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Assessing the potential for sustainable transport activity in suburban areas of metropolitan Adelaide using permeability indices

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Abstract

A primary transport challenge for Australian cities from the perspective of minimising greenhouse gas emissions, restricting consumption of limited fossil fuels and improving the physical health of urban dwellers is to develop policies that encourage walking and cycling as the preferred local urban transport modal choices.

With the current structure and densities of cities such as Adelaide, however, how feasible is it to expect urban populations to switch from motorised urban transport to walking and cycling for their local transport needs? This paper analyses three Adelaide suburbs using the concept of accessibility indices (Allan, 2001) to ascertain how well they currently cater to walking and cycling modes for local trips and explores what policies would be needed to facilitate a significant modal shift to walking and cycling for local trips.

Norwood was selected because of its relatively fine-grained 19th century grid network of streets and compact village centre which is amenable to access to local residents on foot or bicycle; Golden Grove was selected because it is generally representative of traditional car oriented middle to outer suburban development that had its genesis during the 1980s; and Mawson Lakes was chosen because it is meant to be the latest embodiment of contemporary, compact, integrated suburban development. With reference to current policy approaches, this paper concludes with transport policy options suggesting the changes required to make cities such as Adelaide more conducive to walking and cycling for all residents' local transport needs.

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Introduction

Up until the mid 1990s, transport planning in Australian cities appeared to be dominated by a preoccupation with catering to road based mechanised modes of transport. Whilst the freight transport task is undoubtedly a significant component of the overall scale of transport activities taking place in our cities and most if not all roads are perhaps over-engineered (in terms of space and load bearing capacity) to accommodate the largest trucks using urban roads, nevertheless, the sheer volume of private cars using our roads has been a more powerful determinant of the urban sprawl that has characterised Australian cities during the 20^{th} century.

From 1948, when the Chifley Labor Federal Government oversaw the introduction of the first Holden, which was the manifestation of a policy intended to eventually bring motoring within reach of every Australian household, Australians were no longer constrained about their choice of where they could live according to public transport availability. As mass production techniques were also applied to housing construction, and the federal government favoured policies that encouraged over-investment in housing by individuals, a freestanding suburban bungalow on its own garden allotment (usually $600m^2$ or more), became the residential aspiration for the majority of Australian households.

This housing ideal only began to be seriously challenged in the late 1980s as suburban housing began to become increasingly unattainable even for households on average incomes, particularly in Sydney with its overheated property prices when compared with other Australian capital cities (Stilwell, 1993). Moreover, on the urban fringe where new residential allotments normally became available, in the case of Sydney and Melbourne, suburbs on the urban-rural fringe were becoming much less practical in terms of an acceptable commuting period and/or distance from city and metropolitan regional centres. The Australian Model Code of Residential Development (AMCORD) introduced in 1995, was an attempt by the Keating Labor Federal government to produce a set of residential development guidelines that advocated higher residential densities and supposedly lower housing construction costs. The Planning Strategy for metropolitan Adelaide, like most metropolitan planning strategies around Australia, encouraged urban consolidation through urban infill and redevelopment of sites in the more accessible metropolitan locations. Notwithstanding the general thrust of metropolitan planning policy rhetoric around Australia that advocates greater residential densities, however, the Howard Liberal-National Coalition Federal Government, with its First Home Owners' grant, skewed to support new housing construction, has to some extent confounded this trend towards the densification of residential areas in our cities (Allan, 2001).

The confluence of the means to mass-produce both cars and houses relatively cheaply, government policy and a finance sector which encouraged home ownership and the abundance of affordable land for new housing on the metropolitan fringe of Australia's cities, have been the driving forces behind the rash of low density urban sprawl that afflicts all of Australia's major conurbations. Initially, state and federal road building authorities were slow to respond to the transport demands associated with suburban sprawl, however, by the early 1990s, this reticence was largely overcome, with state and federal governments contemplating, embarking or completing massive urban freeway projects in all mainland capital cities, the more notable of which included Melbourne's City Link, the Sydney Harbour Tunnel, Sydney's Anzac Bridge and Sydney's Castlereagh M4 Motorway. Even Adelaide embarked on freeway building projects such as the Southern Expressway (albeit a one-way tidal flow system), and extending the South-Eastern freeway to the edge of the city (a peri-urban link into the Adelaide Hills dormitory communities). The upshot of all this is that Australian cities have developed in such a way that the majority of the community rely on motorised means for accessibility and mobility in urban areas. Few Adelaidians (or Australians for that matter), in the crucial "journey to work" category, chose walking or cycling for part or all of the journey to work, with a mere 4.9% of commuters opting for these modes in 1991, which then declined to 3.7% in 1996 (Forster, 1999). The results from both the 1986 and 1999 Adelaide Household Travel surveys confirm these patterns, although based on very much smaller but statistically valid samples, as opposed to the ABS census which while cruder in detail, provides an accurate snapshot of the travel mode behaviour for the whole metropolitan Adelaide population. Although Australia is amongst the most urbanised of nations, paradoxically, it has not resulted in very urbane responses to solving its intra-urban transport needs. The wide dispersal of homes, jobs and community facilities in Australian cities is such that cars are inextricably reliant on the fabric of roads that seems to form the basis of the physical tapestry of Australian cities.

