THE IMPACTS OF A NEW RAILWAY: TRAVEL BEHAVIOUR OF RESIDENTS IN NEW STATION PRECINCTS

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ABSTRACT

This paper reports associations between transit oriented development (TOD) characteristics and behaviour of households following the construction of a new suburban railway through southern Perth, Western Australia. Three precincts have been selected for comparison representing the different development opportunities ranging from potentially congenial configurations of railway station precincts, containing a variety of shops, services, and other attractions to station precincts acting primarily as origin stations or transit interchanges.

Drawing on a quasi longitudinal study, examining behaviours before and after the railway opened, we measure the degree to which TOD has resulted in residents reducing their motorised travel and substituting car travel with public transport within the region and walking or cycling within the local neighbourhood. We report on overall travel behaviour change and also drill down to the detail of individuals and households to examine the associations between household characteristics and their location and travel behaviour.

1 INTRODUCTION

The growing popularity of smart growth policies has led to an explosion of empirical studies investigating the impacts of the built environment/land use (BE) on activity-travel behaviour (ATB). Although a strong stream of research is stressing the importance of spatial structure in adequately describing residential location choice, accessibility, and travel behaviour or the effectiveness of the land-use policies on travel and location changes (Salomon et al., 1998; Bhat & Poszgay, 2002; Cervero, 2005; Khattak & Rodriguez, 2005; Næss, 2005; Handy et al., 2005; Zhang, 2005), definite evidence on whether association or causal link between BE and ATB remains elusive. Substantive work is questioning the level of significance that spatial context plays in travel behaviour and supporting individual characteristics as the main factor in explaining observed behaviour (Meurs et al., 2001; Handy and Clifton, 2001; Timmermans, 2002; Weber et al., 2003; Kim, 2007; Chen & McKnight, 2007; Circella et al., 2008; Cao et al., 2009). And increasingly, in the last decade, the research is supporting separate effects of built environment and self-selection (e.g., Cao et al., 2006; van de Coevering & Schwanen, 2006; Chen & McKnight, 2007) but it remains the researchers' task to correctly capture these elements through design of data collection and modelling approaches (Cao & Mokhtarian, 2008).

Transit oriented development (TOD), the “New Urbanist” or “Compact City” principles, or the “Smarter communities” have been designed 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 (Salomon et al., 1998; Cervero, 2005; Khattak & Rodriguez, 2005; Chen & McKnight, 2007). Where activity opportunity intensities are high and the land use mix appropriate, fewer separate locations are needed to fulfil the daily activity needs. This may come with the additional bonus of improved accessibility to public transport or other non-motorised alternatives of transport, with benefits on the quality of environment and health. Positive results of TOD on more sustainable transport use have been found in USA (Cervero, 2005), Europe (Lund, 2006; Aguilera et al., 2009), and more recently in China (Cervero & Day, 2009). This is clearly in contrast with the demonstrated negative impacts of sprawl (see for example Newman & Kenworthy, 1999; Ewing et al., 2002; or recently Travisi et al, 2009), which were conducive to increased travel and environmental costs.

A variety of methodological approaches have been applied: instrumental variables (Khattak & Rodriguez, 2005; Bhat & Guo, 2007), sample selection modelling (Curtis & Headicar, 1996; Næss, 2005; Zhou & Kockelman, 2008), structural equations modelling (Circella et al., 2008), all attempting to reveal the individual “contributions” of urban form and household attitudes towards travel and environment (the eager reader is recommended Cao & Mokhtarian, 2008, for a detailed review of the models). Recognising the vulnerability of cross-sectional studies on showing how the presence of mixed land uses, improved street connectivity, and higher densities support non-motorised modes of travel and shorter trips, due to the self-selection process, more studies have used panel or quasi-longitudinal data (Meurs & Haaijer, 2001; Krizek, 2003; Boarnet et al., 2005; Frank et al., 2007; Aguilera et al., 2009). Making sense of the findings is further compounded by differences between studies in spatial unit; ways of measuring urban form attributes (items, scale etc); controls for effect of socio-demographics.

This paper uses ‘before and after’ measurements of travel behaviour to compare to socio-economic characteristics and TOD features to capture changes in residential and activity-travel decisions as result of the opening of a new railway corridor (and its associated TOD attributes) in Perth, Western Australia.

The paper is structured as follows. A review of the relevant literature on the TOD links with travel behaviour is provided. Section 2 presents the geographical setting, Section 3 describes the data collection, and the hypotheses and methods used in this paper and Section 4 the empirical results. The paper concludes with a discussion of the findings, implications and recommendations for future research.

2 TOD CHARACTERISTICS

To break the vicious circle of urban sprawl and car dependence (Ewing et al., 2002), TOD has been promoted and implemented as one strategy for integrating LU and transport, promoting smart growth, injecting vitality and expanding lifestyle choice, whilst fighting against urban sprawl (Newman & Kenworthy, 1999; Renne & Wells, 2004; Cervero et al, 2004; Dittmar & Ohland, 2004). Varying definitions of TOD exist (for example *TCRP Report 102,* 2004). TOD is assimilated with moderate to higher density development, located within an easy walk [approximately 1/2 mile or 800 m] of a major public transport stop [with extended hours of highly reliable service at 5-15 min headway], generally with a mix of residential, employment, and shopping opportunities, in an environment designed for pedestrians and cyclists, without excluding the automobile (*TRCP, 2006*). TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use. In terms of residential and commercial density, various guidelines have been proposed: Calthorpe (2003) recommended that TODs devote at least 20% of the land area to housing, with an average residential density of min 10-15 dwelling units/acre, depending on the location of TOD. Calthorpe also suggested minimum floor area ratios (FARs) of 0.3 for retail with surface parking and 0.35 for offices without structured parking. These values, however, are rarely achieved in the emergent TODs in Australia. In a related study, Australians Newman and Kenworthy (2005), suggest that a minimum of 35 people and jobs/ha is required to support a decent public transport system; this kind of density is associated with a minimum range of urban services and amenity. A local centre (for an area of a 1 km radius) can be created with about 10,000 people and jobs, or a town centre (3 km radius) can be created with about 50,000 population and jobs.

With respect to the size of a station precinct there is a wide variety of walking distances from the transit station used as guidelines: in the US they generally vary between 400 and 800 m, although Cervero (2001) found up to 1 km walking distance in the Bay Area Rapid Transit (BART) system in California. This is certainly low compared to the distances advocated by the World Health Organization (WHO) as acceptable and realistic for an able bodied adult (5 km) – WHO (2004).

TOD can easily be confused with "transit-adjacent development" (TAD), which occurs in close proximity to transit, but is not oriented to transit, as reflected in the travel behaviour of population around it. Numerous planning authorities consider that park-and-ride (P&R) is more associated with TAD than conducive to sustainable travel behaviour attributed to TOD practices. In Australia's conditions and particularly Perth, we argue there is a need to consider how to evolve from a city designed around car reliance towards one designed for sustainable transport (further discussed in Curtis, 2008), in this case there may occasionally be a case for provision of P&R capacity at railway stations in order to attract households to train travel under the extremely low-density conditions where public transport services are also poorly integrated. Considering that 90% of the catchment area in Perth's railway precincts is outside the 1 km radius and average distance between residences and station for P&R riders above 5 km (similar distances were found by Kim et al., 2007 in St. Louis), P&R may be considered a feature of the Australian urban landscape. However, an appropriate approach would be to combine car parking with commercial/office development, designing parking areas in such a way to maximize pedestrian comfort and amenity in the TOD station area.

In order to correctly identify a TOD, Renne & Wells (2005) collated indicators proposed by 30 professionals based in the US; the list includes transit ridership, population/housing density, employment density, qualitative rating of streetscape (pedestrian orientation, human scale), mixed-use structures, pedestrian activity counts, # intersections or street crossings for pedestrian safety, estimated increase in property value, # public transport services connecting to station, # parking spaces, # convenience/service retail establishments (TRCP, 2007, Table 17-43, 17-98). This vector of measurements should provide unequivocal evidence on the differences between TOD and TAD.

