

Modeling Local Accessibility Networks to Optimize the Planning of Transit Oriented Developments in Adelaide

Andrew Allan and Matthew Fielke

Abstract

In 2010, the State Government of South Australia released its 30 Year Plan for Greater Adelaide, a city of 1.2 million people, dominated by car centric low-density suburban sprawl. The intention of the Plan, and its complementary draft 2013 Integrated Transport and Land Use Plan, was to transform Adelaide into a network of Transit Oriented Developments (TOD), linked by rail, tram and bus routes. These Plans made use of existing public transit routes and transport interchanges, with the exception of modest extensions to the inner suburban tram network, the Bowden TOD, the new Wayville train station and the Seaford Rail line in Adelaide's outer southern suburbs. This paper examines the application of Local Area Accessibility Appraisal Planning Tool (LAAAT) to assess the potential of Adelaide's 12km long north-eastern OBahn bus corridor to facilitate increased residential densities, TODs and public transit usage.

A. Allan (Corresponding author)

School of Natural and Built Environments, University of South Australia,
P.O. Box 2471, Adelaide, SA 5001 Australia
Email: Andrew.Allan@unisa.edu.au

M. Fielke

School of Natural and Built Environments, University of South Australia,
P.O. Box 2471, Adelaide, SA 5001 Australia
Email: fiemr001@mymail.unisa.edu.au

1 Introduction

During the postwar years, Australian metropolitan transport and planning authorities pursued metropolitan strategic directions that emphasized road based transport networks serving car oriented low density suburbs dominated by freestanding single storey bungalows on allotments typically 400-650m² in size. However, the rapid growth of Australian cities has resulted in this approach to urban transport becoming dysfunctional. Long commute times, economic inefficiencies and a declining quality of urban life, combined with Australia's international treaty obligations to the 2005 Kyoto Climate Change Protocol, which were ratified by the Australian Government under Labor's Prime Minister Kevin Rudd in 2007, resulted in changed urban policies and strategic planning at all hierarchies of government. Australian state governments modified their strategic policy directions in their metropolitan planning to emphasize a modal switch to environmentally sustainable urban transport modes such as walking, cycling and public transit. The growth of the third force in Australian politics, the Australian Greens at all levels of the polity (local/city, state and national), created instability in Australia's mainstream politics to the extent that urban planning policies were infused with a very strong and direct commitment to policy actions that would reduce Australia's carbon emissions and minimize the impact on the environment.

The 2010 30 Year Plan for Greater Adelaide (30YPGA) strongly reflected a green philosophy to transform Adelaide into a transit oriented city, through an ambitious strategic plan to create an interconnected transit network with 5 major metropolitan wide transit arterials (one guided bus-way, one tram corridor, and three major rail routes), and around 60 TODs (14 classified as "major"), and urban densification up to 800m on either side of 24 significant transit routes. Each TOD in the 30YPGA was to have an average of approximately 4,300 dwellings when completed and the Strategy called for residential densities to increase from 15 to 25-35 dwellings/ha (GSA, 2010, p72). The significance of the network of TODs as a means of accommodating future urban growth through urban redevelopment and infill strategies, represented a major shift from previous metropolitan strategic plans for Adelaide that had planned most new urban development on the periphery of Adelaide's metropolitan area. Previous metropolitan planning strategies for Adelaide (the 1962 and 1994 strategies) had perhaps unwittingly created a sprawling two dimensional, mono-centric car oriented city. Despite Adelaide never having formally embraced an urban freeway plan,

outside the city center, Adelaide's metropolitan area was generally a 2 dimensional city extending 70km north-south along its northern axis and 20km across its east-west axis at its widest point. The extent of this spatial inefficiency was a function of mono-zoned suburban housing of uniformly low density (usually 5-10 dwellings/ha), with cars having an 80% modal share for commuting trips, resulting in excessive energy consumption, rapidly declining levels of service on the road network, and high environmental impacts, particularly with regard to carbon emissions. The 30YPGA's aim is to reverse the current unsustainable travel and urban development trends for Adelaide. By the Plan's conclusion in 2040, it is envisaged that 70% of new housing for a planned population growth of 560,000 people would be within established areas, and at least 60% of the planned total population growth would be serviced by the new network of TODs and transit corridors (GSA, 2010, p72).

The development of Transit Oriented Developments (TODs) in car centric cities in existing urban areas dominated by low-density suburban development requires a two-staged strategy. The first part of this strategy involves developing a functioning public transport network with interconnected routes that provide commuters with a range of desirable trip destinations and which have the capacity to accommodate long term growth in public transport patronage over one or more decades. The second part of this strategy requires commuter catchments around nodes/transport interchanges in a city's public transport network to be transformed into TODs through the densification of urban development and population. This transformation of land use is in practice quite challenging because in the Australian planning system, existing land use rights of property owners are staunchly defended by current residents, and rather than seeing opportunities for local area improvement, a move to increased densities is viewed as threatening and unsettling to their existing (and often envious lifestyles). Part of the challenge facing Australian governments is that they can only initiate a change in land use to higher densities when intensely competitive housing market pressures results in high and often unaffordable housing values to the majority of home buyers or housing investors. When that occurs, current owners can capitalize on the increased value of their housing and accept the trade-off from the loss of their traditional low-density neighborhood.

