0.89 | 0.93 | *0.72* | *0.99* | *0.69* | *0.99* |
| **Individual level** | | | | | | |
| Daily travel distance (km) | *31.73* | *23.32* | 28.42 | 28.82 | 28.95 | 28.03 |
| Daily travel time (min) | *77.31* | *64.61* | *70.94* | *74.38* | 72.5 | 73.28 |
| N trips | 4.22 | *3.87* | 4.07 | 4.11 | 4.10 | 4.08 |
| N motorised trips | 2.93 | *2.48* | 2.87 | 2.72 | 2.74 | 2.83 |
| N trips walking & cycling | *0.79* | *0.89* | 0.79 | 0.84 | 0.82 | 0.85 |
| N trips by PT | 0.40 | 0.41 | *0.33* | *0.44* | 0.41 | 0.38 |
| **Trip level** | | | | | | |
| Distance (km) | *8.13* | *6.16* | 7.60 | 7.37 | 7.45 | 7.39 |
| Trip duration (min) | *18.81* | *16.78* | 18.19 | 18.06 | 18.15 | 17.94 |
| % motorised trips | *72.50* | *66.69* | *73.35* | *69.11* | 72.21 | 71.35 |
| % trips walking & cycling | *16.32* | *22.68* | 17.03 | 18.94 | 18.28 | 18.47 |
| % trips by PT | 11.18 | 10.63 | 9.62 | *11.91* | 9.51 | 10.18 |

Note: Italic values indicate statistical significance at 0.05 level.

When we compare individual travel and mode shares between the public transport access clusters (last two columns of the table), the findings are inconclusive. However, there is significantly more walking and cycling and less motorised travel in zones of higher local access. In zones with better pedestrian facilities and closer to local recreation, shopping services, and schools, the daily travel distance and trip distances are significantly lower. Another interesting finding is that public transport use appears higher in clusters of better access by bicycle.

Considering the benefits of walking and cycling for public health, we have investigated the relationship between pedestrian behaviour and the TOD access elements and how they foster this behaviour. Again, a MANOVA test has shown significantly more cycling and walking in the walking and cycling high access areas ($p < 0.001$).

# SUMMARY OF FINDINGS

As highlighted by Handy & Clifton (2001: 76), *"developing a comprehensive neighborhood accessibility database, consisting of detailed data about a wide range of accessibility indicators requires a significant commitment of resources..."* as data is readily available for only a small subset of factors. In this respect, this research contributes to both body of knowledge and the local planning practice by compiling a detailed database of quantitative and qualitative factors, identifying the most relevant indicators in the given context (through commonality of metrics), and showing how to use these constructs to highlight the uneven distribution of facilities in order to guide improvements in neighbourhoods planning.

The second contribution is represented by the analysis of travel behaviour by TOD access (city-wide and within the precinct). The results confirm our expectations. TOD measures that reduce segregation of residential and other commercial, education, productive, and recreation activities and enhance access and quality of transport features, contribute to residents' reduced car-based travel. Better cycling and walking access are associated with higher proportion of walking and cycling trips and improvements of the city-level public transport access are converted in higher public transport ridership. At the same time, greater access at the city level means increased spatial reach of the residents' travel, as shown in their activities' destinations.

At the local level (station precinct), we found accessibility mismatches between infrastructure and proximity to facilities, whereby neighbourhoods with a high standard of infrastructure for walking and cycling do not have corresponding facilities that they may walk or cycle to and vice versa. This emphasises the need of recognising the dual nature of access, determined simultaneously by transport system and patterns of land use. Transport alone is not enough to ensure high accessibility.

Better access (measured both by transport services and distribution of urban features), therefore, is expected to reduce the need for car travel and encourage alternative transport modes. Nevertheless, urban design and planning for TOD alone will not be translated automatically in travel behaviour changes. Many households select residential locations consistent with their travel and lifestyle preferences. It is argued therefore, that researcher's should consider the self-selection process when quantifying the contribution of access changes to travel changes. While self-selection may be evident, it is not an argument, however, against making changes to accessibility by more active travel modes. Whether residents move to locations selected for their transport choices or not, where more sustainable travel behaviour results there is a positive outcome.

While, theoretically, TOD holds a promise for more sustainable travel, its implementation in real places may be challenging for multiple reasons. In places where TOD is retrofitted within an existing city structure it is not always possible to control the distribution and density of activities. Furthermore, land use change may be asynchronous with transport accessibility across the full range of accessibility measures, and vice versa.

## Limitations and Future Research

Utility-based measures at the household level would enable a more complex and deeper understanding of the human needs for activities and the importance of TOD, providing a bundle of transport and mixed land use in the vicinity of the railway stations.

Similarly, longitudinal analysis would assist in examining changes in behaviour related to changes in accessibility at a disaggregated level and complex structural equation models, accounting for the individual preferences for transport and urban facilities before considering travel behaviour, would eliminate the overestimation of the built environment impacts. In addition, accessibility can represent a measure of performance only if it is consistent with residents' needs and wants.

Nevertheless, our results support the view that TOD policies, designed to provide viable alternatives to car travel and multiple facilities closer to residents, will actually lead to less reliance on driving and more use of public transport, cycling and walking.

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# REFERENCES

Aguiléra, A., Wenglenski, S., & Proulhac, L. (2009). Employment suburbanisation, reverse commuting and travel behaviour by residents of the central city in the Paris metropolitan area. *Transportation Research A*, *43*, 685–691.