TOD access can and should be evaluated at different spatial scales (Chang & Yu, 2004). This is primarily supported by the contrasting findings of the effects of TOD with mixed land use on travel behaviour and the quality of cycling and pedestrian facilities at local level, or the clustering of neighbourhood services and the amenity on activities and travel. At a more coarse spatial level, the access can be measured by transport service quality to reach opportunities outside of the neighbourhood. Nevertheless, urban design and integrated land use and transport planning alone will not necessarily bring about changes in travel behaviour that, in turn, lead to less traffic congestion and other social, environmental, and economic benefits.

2.1 Behavioural Changes in Context

The characteristics of neighbourhoods can be defined both by their physical (urban form attributes) and the socio-demographic characteristics of the residents. Both can influence travel and the "habitual" car reliance is expected to be broken if disincentives for car travel and incentives for more sustainable modes and for more activities are combined in clever ways.

However, the changes are not uniform for individuals and households and location and travel decisions are moderated by personal factors, preferences and attitudes. A dearth of literature considers self-selection/residential sorting a significant issue in assessing the impact of TOD attributes on travel choices (e.g., Cao et al., 2006; Bhat & Guo, 2007; Circella et al., 2008). This does not mean that urban planning practices preserve unaltered travel patterns. After controlling for individual attributes and attitudes (and relaxing the assumption of independence of travel using different modes), Curtis & Headicar (1996), Chen & McKnight (2007) and Cao et al. (2009) found relations between built environment and travel for work and non-work travel.

Considering urban structure, intrazonal trips are more likely to be shorter in distance and the associated activities more quickly completed, Greenwald (2006) focused on intrazonal trips to discuss the influence of urban form changes on these trips as the most likely candidates for mode and destination switch. Variety and scale of economic activity played significant roles in choosing intrazonal destinations, with a small influence of street design and housing concentration (albeit statistically significant). Greenwald (2006) has also suggested the existence of threshold effects for size of economic activity (5-10 employees/business) in the ability to alter travel behaviour. Aguilera et al. (2009) showed relations between changes in housing and job locations and travel patterns in Paris using two data sets at 17 years apart. As a result of the job loss in the municipality of Paris and increase in employment in the suburbs, the phenomena of reverse commuting and suburb-to-suburb commuting have become present in the last decade.

Another body of research has been developed with respect to the links between built environment, socio-economic characteristics and the physical activity and public health (Giles-Corti et al., 2005; Handy et al., 2005; Ewing et al., 2006; Papas et al., 2007). Neighbourhood changes associated with TOD (increased walkability and cycling facilities, improved local access and amenity) show increased walking and reduced driving and combined with the socio-economic structure of the neighbourhood may reinforce physical activities as a community norm (Handy et al., 2005; Frank et al., 2007).

2.2 Measures of Success and Modelling Challenges

Traditionally, TOD is measured by increased transit ridership, walking and cycling and reduced driving (Cervero, 2005; Chen & McKnight, 2007; Curtis, Renne & Bertolini, 2009). This is a combination of the more appealing transport services that can lead to mode shift (as shown by Metrolink in Great Manchester – Senior, 2009) and providing opportunities for non-work travel to be realised closer to home (Simma & Axhausen, 2003). Greater modal accessibility is likely to contribute to a higher usage of that mode (Ramajani et al., 2003, cited in van Acker & Witlox, 2010:66). In addition, increases in property values are associated with TOD (Cervero et al., 2005). Chen & McKnight (2007) have suggested trip chaining as a success measure of the access (individual's activity sequencing behaviour may be deterred or fostered by transport network and service patterns and relationship to urban land uses). They also noted that a 'smart' urban form could even increase the mobility (number of trips and distance) of its population, as a lot more activities could be realised within given time constraints.

The myriad of associations/impacts and the inter-relations between individual characteristics (socio-demographics), attitudes (preferences, concerns, and perceptions) and travel (Kim et al., 2007) need to be carefully addressed in order to enhance our understanding of the relationship between land use and travel behaviour. This is particularly challenging, considering the different time and space scales to be accounted for. As Bhat & Guo (2007) have highlighted, two major inter-related problems: (1) complexity and multi-dimensionality of the relationships, and (2) controlling for the spurious association due to residential sorting, based on demographics and other characteristics, need to be incorporated in the modelling in order to obtain insights about the ‘‘true’’ causal impact of the built environment on travel behaviour. There are three ways to capture changing behaviour (Cao & Mokhtarian, 2008): asking households how they would change the behaviour in the future (interactive interviews, SP-Stated response); observing changes long enough (panel, repeated, mobility biographies, official statistics); retrospectively to get data about time spans in the past (but these suffer from respondent error – selectivity phenomena, transfiguration of the past, post-rationalisation, simply forgetting).

In this research we used repeated measurements to see the physical and socio-economic neighbourhood features and households' travel before and after the opening of three TOD precincts along the railway corridor.

3 EMPIRICAL SETTING

The overall objective of our research was to assess the behavioural responses to emerging TOD precincts. We use a quasi-longitudinal approach with three waves of survey spanning four years, examining three railway precincts along the southern railway corridor Perth-Mandurah, Western Australia. Households within station precincts have been surveyed at pre-rail station opening (November-December 2006), after the opening of the railway corridor (July-September 2008) and resurveyed again in July-September 2009. The decreasing response rate, from wave to wave has led to replenishments, particularly with incoming households, as necessary. However, this approach to compensate for attrition has not achieved/maintained a similar sample size over the three waves.

3.1 Station Precincts

The new strategic railway corridor through metropolitan Perth's southern suburbs to Mandurah has added a further 72 km to the electrified passenger rail network. This rail line traverses partly through existing suburban development (disruption has been minimised by routing the railway along the centre of an existing freeway reserve) and partly through ‘greenfields’. In existing areas, the redevelopment approach has been to re-orient the land use activity towards the station in some cases. Greenfield areas have provided new opportunities and in order to further increase accessibility and economic opportunity, the government and the private sector have planned for new TOD communities at some railway precincts. This mixture of designs created a variety of emerging TOD precincts in Perth. At one end of the spectrum is the precinct which acts primarily as an origin station or transit interchange (rather than a destination station); 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 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. Other stations fit within this continuum as recipes with various TOD ingredients. The three precincts we selected (Bull Creek, Cockburn Central, and Wellard) vary systematically not only on the TOD dimension, but also on their citywide access and socio-economic profile. Figure A1 – Appendix presents the limits of the three precincts and their split into four access and travel zones (discussed later).

As detailed by Curtis and Olaru (2007), the primary focus at Bull Creek is the transit interchange. The station lies at the intersection of a primary distributor road and the main freeway. The freeway reserve effectively constrains the opportunity for development of a pedestrian scale precinct within close proximity of the station. The station caters for a high volume of car access (610 car parking bays) and a feeder bus system along the distributor road serving the surrounding suburbs. Presently, there are no plans to promote mixed-use development.

At Wellard Station the design objective is to mirror both TOD and the "New Urbanist" principles. The promise was to develop, by railway opening, a mixed use 'Main Street' (including 4,070 m^2 of retail space) centred on the station surrounded by higher density residential development. The street network is designed to give a good pedestrian environment, residential development is rapidly occurring, but the main street is yet to be achieved and 18 months after the railway opening this area remains a building site.

The Cockburn Central precinct features aspects of both Wellard and Bull Creek. It provides for high car access (414 park and ride car bays and 928 car parks for the exclusive use of commercial premises) but the precinct is dissected by a 100-metre freeway reserve, which reduces amenity for non-motorised modes. Like Wellard, development of a mixed-use town centre is being developed next to the station. This multi-functional Town Centre will provide a range of recreational, commercial, entertainment and cultural facilities, including a residential component. An existing big-box suburban shopping centre is located on the opposite side of the railway station and new Town Centre; pedestrian access requires traversing a major urban arterial road.