Transitioning a low-density city towards a TOD networked city with an overall population density nearly 50% higher than is currently the case presents an interesting policy dilemma. Should policy-makers focus on land use changes that increase density to the point that they allow public transit to have viable transit catchments or should the transit capacity needed to meet

the projected population be developed in advance of future urban densification? At the very least, analysis is needed to determine what the ultimate transit capacity is for a transit corridor before determining land use changes that will increase populations to the preferred population projection in the 30 YPGA. Catchment analysis using pedestrian catchments (or pedsheds) can then be used to ascertain the development and population potential of a TOD, and then this can be checked against the transit capacity of the transit corridor and its stations. A complicating factor is the current South Australian Government's shift from using feeder bus services to direct transit patronage into interchanges to one emphasizing park and ride for private car users as the favored travel method for transit commuters to access transit corridors from home. Hence, whilst the literature on TODs assumes that a local population within the pedshed commuting catchment would provide the bulk of transit patronage for the TOD and its transit corridor, in the case of Adelaide, park and ride commuters may be drawn from 10km beyond the pedshed, resulting in local traffic congestion and unpredictable passenger loadings on transit. The Adelaide OBahn, which is the focus of this paper, experiences this phenomenon, with the South Australian Government recently completing two major park and ride facilities at Tea Tree Plaza and Klemzig along this bus based public transit corridor.

However, whilst Australian state government planning authorities have focused almost exclusively on investing in public transit routes and in creating new TODs in either brownfield or greenfield locations, there is limited research into the planning and design of an optimum local accessibility network of commuter catchments in potential TODs in existing urban areas characterized by development and population at low densities. In planning and designing a local accessibility network for transport modes such as feeder bus routes, cycling and walking, a planning support system (PSS) in the form of an appraisal tool is required to quantify the performance of an existing area's local accessibility network, in terms of its effectiveness in maximizing a TOD's potential to attract local commuters within its catchment. The next section in this paper discusses an appraisal tool that produces metrics and graphical outputs that analyses the performance of both existing and planned local accessibility networks. It also examines the challenges faced in implementing this PSS in planning and traffic engineering practice at the local government level, within the context of metropolitan Adelaide.

Transport planning for today's modern cities has to contend with pressures such as the need to reduce carbon emissions and facilitate more physically active healthier lifestyles that reduce sedentary behaviors. Greater investment in public transit is a major part of the approach adopted by

Australian urban planning departments to encourage a modal shift from private motor vehicles to public transit. Networked public transit solutions are being pursued where transport nodes (otherwise known as interchanges) provide a multiplicity of routing options, origins and destinations to urban commuters. As part of this approach, changes in urban form are required whereby urban development and population is intensified around the transport network's nodes to create transit-oriented developments (TODs). However, the particular urban challenge faced in car-centric cities such as Adelaide in Australia, a city of 1.2 million people, is that existing suburban development is at such low densities and quite dispersed, that it is very difficult to ensure public transit catchments generate sufficient patronage to ensure economic viability of the transit services. The current planning focus for metropolitan Adelaide is for the majority of the metropolitan area to be served by a web of integrated rail, light rail and bus based public transport routes ultimately connecting as many as 34 transit nodes across Adelaide's metropolitan area. However, the success in transitioning metropolitan Adelaide's residents from car centric travel behavior to public transport will be critically dependent on having excellent local transport infrastructure for active transport modes such as walking and cycling that allow safe, direct, legible and enjoyable access to transit interchange nodes in the public transport network.

The use of pedsheds for mapping local accessibility around transit interchanges is an established analytical technique. Assessment tools that assess the degree of walkability in a local urban precinct based on subjective assessments in the form of individual ratings resulting in aggregate scores are also commonplace. The transit corridor of the Adelaide OBahn, a high speed public transit busway with three bus interchanges and the potential for a new interchange with a planned track extension, were selected for the case studies. With the exception of the Tea Tree Plaza bus interchange at the end of the 12km long Adelaide OBahn, the interchanges of Klemzig and Paradise are little more than park and ride commuting stops. At the city end of the OBahn at Gilberton, 2km from Adelaide's city center, there is potential for a new TOD. The selection of these four case studies illustrates well the second stage of an urban densification and transit oriented strategy underpinned with an existing mass public transit corridor. The research identified commuter catchments around each of these bus interchanges and then applied the Local Area Accessibility Appraisal Tool (LAAAT) to analyze the accessibility performance of the existing street network. LAAAT was then used to optimize the design of the network in relation to the urban and population densities required to achieve the TOD objectives for each of the case studies,

consistent with the objectives of the South Australian Government's 2010 30 Year Plan for Greater Adelaide 2010.