Appleyard, D. & Lintel, M. (1972). The Environmental Quality of City Streets. *Journal of the American Planning Institute*, *38*(2), 84-101.

Barton, H., Grant, M. & Guise, R. (2003). *Shaping Neighbourhoods: a guide for health, sustainability and vitality*. Spon Press, London.

Cao, X.(J)., Mokhtarian, P.L., & Handy, S.L. (2009). The relationship between the built environment and nonwork travel: A case study of Northern California. *Transportation Research A*, *43*, 548–559.

Carr, D. (1979). Metropolitan Design. In *Western Landscapes* (J. Gentilli, ed.), University of Western Australia Press, Perth.

Cervero, R. & Kockelman, K. (1997). Travel Demand and the 3Ds: Density, Diversity, and Design. *Transportation Research D*, *2*(3), 199-219.

Cervero, R. (2001). Efficient Urbanisation: Economic Performance and the Shape of the Metropolis. *Urban Studies*, *38*(10), 1651–1671.

Cervero, R. & Day, J. (2008). Suburbanization and transit-oriented development in China. *Transport Policy*, *15*, 315–323.

Chen, C. & McKnight, C.E. (2007). Does the built environment make a difference? Additional evidence from the daily activity and travel behavior of homemakers living in New York City and suburbs. *Journal of Transport Geography*, *15*, 380–395.

Circella, G., Mokhtarian, P. & Handy, S. (2008). Land use, attitudes, and travel behaviour relationships: A cross-sectional structural equations model for Northern California. In the *Proceedings of The 88$^{th}$ Annual Transportation Research Board Meeting*, Washington DC, January, 13-17.

Curtis, C. & Olaru, D. (2010). The Relevance of Traditional Town Planning Concepts for Travel Minimization. *Planning Practice and Research*, *25*(1), 49-75.

Curtis, C. & Scheurer, J. (2010). Planning for Sustainable Accessibility: Developing tools to aid discussion and decision-making. *Progress in Planning*, *74*, 53-106.

Ewing, R. & Cervero, R. (2001). Travel and the built environment–synthesis. *Transportation Research Record*, 1780, 87–114.

Ewing, R., Pendall, R. & Chen, D. (2002). Measuring Sprawl and Its Impact. Vol.1, Available at http://www.smartgrowthamerica.org/documents/MeasuringSprawlTechnical.pdf.

Frank, L. & Pivo, G. (1995). Impacts of mixed use and density on utilization of three modes of travel: Single-occupant vehicle, transit, and walking. *Transportation Research Record*, 1466**,** 44–52.

Gehl, J. (1987). *Life Between Buildings - Using Public Space*. Van Nostrand Reinhold Company, NY.

Handy, S. & Clifton, K. (2001). Evaluating Neighborhood Accessibility: Possibilities and Practicalities. *Journal of Transportation and Statistics*, September/December, 67-78.

Handy, S., Cao, X. & Mokhtarian, P. (2005). Correlation or causality between the built environment and travel behaviour? Evidence from Northern California. *Transportation Research D*, *10*, 427-444.

Jacobs, A.B. (2001). *Great Streets*. MIT Press, Cambridge, Massachusetts.

Khattak, A.J. & Rodriguez, D. (2005). Travel behaviour in neo-traditional neighborhood developments: A case study in USA. *Transportation Research A*, *39*(6), 481-500.

Lund, H. (2006). Reasons for living in a transit-oriented development, and associated transit use. *Journal of the American Planning Association*, *72*(3), 357–366.

Madanipour, A. (2001). How relevant is 'planning by neighbourhoods' today?. *Town Planning Review*, *72*(2), 171-191.

Meurs, H. & Haaijer, R. (2001). Spatial structure and mobility. *Transportation Research D*, *6*(6), 429–446.

Murray, A.T. & Wu, X. (2003). Accessibility tradeoffs in public transit planning. *Journal of Geographical Systems*, *5*, 93-107.

Newman, P. & Kenworthy, J. (1999), *Sustainability and Cities: Overcoming Automobile Dependence*. Island Press, Washington DC.

Sanchez, T.W. & Dawkins, C.J. (2001). Distinguishing City and Suburban Movers: Evidence from the American Housing Survey. *Housing Policy Debate*, *12*(3), 607-631.

Scheurer, J. & Curtis, C. (2008). *Spatial Network Analysis of Multimodal Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure - A Case Study of Perth before and after the Perth-to-Mandurah Railway*, Available at http://abp.unimelb.edu.au/files/miabp/5GAMUT2008_JUN_02.pdf.

Schwanen, T. & Mokhtarian, P.L. (2005). What if you live in the wrong neighborhood? The impact of residential neighborhood type dissonance on distance travelled. *Transportation Research D*, *10*(2), 127–151.

Tibbalds, F. (2001). *Making People Friendly Places: Improving the public environment in towns and cities*. Spon Press, London.

Travisi, C.M., Camagni, R. & Nijkamp, P. (2010). Impacts of urban sprawl and commuting: a modelling study for Italy. *Journal of Transport Geography*, *18*(3), 382-392.

Urban Task Force (1999). *Towards an Urban Renaissance*, E & FN Spon, London.

Van Acker, V. & Witlox, F. (2010). Car ownership as a mediating variable in car travel behaviour research using a structural equation modelling approach to identify its dual relationship. *Journal of Transport Geography*, *18*, 65–74.