These three precincts have different levels of accessibility at both city-wide level and local level and different urban and socio-demographic fabric. Table 1 presents the main characteristics of the precincts compared to the whole metropolitan area. Bull Creek is the closest to the city, the most expensive (land and housing), and has the highest proportion of more highly educated residents and the highest household income (although many households include retired or home duties members). Cockburn have the largest proportion of young families and the highest employment. Wellard is the furthest precinct from the city, has the lowest employment, household income and car ownership, and the lowest real estate values. It also exhibited the lowest public transport and walk/cycle proportion of trips in the 2006 Census.

Table 1: Profile of precincts compared to metropolitan Perth

Variable	**Bull Creek**	**Cockburn Central**	**Wellard**	**Metropolitan Perth**
Population density pers/km^2	***1925***	538	625	271
Dwellings/km^2	***674***	175	112	97
Persons per dwelling	***2.85***	3.07	2.90	2.78
Education >= year 12	47.6%	33.1%	***20.6%***	36.8%
Born in Australia	59,5%	***68.4%***	65.8%	64.1%
Employed	50.4%	***56.1%***	***38.6%***	48.2%
Household Car Ownership	1.67	1.69	***1.36***	1.51
Journey to Work				
- Car only	69.8%	73.2%	***74.0%***	69.3%
- Public transport & walk/cycle	16.1%	10.7%	***9.9%***	12.4%
Distance from CBD (km)	12	21	39	N/A
Median Weekly Household Income	$1,275	$1,244	$945	$1,042
Median housing price 2006 (AUD)	$553k	$394k	$272k	$380k
Median housing price 2008 (AUD)	$662k	$470k	$301k	$455k

Source: Australian Bureau of Statistics (2006) and REIWA (http://reiwa.com/res/res-suburb-profile.cfm)

4 DATA AND METHODS

The benefits of panels in detecting changes has been previously articulated in the field of travel behaviour (Kitamura et al., 2003:191; Stopher et al., 2009). Having in mind the research objectives of the study, and within the budget constraints we considered discrete-point observations for measuring changes. Four surveys have been conducted on the three TODs lined along the southern railway corridor: Wave 1 ("Before opening") in November-December 2006, Benchmarking survey during July-August 2007, Wave 2 survey ("After opening") during July-September 2008, and Wave 3 during July-September 2009. The 'benchmarking' survey was introduced to account for the seasonal differences in travel behaviour produced by the delayed opening of the railway (23rd of December 2007) and focused on the trip diaries.

Our three precincts were split into four travel zones: households within 5, 10, 15 min walk to the railway station and (the fourth zone) households within 5 min drive to the station. Our precincts were defined by 5 min drive from the station, considering the catchment area for rail stations in Perth. Random sampling was applied for selecting the households using a utility provider users' list. The sample size was calculated to ensure 95% CI for several socio-demographic statistics and parameter estimates and a minimum quota of 50 households had been set for each of the four travel zones within each precinct.

To achieve the best possible measure of changes through time, households previously sampled were contacted for interview again; replenishments were drawn again by simple random sampling, but the sample sizes continued to decrease. The interviews were conducted between 3:30pm and 6:30pm on weekdays and 9-5pm on weekend days by a team of students trained for this activity. After an introductory letter posted to households and informing that a field assistant will visit the household on a certain week, each sampled household was visited up to three times (if not found at home during different days and various times). Households not contacted during these three repeated visits or who refused to participate were recorded as non-response and information sought to identify potential sources of non-response bias.

4.1 Surveys Collected and Response Rates

The data collection process changed between waves according to the type of data. Figure A2 – Appendix presents the variables considered in the modelling and consequently included in the survey questionnaires.

Both revealed and stated preference data for household and individual characteristics, car ownership, travel behaviour, location, physical activity and mobility restrictions were considered in the surveys, as follows (Table 2):

Table 2: Contents of the surveys

Type of information / Wave	"Wave 1"	"Bench-marking"	"Wave 2"	"Wave 3"
Information on household: - size, type of dwelling and tenancy, when moved to the residence and plans to move from the area, number of cars, bicycles, scooters, motorcycles, parking bays (income and contact details at the end of the interview)	✓	✓	✓	✓
Information about vehicles: (not used in this study) - type, make, age, fuel, costs amount and who bears them	✓	✓	✓	✓
Information on household members: - relation to the interviewee, 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 household member on the specified Wednesday (origin, destination, departure and arrival time, purpose/activity, mode of travel, route, party size, out-of-pocket cost, parking, transfers)				
Information on previous location: (not used in this study) - address, size, type of dwelling and tenancy, number of cars, bicycles, scooters, motorcycles, parking bays, previous work/education location	✓*		✓*	✓*
- push (26) reasons for moving from the previous residence (not used in this study)	✓*		✓*	✓*
- pull reasons (14) for moving in their current neighbourhood	✓*		✓*	✓*
- stated importance of having access to various facilities when selecting the current location and residence (15 elements): availability of facilities within walking, cycling, and 5-min driving distance	✓*		✓*	✓*
Stated choice experiments: (not used in this study) - eight scenarios in a location stated choice experiment	✓			
- eight scenarios in a mode choice stated choice experiment			✓	

* Questions only for those households who moved in the precinct area in the previous five years.

Given the rich information in the surveys, to limit the respondent burden, some parts of the survey were collected at different times. During the interviews in wave 1, households were left with memory joggers and trip diaries to be completed by every household member travelling independently on a specified Wednesday. The field assistant visited the household again when collecting the trip diaries, checking the accuracy of the information. For the benchmarking and wave 2 surveys, the trip diaries were posted along with the memory joggers and introductory letter, with the intention of collecting and entering the travel data at the interview time. The waves 1 and 2 surveys were CAPI (computer-assisted personal interviews) because of the stated choice experiments included and their conditioning on the specific households and travel behaviour patterns. The benchmarking survey was also a computer-assisted survey, while the wave 3 survey was conducted with a mail-out and Internet survey (considering the costs and response rates in the previous occasions).

Table 3 presents the number of household surveys conducted during 2006-2009.

Table 3: Surveys and response rates (in brackets) by precinct

Precinct	**Nov–Dec 2006 "Wave 1" (personal interview)**	**Jul-Aug 2007 "Benchmarking" (personal interview)**	**Jul–Sep 2008 "Wave 2" (personal interview)**	**July-Sep 2009 "Wave 3" (mail-out & Internet)**
Bull Creek	317 (52%)	108 (36%)	188 (21%)	229 (11%)
Cockburn Central	369 (48%)	105 (35%)	229 (24%)	161 (8%)
Wellard	348 (49%)	97 (31%)	257 (29%)	136 (7%)
Total	1,034 (49%)	310 (34%)	674 (25%)	526 (9%)

Considering the benefits of the panel data for measuring changes, the research team made all efforts to maintain the motivation of the respondents to participate in the study, to stay in touch with them (Christmas cards, thanking for participation and snapshots of the results from previous waves were sent every year) and try to not overburden. Despite this more than half of the sample suffered from panel mortality (people do not want to report again) and fatigue (report with less accuracy). We are aware of the fact that the collection of panel data is very costly and presents difficulties over a longer period ("As respondent burden is usually higher than for cross-sections, it is necessary to have reliable participants" – Zumkeller et al., 2007:371). Low response rates have been reported in numerous studies in Australia and overseas (Stopher and Stecher, 2007; Bennett, 2008) and strategies to counterbalance the panel attrition are commonly included to maintain the sample (e.g., offering rewards to participants), However, we were not able to provide incentives for participation, a requirement of our Human Research

Ethics Committee approval. Because of the decreasing response rate in September 2008 we offered either two 24-hr SmartRider cards or 2 one-movie Video Ezy gift vouchers per family (at the end of the interview) to our households as a token of appreciation for their effort.