The Adelaide OBahn, as the name implies, is a high speed bus service that operates conventional single deck rigid (62 passenger capacity) and two segment articulated buses (88 passenger capacity) with modified steering guides along an elevated channelized concrete track. The unique feature of these buses is that although they require modification to their steering to allow hands free steering operation when using the OBahn, they are able to operate as a conventional bus would on Adelaide's road system. The first stage of the service from Gilberton (2km from Adelaide's City Centre) to the Paradise interchange, was opened on the 9th of March 1986, and the second stage to Tea Tree Plaza interchange (adjacent to the Westfield Tea Tree Plaza shopping mall, 14km from the city centre), was opened on the 20th of August, 1989. A third stage to this transit route is currently in the design phase to extend the bus right of way from Gilberton to Grenfell Street in the city centre with a bus right of way and a tunnel under the Adelaide Parklands at a cost of \$AU 160m. Completion for this stage is scheduled for mid 2017, however, it is in the community consultation phase (as of May 2015) and the project proposal is facing vocal and vigorous opposition from inner suburban Councils and residents. This last stretch of the bus route currently has compromised on-time performance, particularly in peak periods, with as much as 4 minutes added to the 15 minute OBahn trip because buses have to rejoin the some of the busiest sections of Adelaide's arterial road network along Hackney Road and North Terrace where 79,000 vehicle movements daily during weekdays are typical. Unfortunately, the new improvements do not overcome the barrier of the Torrens River crossing, with buses having to cross traffic to access the new bus lane in Hackney Road after leaving the OBahn, rather than being routed under the Torrens River, or over it with a flyover to avoid merging traffic conflict. The heritage nature of the Hackney Bridge (circa 1885) and high costs are the probable reasons for this design limitation. The bus operating speeds currently range from 40km/h through the interchanges to 80km/h for the stage from Gilberton to Paradise and 90-100km/h for the stage from Paradise to Tea Tree Plaza. Operating speeds between the city center and Gilberton range from 50km/h in the CBD to 60km/h on suburban arterial roads. The history behind the OBahn is interesting and partly explains the tension between land use and urban transport. Adelaide originally did have an urban freeway plan that emerged out of its 1962 Metropolitan Area Transport Study that recommended piping the Torrens River underground and building a freeway above it. When the freeway plan was abandoned in the early 1980s, the remaining transport corridor could not accommodate any infrastructure wider than a railway or two lane

road. Initially a light rail service was proposed, but with a change of government, the incoming Liberal state government of Premier Robert Tonkin, opted for the then somewhat experimental OBahn as a point of political difference from its predecessors. The bus based approach appeared to be the ideal solution. It was faster than light rail with service speeds close to that of a freeway and unlike an urban freeway, it was unlikely to become congested, and because low density suburban development was already in situ, the OBahn had the unusual advantage of allowing modified buses to operate on the OBahn and provide feeder routes extending deeply into the OBahn station commuter catchments. This meant that in theory, many neighborhoods could have a single service into the city without the need for transfers at the OBahn interchanges.

Hence, the rationale behind the original OBahn project was partly a response to a very narrow transit corridor zoned along the Torrens River valley. Adelaide's lack of an urban freeway system has meant that it has had to make do with a 60km/h arterial road corridors super-imposed on a grid network of streets, that despite allowing many travel route options, has its efficiency compromised with numerous junctions that become traffic choke and conflict points. The OBahn's dedicated right of way with its grade-separation from other roads has resulted in this service being one of the most successful public transit services in Australia, with 1000 bus services daily along its two way track, carrying an average of 22,000 passengers daily (or 8 million annually). The catchment for the route is approximately 20.5km² using the 30YPGA criterion for a transit corridor, which in theory provides a potential catchment of current dwellings of 30,750 dwellings or 80,000 people (assuming 2.6 persons/dwelling). If the ambitions of the 30YPGA are realized to increase dwellings and populations in Adelaide's transit corridors to dwelling densities of 25-35 dwellings per hectare, then within the OBahn's theoretical catchment, 71,750 dwellings providing housing for 157,133 persons (at 2.19 persons/dwellings as projected in the 30YPGA), could be accommodated.

The OBahn achieves its high average service speeds and capacity with limited stops. The OBahn follows the course of the Torrens River between Gilberton and the Paradise interchange, before continuing in its own right of way in a narrow strip of parkland to the Tea Tree Plaza transport interchange. Between Gilberton and Tea Tree Plaza, there are only two transport interchanges, Klemzig and Paradise, and these are roughly equidistance from each other. Klemzig is not strictly speaking a transport interchange, and functions largely as a park and ride bus station. O.G. Road is a suburban arterial with a flyover across the OBahn at Klemzig and in theory,

does allow bus transit services to interchange at Klemzig. The suburban development surrounding the Klemzig OBahn station is low density suburban development at densities of about 5-10 dwellings/ha. The Paradise bus interchange does allow modified OBahn style buses to enter and leave the OBahn to serve both local feeder services and longer routes, however, as with the Klemzig interchange, it is virtually identical, with a suburban arterial flyover (Darley Road) and it serves as a major park and ride facility surrounded by low density suburban development at densities of 5-10 dwellings/ha. The Tea Tree Plaza interchange is a major interchange, with many services radiating out as far as Elizabeth, 18km north of the interchange. It now has an 800 car capacity park and ride multi-deck parking garage. It is co-located with the Tea Tree Gully Westfield regional shopping mall complex, which has dedicated shopper parking. A community library and Adult Education College is located nearby. There is also a major suburban hospital, local government offices, professional services and various retail services within the commuter catchment. Unfortunately, there is very little residential development within the pedshed of the interchange, and net residential densities are also less than 10 dwellings/ha. The State Government is attempting to change this through allowing 5 storey residential developments within the catchment, but intense local opposition from residents and Tea Tree Council has resulted in a standoff. Despite the TTP interchange being co-located to major retailing and community services, it is poorly integrated with the pedestrian network in its pedshed. The reason for this is that the land uses in the pedshed are car oriented and designed to facilitate intense parking demands and vehicular access to the parking areas. Paradoxically, recent redevelopments such as Lochiel Park (between Paradise and Klemzig), a new eco-suburb at modestly increased densities of around 20 dwellings/ha and the conversion of the old 11 storey high Transport SA offices at Walkerville (between Gilberton and Klemzig) into residential apartments and a hotel, were not within the direct pedshed of any of the interchanges, and hence failed to realize any of the TOD objectives inherent in the 30YPGA. A dedicated cycle path does run in parallel with the OBahn, and whilst this does help to feed limited and modest bicycle commuter traffic into the OBahn's interchanges, it is largely used for recreational purposes.