The mortality rate we experienced is not unprecedented; Zumkeller et al. (2007) demonstrated similar mortality rates from surveys conducted in Europe (German Mobility Panel, London Regional Panel, Littlemore Panel, South Yorkshire Panel, Longitudinal Verplaatsingsondezoek): 37-70% after one wave, 40-50% after 2 waves.

When addressing the non-response bias, we compared the non-respondents with respondents in terms of their socio-demographics. The two groups did not differ significantly in socio-demographics (checked with Census data 2006); unfortunately the heterogeneity between respondents and non-respondents in terms of their attitudes and travel behaviour remains unknown.

4.2 Trip diaries

This research is analysing the household and travel data from the trip diaries collected in waves 1 and 2 of the survey. As indicated in Table 2, travel data captured the location of all destinations visited, time of day, modes of travel, purpose of travel, distance and time between origin and destination, out-of-pocket costs, parking details or transfer for public transport, and the party size. 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 or receiving visitors, eating out, sightseeing, fitness/exercise, other), pick-up/drop-off or accompanying someone, plus returning home. The trip diaries recorded separately transfer between transport modes and waiting for transport services and included a page of examples on how to complete the trip diary.

Trip diaries were manually geo-coded and this created considerable challenges for the analyst when data was incomplete or missing. To obtain precise and exhaustive datasets of travel behaviour in space and time, the researchers worked several months after each wave to check the information. The data from wave 3 is still subject to checking and finalising geocoding.

4.3 Hypotheses

The focus of this paper is not to quantify specific TOD characteristics that may affect travel patterns vs. the personal attributes and attitudes using complex multivariate data techniques, but to test specific hypotheses that link built environment, socio-demographics, and travel patterns as a first step towards more comprehensive further modelling.

The analysis regards before and after changes in travel behaviour and differences across the various TODs as follows:

H1 – changes in accessibility and TOD as result of the opening of the railway corridor are associated with changes in car ownership and use (before – after t-tests);

H2 – precincts with higher degree of TODness and access are associated with lower car driving and higher public transport ridership (ANOVA and Kruskal-Wallis tests across precincts);

H3 – precincts with higher degree of TODness and access are associated with increased walking and cycling (ANOVA and Kruskal-Wallis tests across precincts);

H4a – households who value more TOD features chose to relocate in precincts according with their preferences (ANOVA and Kruskal-Wallis tests across precincts);

H4b – changes in accessibility and TOD as result of the opening of the railway corridor are associated with changes in stated importance of the TOD features (before – after t-tests);

H5 – households who value more TOD features are associated with increased non-motorised travel, increased physical activities and reduced car driving (correlations between features and travel and physical activity, using data from Wave 1);

H6a - households who reside in precincts with higher degree of TODness and access have lower activity spaces (ANOVA across precincts);

H6b - changes in accessibility and TOD as result of the opening of the railway corridor are associated with changes in activity spaces (before – after t-tests).

The paper makes the assumption that there are no significant information and communication technology changes occurred during the waves to impact the travel behaviour by reducing the need of physical mobility. This assumption needs to be rechecked once more data becomes available. Although control groups are recommended, the practice has shown that the changes in this group are consistently small, largely because of the short time between the waves (Brög et al, 2009). Given the cost considerations, this research has not included a control group and city-wide measurements were applied to obtain the baseline information.

5 EMPIRICAL RESULTS

To address the first three hypotheses, in Table 4 we present a selection of descriptive statistics regarding socio-demographics and travel behaviour in the three precincts.

Table 4: Descriptive statistics by precinct

Variable	**Bull Creek**	**Cockburn Central**	**Wellard**	**Bull Creek**	**Cockburn Central**	**Wellard**	**Parametric and non-parametric tests across precincts (p values W1/ W2)**
	"Wave 1"			**"Wave 2"**			
Access measures							
Composite local access**	18.9	16.2	17.4	19.1	17.5	17.9	
City-wide road distance accessibility**	24.1	30.2	39.9	23.2	28.8	38.5	
City-wide public transport centrality accessibility (time/freq/transfers)**	68	89	131	40	45	72	
Socio-demographics							
Family size	2.85	3.0	2.76	2.79	2.92	2.59	0.075/0.126
# bedrooms	3.63	3.73	2.75	3.68	3.70	3.13	0.258/0.334
Weekly working hrs/person	31.2	30.7	28.7	32.5	31.4	31.9	0.119/0.305
Car availability	1.95	1.94	1.83	1.86	1.98	1.69	0.180/0.249
Travel behaviour							
Daily travel time (min)	55.2	60.2	45.9	53.9	54.1	48.3	0.092/0.273
Daily travel distance (km)	33.5	44.36	45.94	34.2	41.85	42.30	*0.007/0.054*
# legs/day and person	3.79	3.74	3.57	4.86	4.5	4.84	0.022/0.108
Trips by mode:							
% private motorised	77.8	81.8	91.2	72.5	78.7	74.4	
% public transport	5.9	5.8	1.3	11.6	7.3	7.4	*<0.001/0.036*
% cycling	2.3	1.0	0.6	1.8	1.3	2.5	
% walking	13.1	10.0	6.9	13.2	12	12.1	

Trips under 5km:							
% private motorised	63.6	66.4	82.8	67.4	72.9	75.6	*<0.001/<0.001*
% walking and cycling	27.9	24.9	14.7	22.2	19.3	11.5	
Parking space	2.86	3.14	3.15	3.02	3.13	3.18	0.080/0.413
# bicycles adults/hh	1.26	0.92	0.72	1.21	0.98	1.13	0.241/0.130
# bicycles children/hh	0.47	0.70	0.64	0.59	0.76	0.87	0.072/0.096
Mobility restrictions (%)							
N	317	369	348	157	221	254	

** Details in Curtis and Olaru (2007) and Scheurer and Curtis (2008)

These confirm the different socio-demographic composition of the population in the three precincts as indicated in the Australian Census data (Table 1) and shows various travel patterns across precincts.

Bull Creek residents have the lower travel distance, they use car least, and have the highest proportion of walking and cycling trips (significance level < 0.05, see Table 4). The situation holds for both ‘before’ and ‘after’ surveys. Wellard residents travel the furthest; have the highest car ridership and lowest use of sustainable transport modes, but after railway opening they catch-up with the other two precincts in terms of total walking and cycling.

Although not statistically significant, Bull Creek residents appear to be busier people, with larger houses, higher number of cars and bicycles, compared to residents living in Cockburn Central, and especially Wellard.

When comparing the socio-demographics and travel behaviour measures between waves, we notice significant changes in car availability and use, with the most remarkable change in the number of legs /day and person (significant at 0.05 level, confirming the first hypothesis). Travelling in more complex chains is consistent with the increase in public transport ridership. We also note some reduction in daily travel distances and times (except Wellard).

In the ‘before opening’ survey, the higher uptake of public transport and walking and cycling in Bull Creek (compared to Cockburn Central and Wellard) was thought to be due to the quality of cycling and pedestrian facilities and to the richer public transport, but this has been challenged following the result ‘after opening’ by a highly significant change experienced by Wellard (Figure 1). The situation appears slightly different for trips under 5km (mostly local), where the “winner” is the public transport (possibly a product of trip chaining).

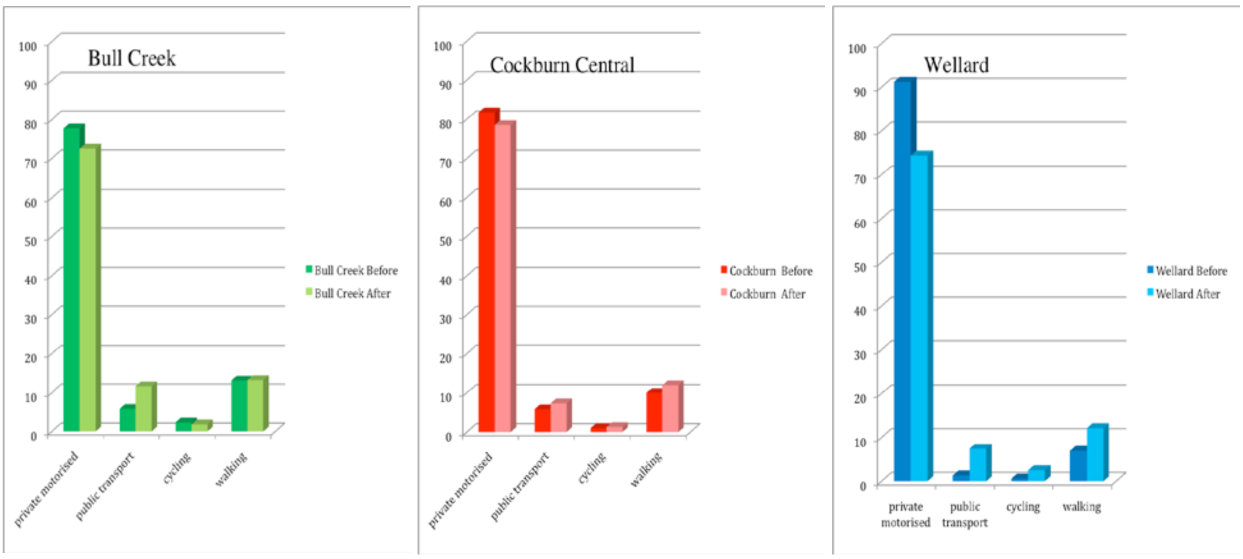

Figure 1: Changes in travel modes (before and after opening of the railway corridor)

Figures 5a-c – Appendix shows the main destinations for before and after the opening of the railway (the size of the circle is proportional with the frequency of visiting the activities). As indicated in the maps, many activities take place within the precinct areas, but the Perth CBD is increasing its attractiveness.

Given the mixed results, hypotheses 2 and 3 are supported only partially.

It has been well documented that travel and relocation decisions of households moving into the precincts are strongly related to each other, households trading-off housing and transport costs when making their location decisions (Scheiner, 2006). TOD is a bundle of attributes, which are valued differently by residents (enhanced accessibility, varied landscape with more consumer retail and community services, pedestrian and cycling amenities, etc.) depending on their needs, values, lifestyle choices.

When respondents were asked to specifically state the importance of 14 neighbourhood attributes, it appeared that households seek affordable and accessible locations in both 2006 and 2008 waves. Results indicate that concerns about travel to work, proximity of transport and local facilities are of increasing importance in all three precincts, but to a lesser extent than affordability and safety. Wellard and Cockburn Central households are more interested in affordability and closeness to facilities, whereas Bull Creek households showed a keener interest in the quality of schools and environment, confirming the consistency between preference and choice of precinct based on the offering (H4a). We noticed that stated importance for social elements (social contact, familiarity, closeness to family), size of the property, real estate value, and safety diminished in the second wave, while style of the dwelling, school quality, scenery, and proximity to facilities and transport have become more prominent (Figure A3). This may be explained by the changes in built environment that occurred between the two waves and the expectations of even greater modifications of the local landscape. H4b is supported for eight out of 14 elements at 0.05 level.

Considerable attention has been given to attitudinal factors, as they are likely to shape relocation and travel decisions (Handy et al., 2002; Turksever and Atalik, 2001; Circella et al., 2008; Wood et al., 2008; Mokhtarian & Cao, 2008). Recently, Choocharukul et al., 2008 found that preferences for life with frequent car use in the future are associated with lower likelihood to stay in an area with convenient public transport.

For those households who indicated a concern with proximity to facilities, further exploration of the importance of access by mode and time was made (Figure A4). Having shops and parks within a 5-minute walk was confirmed as being of high value. Wellard households showed a greater interest in facilities of all types being within 5 minutes walk, whereas Bull Creek households again indicated preference for schools within walking distance. Relevant are statistically significant increases for proximities within 5 min walking and driving after the railway opening.

Table 5 presents correlations between attitudinal questions[1] with respect to TOD facilities and walking time and percentage of car, public transport, and non-motorised trips made by households, using data from Wave 1. The presence of urban facilities within walking distance it is associated with increased physical activity (expressed as time spent walking) and with trips by public transport. Preference for schools in the neighbourhood and quality of surroundings is positively associated with walking, proportion of non-motorised trips, and negatively with car travel. Finally, the preference for good transport facilities is significantly correlated with proportion of trips using public transport, supporting H5.

[1] The attitudinal questions were factor analysed and here we tested the factor scores against the trip making and walking time.

Table 5: Correlations attitudes with physical activity (walking) and use of transport modes (correlation and significance level below)

	Urban facilities walking distance	**Proximity of schools**	**Neighbourhood and surroundings**	**Transport features**	Walking time (min)	Walking and cycling trips (%)	Car trips (%)	PT trips (%)
Urban facilities walking distance	1							
Proximity of schools	0.744	1						
	0							
Neighbourhood and surroundings	0.471	0.501	1					
	0	0						
Transport features	0.758	0.571	0.483	1				
	0	0	0					
Walking time (min)	0.193	0.162	0.172	0.031	1			
	0	*0.044*	*0.048*	0.607				
Walking and cycling trips (%)	0.185	0.217	0.264	0.119	0.121	1		
	0.064	*0.03*	*0.008*	0.236	0.228			
Car trips (%)	-0.126	-0.102	-0.205	-0.168	-0.172	-0.669	1	
	0.206	*0.04*	*0.039*	0.091	0.083	0		
PT trips (%)	0.224	0.125	0.122	0.333	0.086	0.258	-0.813	1
	0.031	0.233	0.244	*0.001*	0.412	0.013	0	

In order to jointly analyse the travel and opportunities for activities, we derived activity spaces measured as eccentricity from residence and 95% confidence ellipse. Trips for all purposes made by a household during the travel day were considered in the activity space. The details of calculating the activity spaces are found in Olaru & Curtis (2007). In this paper we compare the sizes of the activity spaces before and after the opening (Table 6).

Table 6: Activity spaces as standard distance and confidence ellipse

Measure	**Bull Creek**	**Cockburn Central**	**Wellard**	**Bull Creek**	**Cockburn Central**	**Wellard**	**Parametric and non-parametric test (p values W1/ W2)**
	"Wave 1" Nov-Dec 2006			**"Wave 2" Jul-Sep 2008**			
Standard distance	4.57 (3.32)	11.39 (12.19)	6.67 (7.42)	3.86 (6.04)	6.78 (6.47)	8.56 (7.75)	0.004/0.009
Confidence ellipse	149.42 (105.68)	256.06 (271.09)	178.84 (182.95)	136.95 (191.91)	186.85 (209.82)	211.63 (254.49)	0.092/0.074

The standard distance varies significantly across the three precincts (at α=0.01 level), but the confidence ellipses only at 0.1 level. The activity spaces are smaller for precincts with higher access, but lower TODness.

The activity spaces have decreased in the two precincts with higher access to the city (Bull Creek and Cockburn Central) but not in Wellard. The finding is consistent with the increased access toward the city (the train has made possible reaching the city in 27-30 min), many shopping and recreating trips being now 'attracted' by the city of Perth area. We have also noticed some changes in the shopping destination of Wellard residents from the nearby or southern retail areas (Kwinana Hub, Rockingham, Mandurah) to Gateways Cockburn Central, which has become the largest commercial area in the south of Perth. Hypotheses 6a and b are therefore not supported.