The transit corridor along the Adelaide OBahn bus transit corridor along with its proposed tunnel extension into the city, falls within the boundaries of six different Local Government Council areas, which complicates the management of land use, because whilst the 30YPGA is the overarching metropolitan strategic planning document that controls the corridor and

which all Council Development Plans (DPs) must adhere (as set out in Section 23 of the *Development Act 1993*), to date there has been little effort or expressed long term desire to facilitate the creation of a TOD at any of the three interchanges of Klemzig, Paradise and Tea Tree Plaza. The DPs are essentially a spatial plan setting out the zonings for permitted land uses, with controls over development density and development character.

When analysing the current zoning ordinances directly affecting the subject interchanges, it is also important to consider the neighboring and adjacent land-uses and how their interfaces are currently established. The complicating feature of the OBahn TC is that for much of its length, it is located within the Torrens (River) Linear Park, a critical component of the Metropolitan Open Space System (MOSS), which is currently sacrosanct within the 30YPGA. This means that any increases in density to support a TOD policy or increased densities in the transit corridor, can only occur outside of and beyond the Linear Park. The interchanges of Klemzig and Paradise have similar residential development controls that favors development of no more than 2 storeys in height in a parkland setting, and even although the Tea Tree Plaza Interchange is located directly within a Regional Centre Zone, its neighbouring and adjacent land uses are quite restricted to those within that zone (i.e. Retail Core, Education and Medical Services).

Although there is quite a variation in residential zoning policy throughout the Council areas in the TC, many of the policies tend to mimic a residential character synonymous with historical development patterns. These patterns allow for the development of detached dwellings on individual allotments, catering for 6-10m building frontage setbacks and with generous landscaping. However, these zones and policy areas often seek slightly higher residential densities and site amalgamations in close proximity to activity nodes (such as the interchanges along the O-Bahn). Land where higher density residential development is envisaged is in close proximity to local services, however none of these zones or policy areas cater for anywhere near the level of densities advocated in the 30 YPGA.

The structure of the local road network can be characterized as a modified local grid network. Many of the suburbs were developed in the post World War 2 era, when car ownership became the norm, hence the usually permeable nature of a grid street network is lacking because of a road hierarchy plan that prevents through traffic from using local streets.

Table 1. Adelaide OBahn (Bus Way)

Station	Characteristics	Distance from city center (km)	Maximum operating speeds (km/h)	Cumulative Travel time	Theoretical capacity/hr (Articulated bus with 88 pax and 2 minute headway (h/w))
Grenfell Street, Adelaide City	High density CBD location	Elevation: 40m	50 km/h		2600
Adelaide to Gilberton	Parkland on one side; low residential density on other side with some mixed uses. (15dwgs/ha)	2.7	50 km/h in CBD; 60km/h on suburban arterial	8.0 minutes	2600 pax from CBD
Gilberton	Medium Density residential (30 dwgs/ha)	Elevation: 30m	40 km/h (tunnel)		—
Gilberton-Klemzig	Linear Park setting with low density residential (10 dwgs/ha)	3.4	80 km/h	10.6 minutes	2600 pax from CBD
Klemzig	Park and ride facility with parking for 450 cars at grade.	Elevation: 40m	40 km/h	11.7 minutes	
Klemzig-Paradise	Linear Park setting with low density residential (10 dwgs/ha)	2.9	100 km/h	13.6 minutes	1733 pax from CBD 866 pax Klemzig-Paradise and TTP
Paradise	Major Bus Interchange connecting with bus routes on adjacent arterial road network; Park and ride for 625 cars at grade.	Elevation: 58m	40 km/h		
Paradise-Tea Tree Plaza	Linear Park setting with low density residential (10 dwgs/ha), light industry and reservoir.	5.7	100 km/h	14.7 minutes	866 pax from CBD to TTP; 1733 pax from Paradise to TTP
Tea Tree Plaza	Major Bus Interchange connecting with bus routes on adjacent arterial road network; major regional shopping mall, hospital, college, library, local government offices, commercial uses; limited residential (10 dwgs/ha)	Elevation: 124m	20 km/h	19.8 minutes	
For whole route-TTP to Adelaide	A 2 way off road bicycle path along the Linear Park connects all interchanges. Linear park along whole route, surrounded by low density residential development (5-10 dwgs/ha)	14.9 km	45 km/h	19.8 minutes	*2600 pax or 2 min h/w (30 buses/hr) *5200 pax for 1 minute h/w (60 buses/hr) *10400 pax for 30s h/w (31900 pax using a triple articulated bus with 270 pax and 30s h/w)

Unfortunately, continuity of the pedsheds is further disrupted by the OBahn which does bisect the TC, although there are flyovers for local suburban arterials. An interesting feature of the OBahn TC is that for much of its length it has a sealed two-way pedestrian cycle path, with grade separations to allow an almost uninterrupted transit by bicycle separate from suburban through traffic between the interchanges and to the edge of the city center. Cycling is however limited due to the variation in track standards of each council with poor lighting, sharp curves, dangerous surface irregularities, 10-15% longer distances than on road commuting, and a large change in elevation ranging from 30m above sea level at Gilberton to 124m at the TTP Interchange. Poor provisioning of cycle parking at the interchanges is indicative of the very low modal share of cycling in Adelaide for commuting (generally 1-2%) and the subsequent reluctance of governments at all levels to provide serious investment in cycling infrastructure even when it can complement enhancement of catchments for transit (ABS, 2011).