6 CONCLUSIONS AND IMPLICATIONS

Empirical evidence from the three precincts in the southern rail corridor Perth-Mandurah, Western Australia, analysed in this research provided partial support for four out of the six hypotheses:

Socio-demographic characteristics of the resident population present considerable variation across precincts and are associated with changes in travel behaviour (reduced number of cars, reduced bike ownership, reduced car use and increased public transport, walking and cycling), but this is a combination of TOD and socio-demographics (household structure affects trip making – e.g. number of children, restrictions). Neighbourhood/TOD features are associated with reduced travel, and especially non-car trip making.

H1 – changes in accessibility and TOD as result of the opening of the railway corridor are associated with changes in car ownership and use (supported – statistically significant at 0.05 level).

After railway opening, the two precincts with the highest degree of TODness, Cockburn and Wellard, have shown a reduced proportion of car travel and corresponding increases in public transport use. However, both precincts were only partially occupied at the time of post survey (and construction in some areas still taking places) and therefore we can anticipate further reductions (the residents indicated their willingness to take advantage of the TOD benefits). In Wellard, households own fewer cars compared to Bull Creek and Cockburn Central, and the number decreased even further after railway opening, suggesting that TOD may have the ability to alleviate the travel by providing good public transport. When walking and cycling were compared before and after the opening the findings were inconclusive - statistical significance between 0.098 and 0.12.

H2 – precincts with higher degree of TODness and access are associated with lower car driving and higher public transport ridership (partially supported - statistically significant at 0.05 level).

Bull Creek and Cockburn Central precincts, with higher access, display lower car travel and increased public transport use. However, after opening of the railway, Wellard households (which also own fewer cars) have decreased their proportion of car use in favour of public transport. The change in Wellard is greater than in the other two precincts, and this may be explained by the considerable 'urban make-up' that has continuously taken place in Wellard.

H3 - precincts with higher degree of TODness and access are associated with increased walking and cycling (not supported statistically).

The highest uptake of cycling and walking is noted for Wellard (for all trips), but not for trips under 5km. Again, this is expected, as the precinct is continuously changing and construction still under way.

H4a and b – households who value more TOD features chose to relocate in precincts according with their preferences (partially supported – statistically significant at 0.05 level) and their stated importance changes post-opening of railway corridor (partially supported at 0.05 level).

The households residing in precincts with higher access (Bull Creek and Cockburn Central) value more the proximity to urban facilities and transport and the amenities compared to Wellard. They have also reported higher preferences for having shops, schools, medical and recreation services within 5 min walk.

We conclude that both attitudinal predisposition for more sustainable travel and TOD features were found to impact the choice for public transport, walking, and reduced driving distances. Especially when located in environments conducive to walking and cycling, the TOD benefits are more visible.

H5 – households who value more TOD features are associated with increased non-motorised travel, increased physical activities and reduced car driving (correlations significant at 0.05 level).

In general it is expected that good TOD would result in reduction of travel by car and substitution with public transport and non-motorised transport. But not all individuals and households are inclined to reduce their travel or switch to public transport, cycling and walking: households with particular lifestyles are actually likely to convert the accessibility benefits into increased distances, albeit by public transport. It is rather that those interested in TOD benefits tend to relocate to places congruent with their attitudes of reduced car use and increased physical activities. The positive correlations between the attitudinal questions reflecting preference for several TOD features and amount of walking and proportion of household trips made by public transport, walking and cycling suggest possibility of self-selection along the corridor.

H6a and b - households who reside in precincts with higher degree of TODness and access have lower activity spaces (not supported). While in Bull Creek and Cockburn Central we notice a significant reduction in activity spaces, in Wellard the results are showing a different trend. In fact, as displayed on the map of destinations, Wellard has experienced increased access to the city and more households are now using the corridor to shop and recreate in the city.

Although too early to draw conclusions on the relationships between built environment/TOD design and activity-travel behaviour, there are indications that households value/prefer TOD characteristics, such as shopping and community services within their neighbourhood, parks and nice places to walk and cycle, and they may respond to the offer of services by taking up more of them. There are changes in households' behaviour and they are likely to be a combination of residential sorting and a result of the increased TODness and accessibility which encourage use of public transport and non-motorised modes, but this is yet to be unveiled.

More advanced analysis is currently underway to consider all elements into a model jointly accounting for built environment and personal characteristics and attitudes.

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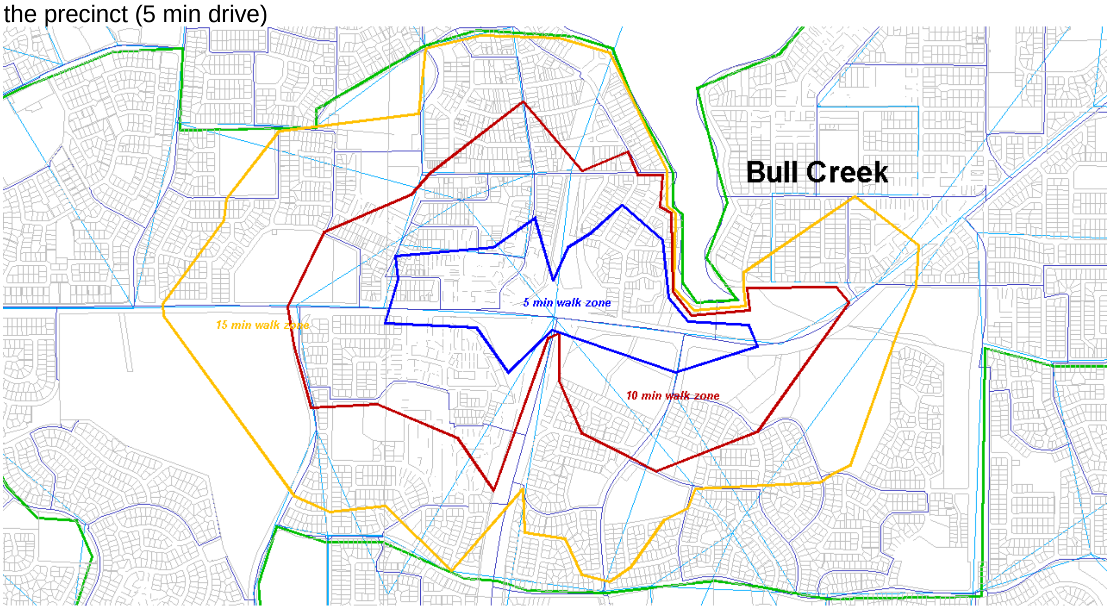
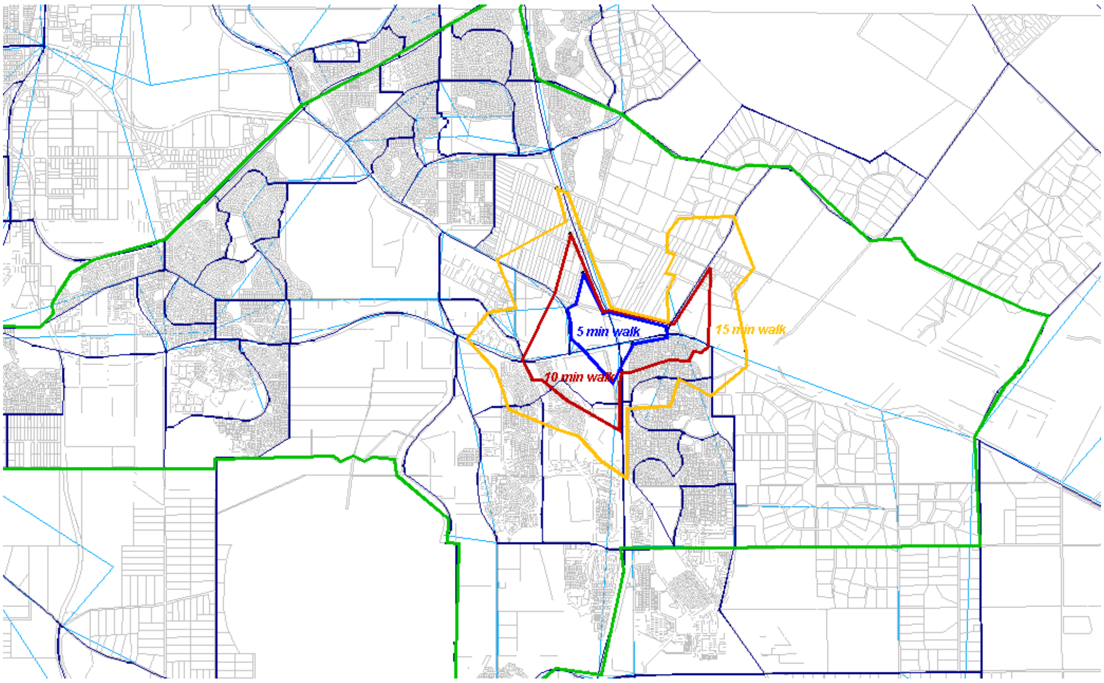
APPENDIX