2 Methodology

There is a considerable body of literature surrounding the concept of TODs and the level of population and housing densities, and the commuter behaviours needed to support mass transit. In a car oriented metropolitan area such as Adelaide, transit, cycling and walking have such a low share of the overall commuting task, that massive catchments are needed to justify mass transit, and trunk routes tends to be spread quite thinly, as is evidenced by Adelaide's experience, with only 5 mass transit routes to serve a population of 1.2 million. Table 1 illustrates the transit capacity of the OBahn. This ranges from as little as 1,860 pax/hour each way for a single deck rigid bus up to 31,900 pax/hr using a triple segment articulated buses similar to those used in Curitiba's BRT (Lindau et. al. 2010). Headways are limited on the route because buses have to slow to no more than 40km/h through the Paradise and Klemzig interchanges, and in practice, actual speeds are much lower because of signalized pedestrian crossings and the merging maneuvers of buses that have to set down passengers. Despite the busway being initially touted as an OBahn by Daimler Benz, the company that designed, developed and built the busway, the treatment of the road design within the interchanges does not allow uninterrupted high speed traffic flow in the same way that a freeway does, even when non-stop travel is possible. Survey observation of patronage along the OBahn in peak hours, found a one third split of passengers across the three interchanges for the outward city-

TTP commuter weekday commuter trip whereas or the inward bound TTP-city commuter weekday morning peak (7am-9am), buses are often full before they reach the Klemzig interchange. Usually there is a three-way split of passenger boardings across the three interchanges inward bound to the city during weekdays, which is perhaps not surprising given the uniformity of residential development density along the OBahn TC. A private commercial bus operator, Transfield under the business name Light City Buses operates 26 routes along the OBahn. Actual bus patronage levels per route are difficult to obtain because of the commercially sensitive nature of the services, however, in peak hours, the preference is to use the larger articulated buses and often these are at capacity at the start of their route. The South Australian Government administers the bus service contract, and does provide overall daily patronage on the OBahn, which is claimed to be approximately 26,000 pax/day and approximately 4500 pax/hour on a weekday during the 8-9am peak period. Hence, it is possible to make a reasonably accurate estimation of the passengers using the OBahn in peak hours, and the theoretical maximum capacity. By comparison, Curitiba's BRT caters to 2.26 million trips/day, achieves a maximum one way loading of 18,000 pax/hr with a 50 second headway and a commercial speed of 17.5km/h (Lindau et. al. 2010). This would suggest that the maximum weekday peak period capacity (i.e. from 7am-9am or 5pm-7pm) for the OBahn would be 63,800 pax, or around 16,000 pax per interchange (including a notional interchange at Gilberton). Currently, around 9,000 pax per peak period (7am-9am) use the OBahn, suggesting a potential additional capacity of 54,800 pax (i.e. 18,300 pax/interchange).

Using a pedshed of approximately 400m radius around each transit interchange, yields an area of 50ha, which would accommodate 1760 dwellings at the predicted 35dwgs./ha planned for in the 30YPGA. The 400m radius pedshed was selected because the 30YPGA highlighted this as a development target for walkable communities, particularly those anchored by a transit node. However, the 30YPGA's target number of dwellings for the 13 major TODs across the Adelaide metropolitan area (discounting the Adelaide city center) is approximately 3,460 dwellings per TOD, of which 60% (i.e. 2076 dwellings) would be high density dwellings. Hence, whilst it is a derived estimate based on the information presented in the 30YPGA, it can be assumed that all of the 400m pedshed would be available for development at high density. The household occupancy ratio is projected in the 30YPGA to be a modest 2.16 persons/dwelling. For the proposed TODs along the Adelaide OBahn interchanges, this would yield populations of 3,814 persons per TOD at the maximum dwelling density of 35 dwgs/ha. The 30YPGA estimate of the likely ratio of jobs/population is 0.503 jobs/person

but no estimates are provided on the anticipated level of participation of the population in senior high school or in higher education that would affect the level of demand for commuter transit in weekday peak periods on the OBahn. This would imply that each TOD would generate 1,918 commuter trips for employment purposes one way. This project assumed that persons 0-16 and 70 years or older, would not be commuting to work or study because these age cohorts were either at home, schooled locally within the TOD (or nearby) or retired. Persons in the remaining age cohorts (i.e. 17-69 years old) were assumed to commute in the peak periods on the OBahn for the purposes of work, education or to seek employment. This results in an estimated 67.7% of residents making commuting trips based on population pyramid projections for the South Australian population for 2040 estimated by the Australian Bureau of Statistics (ABS, 2014) to yield 2,582 outward bound trips from the TOD. Employment and education trips can be assumed to be one way and city bound along the OBahn, but if the concept of a networked metropolitan system of TODs were to succeed, then outward bound trips would be bi-directional. However, the city center is likely to remain as dominant as it currently is, relative to the jobs and tertiary education opportunities provided in the nominated TODs along the Adelaide OBahn. With the exception of Tea Tree Plaza, it is unclear from the 30YPGA whether this center would diversify and expand beyond retail and medical services employment. A complicating factor is that if the current modal share of commuting trips on public transit for a suburban TOD in metropolitan Adelaide such as Mawson Lakes were to remain unchanged from what they were in 2011, only 8.8% of commuting would be on transit for non-local trips (compared with 6.6% for metropolitan Adelaide), which for the OBahn TODs, would equate to 227 outward bound commuting trips. In theory however, if strong planning policies were adopted for the OBahn TODs that only permitted non-car households within the 400m pedshed, then this project anticipated that for non-local motorized commuting trips, there would be 100% use of the OBahn (i.e. 2,582 city bound trips/TOD, or 10,328 additional trips during the two hour peak for the busiest segment (Gilberton-Adelaide city center), or 5,164 pax/hr.