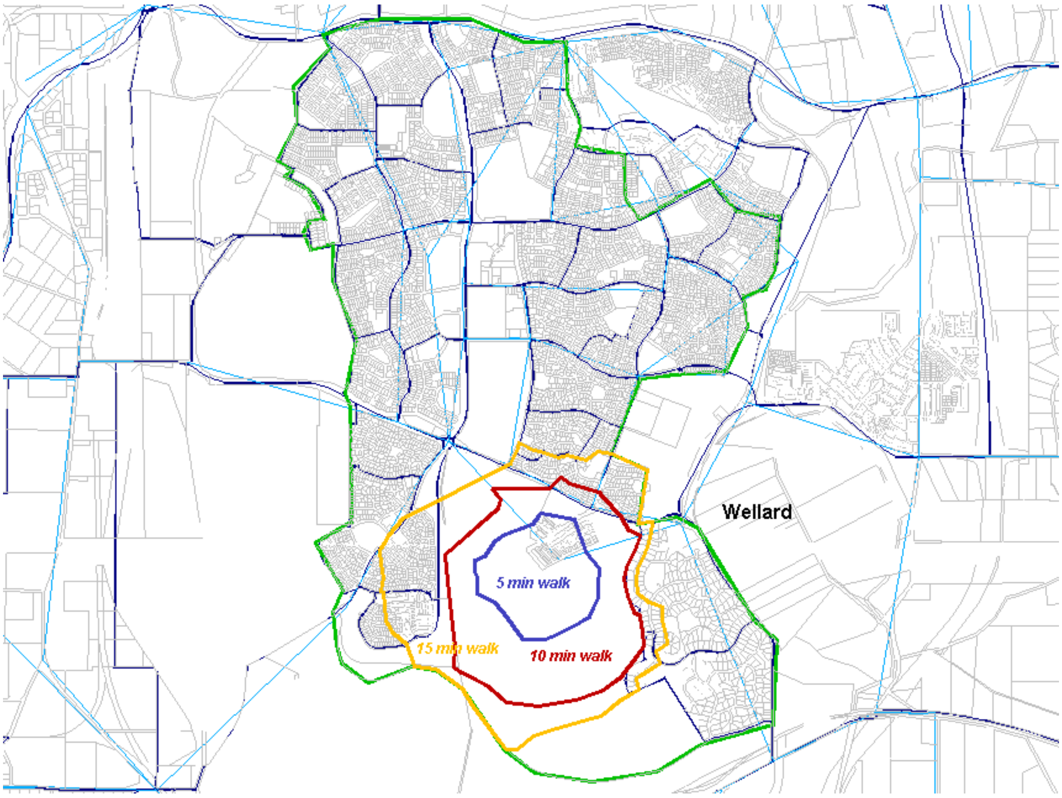
Figure A1: Bull Creek, Cockburn Central, and Wellard precincts
Note: Blue contour represents the 5 min walk area, red – 10 min walk, yellow 15 min walk, and green the border of the precinct (5 min drive)