The use of pedsheds for mapping local accessibility around transit interchanges is an established analytical technique. Assessment tools that assess the degree of walkability in a local urban precinct based on subjective assessments in the form of individual ratings resulting in aggregate scores are also commonplace. The selection of the four case studies (for the three existing bus interchanges at Klemzig, Paradise and Tea Tree Plaza; and a hypothetical bus interchange at Gilberton) illustrates well the second stage of

an urban densification and a networked metropolitan TOD strategy underpinned with existing mass public transit corridors. The next phase of the study was to apply the Local Area Accessibility Appraisal Tool (LAAAT) to analyze the accessibility performance of the existing street network. This tool involved determining what the actual pedshed afforded by the street and pedestrian path network was around each case study TOD that were then compared with the theoretical maximum pedshed for a 400m radius around the centroid of the TOD (usually taken as the signalized pedestrian crossing in the center of each Interchange). Google Earth Pro was then utilized to plot all possible path-link route permutations in the pedshed's pedestrian network (i.e. road sidewalks and off road paths), from the pedshed centroid out to a distance of 400m, for all headings from 0 to 360 degrees. The Google Earth Pro path function was used to do this, and a marker dropped on the map at the end point of that particular 400m path through the pedestrian network for each heading. Once the 400m endpoint of all possible pathway permutations were manually mapped, the Google Earth Pro polygon mapping function was used to manually join all of the path end points to reveal the actual pedshed. This process can be described with the following relationships:

$$\sum \text{Pedshed plotted polygon} = (\text{Consecutive clockwise plotting of locus of mapped endpoints for all 400m long network paths radiating out from pedshed's geometric centroid})_{0 \text{ heading to } 360 \text{ heading}} \quad (1)$$

Where the 400m pedshed path-link is estimated as follows:

$$\sum (\text{segment lengths of a pedshed path-link})_{0-400m} \quad (2)$$

To ensure that a new pedshed path-link is mapped each time, a simple rule in determining each new segment length for a pedshed pathlink, would be to take the nearest new segment option forward that allows a new pedlink path-link to be reached that is in a counterclockwise position beyond the previous pathlink plot (if applicable). This approach allows previously used pathway segments that are close to the pedshed centroid to be re-used as many times as needed in generating the pedshed polygon. ArcView GIS can be used to generate such pedsheds, however the disadvantage of specialized programs such as this, is that it requires highly skilled computer programmers well versed in mapping a network and operational manipulations which would be beyond the skill set of many urban planning professionals. Google Earth Pro allows the mapping of pedsheds to be undertaken as a simple intuitive and logical task that for small pedsheds at least, can be undertaken quite quickly without special GIS skills. Furthermore, the high

quality recent satellite imagery combined with the Street-view function, allowed accurate residential dwelling densities to be determined, even with multi dwelling unit developments, because Street-view allows a visual check of the buildings and mail boxes.

The efficiency of the resulting plot of the actual Pedshed polygon, can then be determined by the following simple metrics associate with application of the LAAAT, where n represents the number:

$$Pedshed\ efficiency = \frac{\text{Area of the actual mapped pedshed polygon (ha)}}{\text{Area theoretical maximum 400m radius pedshed loci. (ha)}} \times 100\% \quad (3)$$

$$Actual\ Pedshed\ housing\ efficiency = \frac{\text{Existing housing in actual mapped pedshed polygon in dwgs/ha}}{\text{Maximum housing potential in actual mapped pedshed in dwgs/ha}} \times 100\% \quad (4)$$

$$Theoretical\ Pedshed\ existing\ housing\ efficiency = \frac{\text{Existing housing in actual mapped pedshed polygon in dwgs/ha}}{\text{Maximum housing potential in theoretical maximum 400m radius pedshed in dwgs/ha}} \times 100\% \quad (5)$$

$$Pedshed\ Path-link\ efficiency = \frac{(\sum (\text{Length of all through path segments in actual pedshed network})_{0-n})}{9,800m^2} \times 100\% \quad (6)$$

Note: (a) Where 9,800m is determined by the length of all pedshed segments of a theoretical orthogonal 100m x 100m grid superimposed on a 400m radius circular pedshed.

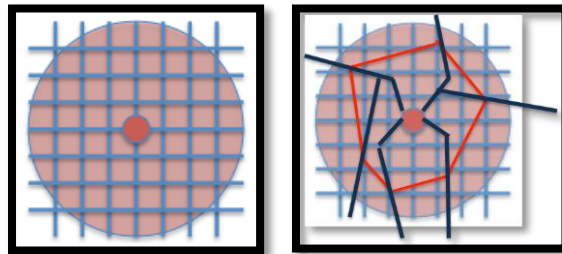


Fig.1 Idealized 100m x 100m block street grid (light blue lines) implying maximum accessibility around a 400m radius pedshed centroid (transit interchange) on left with actual hypothetical 400m pedshed (red polygon) and street network (black lines) superimposed on the right.

$$Average\ Directness\ of\ Path-links = \frac{(\sum (\text{ped-link Euclidean length (m) from pedshed centroid to edge of pedshed})_{0-n})}{(400m \times n)} \times 100\% \quad (7)$$

$$\text{Average Accessibility for each dwelling} = \left(\sum (\text{distance in metres from pedshed centroid via the most direct pedlink for each household}) / (400\text{m} \times n) \right) \quad (8)$$

The advantage of the application LAAAT approach is fourfold:

1. The mapping of the actual pedshed using (1) and (2) provides a clear spatial representation of the pedshed which can then be compared with the theoretically ideal pedshed and pathlink network that maximizes accessibility around the pedshed centroid or TOD (as illustrated in figure 1).
2. Application of the metrics detailed in (3), (4) and (5) indicates the development potential for increased residential density and housing units depending on how underutilized a pedshed is.
3. The metric detailed in (6) illustrates the degree of network efficiency with regard to the overall path-link efficiency relative the idealized street grid presented in figure 1.
4. The metric detailed in (7) illustrates the average degree of directness offered by all pedshed path-links to the centroid. This measure could be modified for even greater utility, by determining the average distance to every household in the pedshed (see (8)).

The use of these metrics with the LAAAT was then used to analyze the design of the network in relation to the urban and population densities required to achieve the TOD objectives for each of the case studies, consistent with the objectives of the South Australian Government's 2010 30 Year Plan for Greater Adelaide 2010.

3 Findings

Table 2 details the findings of the LAAAT in the form of metrics determined for each of the case study pedsheds. Figure 2 illustrates the theoretical 400m radius pedsheds, plotted actual 400m pedsheds determined by 400m pathlinks through the network around the pathshed centroid (i.e. the bus interchange), and the 1,600m wide transit corridor (higher density transit oriented development 800m either side of the OBahn) as set out in the 2010 30YPGA. Figures 3 details the actual plotted pedsheds and theoretical 400m radius pedsheds superimposed over satellite imagery of each OBahn case study area. The satellite imagery permitted analysis of the nature of land use, housing development and the pedestrian path network and assists in

interpreting the metrics. From the analysis, it appears that all of the pedsheds are grossly underutilized, at least from the perspective of maximizing land use accessible within a 400m walk of the interchange, with 47-50% of the Pedsheds accessible within the theoretical maximum 400m pedshed. The actual pedshed housing efficiencies (line 4, Table 1) for Klemzig, Paradise and Tea Tree Plaza are very low ranging from 12-29%, and at very low gross residential densities (3.5-11 dwgs/ha). The contrast becomes even more extreme when the theoretical pedshed efficiency for existing housing is compared, ranging from 5% to 15%. The net housing density is also quite low at 12-14 dwgs/ha, although for the hypothetical case study at Gilberton, at 33 dwgs/ha it does come close to the 30YPGA target of 35 dwgs/ha. Ped-link path-link efficiencies (line 6, Table 1) range from 30-48% for the case studies, suggesting that there is considerable potential to improve the performance of the pedestrian network through the use of a finer grained street/path grid. However, the average directness of the path-links (as compared with the Euclidian distance) from the pedshed centroid (i.e. the interchange), to the edge of the actual pedshed were reasonably direct, ranging from 70-80%.

The LAAAT was then used to determine the housing development potential for each of the case studies, based on developing the theoretical 400m pedshed at 35 dwgs/ha, in line with the development target in the 30YPGA. If the theoretical pedshed were fully developed with housing, it was determined that relative to the actual pedshed, there was potential for: an additional 1,497 homes at Gilberton (versus 262 existing homes); 1,641 homes at Klemzig (versus 118 existing homes); 1,588 homes at Paradise (versus 171 existing homes); and 1,673 homes at Tea Tree Plaza (versus 86 existing homes). This assumes that all of the area within the 400m radius theoretical pedshed would be developed with housing. With mixed and varied land uses incorporated, and with the need to retain the open space system (The Torrens Linear Park), this could still occur, however, high-rise residential development may be needed. The study predicted that if the maximum residential development potential were to be achieved in line with the 30YPGA objective of 35 dwgs/ha in the TODs, the OBahn would still have sufficient passenger capacity to cope with the projected increased travel demand from commuters to 7,351 commuters/hour. However, with the interchanges in their current design configuration, it is unlikely that the OBahn transit corridor could become a genuine transit corridor beyond the 400m pedshed of the interchanges, if the corridor were developed at the densities targeted in the 30YPGA.

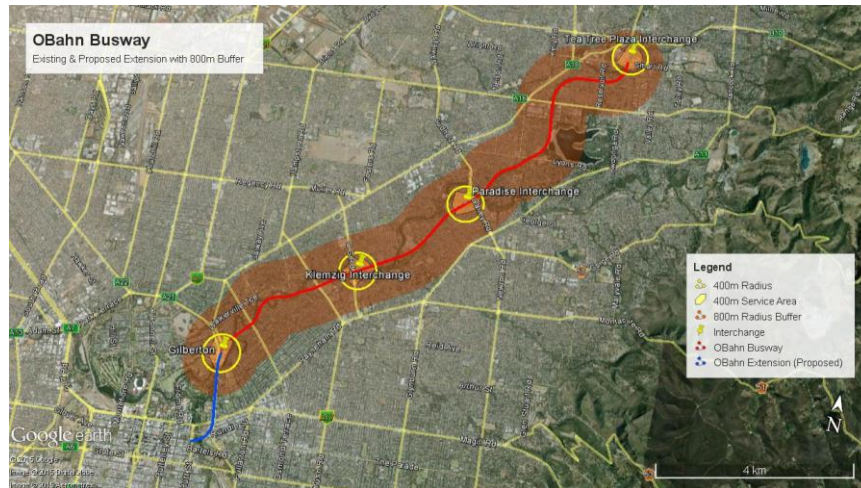


Fig.2 Adelaide OBahn (NorthEast Busway), showing the 3 existing case study interchanges and a hypothetical interchange at Gilberton, with plotted actual pedsheds, 400m circular pedsheds and the 1600m wide transit corridor targeted in the 2010 30 Year Plan for Greater Adelaide for increased residential densities (up to 35dwgs/ha) Source: Google Earth Pro, 2014



Fig.3 Double articulated M.A.N. diesel bus on Adelaide OBahn
Source: <http://www.weekendnotes.com/im/004/05/dunstan-adventure-playground-st-peters-flying-fox-21.JPG>. Accessed March 21, 2015.