a Bull Creek



b Cockburn Central



c Wellard

Figure A2: Data collection process

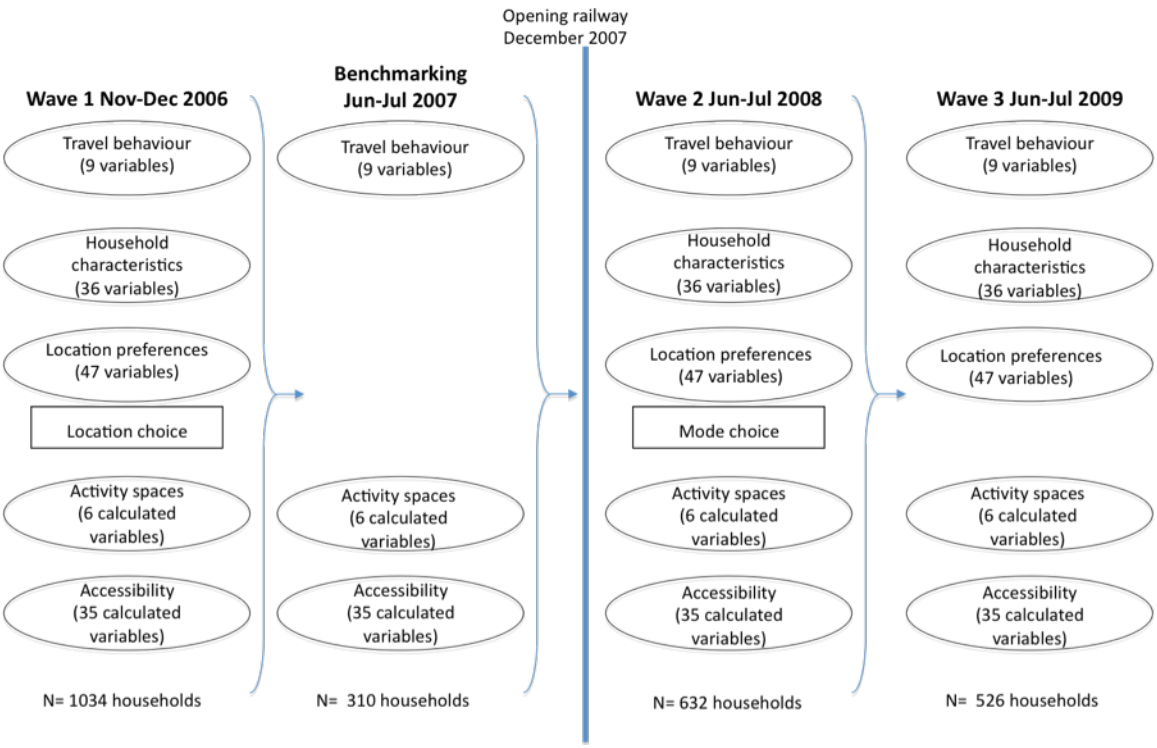


Figure A3: Pull reasons in Bull Creek, Cockburn Central, and Wellard precincts

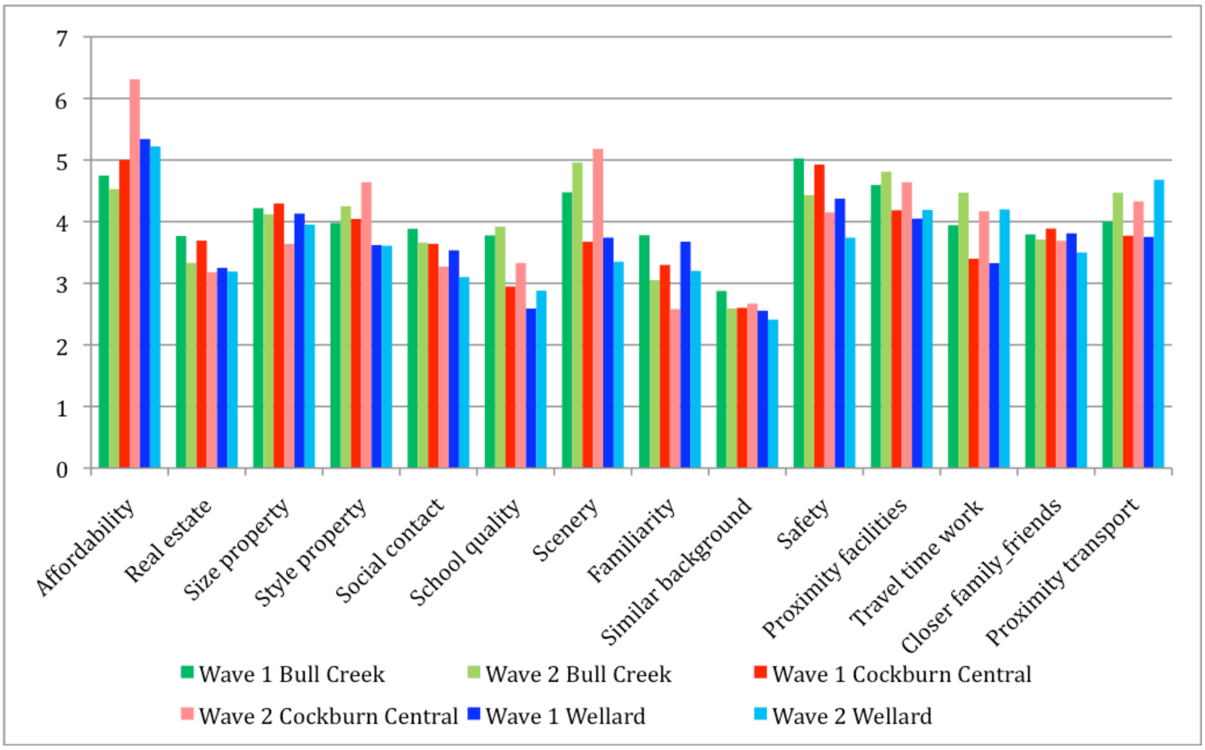
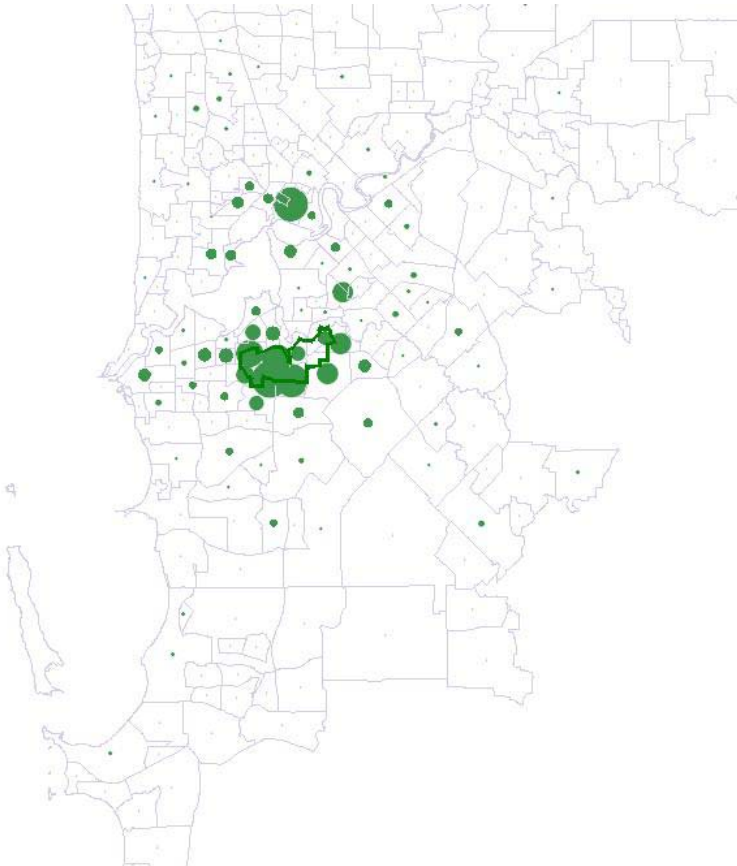
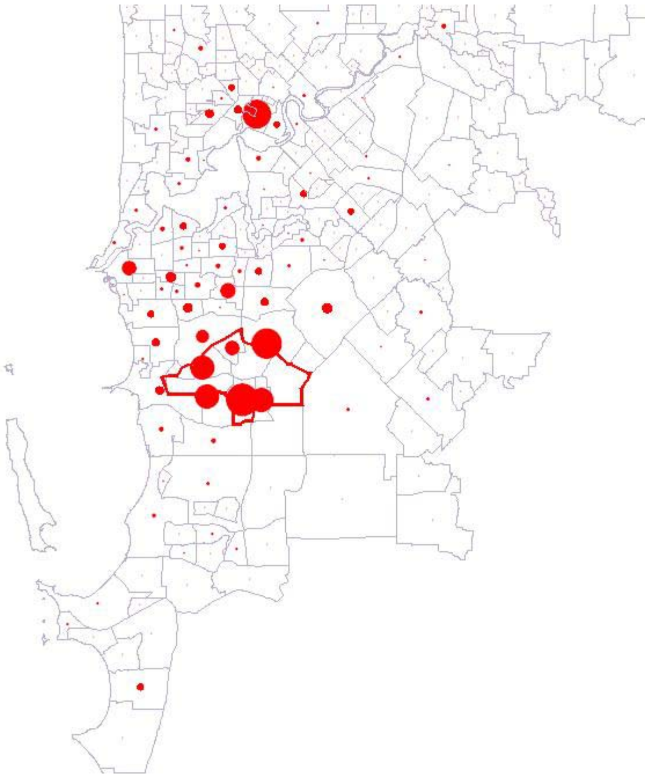


Figure A4: Stated importance facilities in Bull Creek, Cockburn Central, and Wellard precincts
Note: The map on the left presents the values before, the map on the right the values after the railway opening.

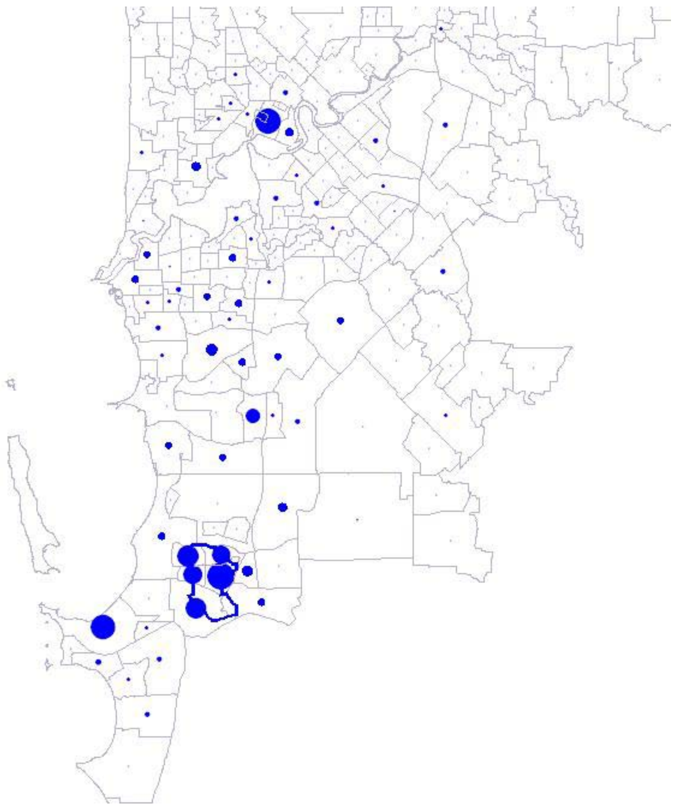
Figure A5: Main travel destinations



a Destinations for residents in Bull Creek precinct



b Destinations for residents in Cockburn Central precinct



c Destinations for residents in Wellard precinct