Fig.4 Pedshed analyses for OBahn case study pedsheds
Source: Google Earth Pro, 2014

Table 2. Local Area Accessibility Appraisal Tool (LAAAT) Pedshed Results for Adelaide OBahn (Northeastern Busway)

Pedshed metrics	Gilberton	Klemzig	Paradise	Tea Tree Plaza
1. Actual Pedshed area (ha)-gross residential density	23.8 ha (11.0 <i>dwgs/ha</i>)	24.4 ha (4.8 <i>dwgs/ha</i>)	24.9 ha (6.9 <i>dwgs/ha</i>)	24.6 ha (3.5 <i>dwgs/ha</i>)
2. Housing area (ha)-net residential density	8.1 ha (33.0 <i>dwgs/ha</i>)	9.16 ha (12.9 <i>dwgs/ha</i>)	14.36 ha (11.9 <i>dwgs/ha</i>)	6.3 ha (13.7 <i>dwgs/ha</i>)
3. No. of dwgs in actual pedshed	262 dwgs	118 dwgs	171 dwgs	86 dwgs
Pedshed efficiency (Eq.3)	47.3% (hypothetical)	48.5%	49.5%	48.9%
4. Actual pedshed housing efficiency (Eq.4) (based on 35dwgs/ha as set out in the 30YPGA)	31.5% (hypothetical)	18.2%	28.6%	12.5%
5. Theoretical Pedshed existing housing efficiency (Eq.5)	14.9%	6.7%	9.7%	4.9%
6. Pedshed Path-link efficiency (Eq.6)	45.2% (hypothetical)	41.3%	47.6%	30.4%
7. Average Directness of Path-links (Eq.7)	79.5% (hypothetical)	72.3%	71.6%	70.4%
8. Theoretical Pedshed potential for new housing (dwgs)	1,206 dwgs	1,517 dwgs	1,413 dwgs	1,583 dwgs
9. Current weekday peak period commuting trips from actual pedshed (7-9am) using OBahn	0	9 trips	13 trips	7 trips
10. Current total weekday peak period commuting trips from actual pedshed (7-9am)	234 trips	105 trips	153 trips	76 trips
11. Theoretical Pedshed weekday peak period (7-9am) using OBahn in 2040: new commuter trips	2,146 trips	2,554 trips	2,546 trips	2,559 trips
12. Current OBahn trip boardings (commuters outside the actual pedshed using the OBahn during a weekday peak period (7-9am))	0	1,491 trips	1,487 trips	1,493 trips
13. Predicted trip boardings on OBahn in 2040 after pedshed densification to 35dwgs/ha	2,572 trips	4,045 trips	4,033 trips	4,052 trips
14. OBahn bus services required for weekday commute (7-9am or 5-7pm) using 88pax double articulated buses (Capacity utilization of buses in brackets)-based in a 43s headway	168 (100%)	168 (83%)	168 (55%)	168 (28%)

4 Major Conclusions

This project developed various methodologies in the form of the LAAAT that allows local government urban planners to analyze the commuter catchments around transport interchanges to determine the housing density

changes and transit capacity needed to develop transit oriented developments along Adelaide's OBahn bus commuter transit corridor. The pedshed metrics for the case studies highlighted that the transit corridor is extremely underutilized and lacks the critical mass of housing development to support transit. The pedsheds in the case studies were at least 50% underutilized relative to the 400m radius theoretical pedshed. However, the OBahn functions effectively as a park and ride transit corridor, drawing bus patrons from more than 10km beyond the OBahn, either via park and ride commuting or via services that originate far beyond the OBahn.

The pedshed analysis suggests that each of the case studies had potential for considerable improvement in terms of the directness of the pedestrian network, the fineness of the grid that makes up the pedestrian network, and the ease of access to the pedestrian network as implied by the total pedestrian network length. This shortcoming could be rectified through the development of new roads and pedestrian links, particularly where pedestrians are forced to take unnecessarily circuitous routes to the interchange from their home in the pedshed.

This project suggested that whilst the OBahn has sufficient spare capacity to cope with intensification of small 400m radius pedsheds around the interchanges, it would not cope with expansion of the whole OBahn transit corridor into transit oriented development, and would not have the capacity to accommodate a substantial modal shift to the OBahn away from car commuting for existing residents residing in low density suburban development between the interchanges. In the longer term, the use of autonomous buses may be able to extract a doubling of passenger capacity with minimal headways, however, the requirements for buses to slow down or stop at each interchange is a severely limiting constraint to significant expansion of commuter capacity on the OBahn. If the 30YPGA ambition for the OBahn as a transit oriented corridor with housing densities of 35dwgs/ha are to be realized, then the northeast bus corridor may have to be converted to a metro rail service with quad tracks (one track each way for local services and one track each way for express services).

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