Interestingly, past urban planning ideas and theory (eg Ebenezer Howard's ideas for a Garden City in 1899; Radburn, New Jersey, USA in 1933; the post 1945 World War II British New Towns; Elizabeth in South Australia in 1949), upheld the principle that neighbourhood facilities, such as a local shop, school, community centre, local public transit stop or park should be within a 400-600m radius within a pedestrian oriented precinct that facilitates walking. Indeed, this principle is still a guiding light in local area planning, but because people demand private car access to their home, the reality is that planning for the car dominates street design criteria even in local residential access streets. Road traffic engineers employ the principle of the road hierarchy to manage and differentiate urban traffic according to whether it requires land use access or maximised mobility to access another part of the city as quickly as possible, but while some provision is made for non-motorised road users to cross roads or for cyclists to share part of the road, the urban road system is primarily built to handle the size, weight and speed requirements of fast moving motorised vehicles. Even though urban areas that developed before the adoption of widespread car usage do exhibit a more human scale, particularly in terms of their street widths, building setbacks and an absence of off-street parking (usually garages), their streets have also become burdened by both parking demands and through traffic.

There has been much research on the perils of car dependency and the high reliance on cars to meet urban travel needs in Australian cities (Newman &

Kenworthy's (1989) work is prominent in this regard). The dominant reason (40.9%) Australians do not cycle to work or place of education is because "the ride takes too long or is too far" (ABS, 1997). Detailed representative and comprehensive population surveys of the reasons why people do not walk to work are comparatively lacking. Cycling advocates such as Parker (1998) argue, however, that in spite of people's predilection for motorised means of getting around urban areas, there is enormous potential for cycling to be increased as the preferred mode of transport since the bulk of local trips are of a local nature, that is, less than 5km, which is well within the capability of cyclists of average fitness. There is also a considerable body of work (eg Gehl, 2001, 1987; Lozano, 1990; Newman and Kenworthy, 1989), about what makes urban areas conducive to walking, although it tends to emphasise the aesthetic experience and emphasises focusing in on city or town centre environments. Gehl (2002), has, however, recently completed a survey in which walking activity and the quality of the pedestrian environment were audited in Adelaide's city centre to identify how the city could be improved to make it more conducive to walking. Cevero (1997) encapsulates well the character of the change required by calling for a paradigm shift from what he terms "automobility", the conscious and also unconscious "default" mode that planning often seems to revert to, towards "accessibility planning", in which transport infrastructure and land use planning allow most urban trips to be made on foot or by bicycle (or at least as far as a public transport stop).

There is increasing support at all levels of government towards accommodating and encouraging a modal shift to walking and cycling. For example, the TravelSmart travel behaviour change programs by state governments in Western Australia, South Australia, Queensland and Victoria have run pilot programs (mainly in inner city suburban communities) with encouraging results from these communities. Furthermore, walking and cycling strategies have been produced by state and local governments around Australia that set out clear (although often ambitious) targets with concrete actions for achieving such targets (eg "Perth Walking: The Metropolitan Region Pedestrian Strategy" (Transport WA, 2000); The Cycling Strategy for South Australia, (DoT South Australia, 1996); Strategic Bicycle Plan (City of Adelaide, 1995)). State Governments' metropolitan strategies (eg Adelaide's metropolitan Planning Strategy, (1994); Perth's 'Metropolitan Transport Strategy 1995-2029 (1999)), have for much of the past decade set policies such as urban regeneration, urban consolidation and integrating land use with transport as their overarching priorities. The work of the Australian Greenhouse Office on Transit Oriented Developments has also strengthened the credibility of "Transit Oriented Developments" as an urban design response capable of encouraging a permanent transport modal shift to cycling and walking. Many of these policies are now being implemented, as manifested by new development which is increasing urban densities in inner city areas, urban infill sites (eg Adelaide's Mawson Lakes) and in greenfield locations.

However, there has been little systematic published research on the Australian suburban environments that attempts to quantify purely in a physical sense, how conducive our cities are to walking and cycling, across a range of different types of suburban environments (as distinct from research which merely describes pedestrian activity or documents sometimes subjective views about the limitations of existing transport infrastructure for these modes). Through the use of what are termed "permeability indices", this paper explores to what extent street connectivity allows transport modes such as cycling and walking to be theoretically feasible modes to access local facilities in three case study suburbs of Adelaide. The suburbs examined are Golden Grove, Mawson Lakes and Norwood. Golden Grove and Mawson Lakes (in Adelaide's northern metropolitan area), were developed by the Delfin Corporation jointly with the South Australian State Government in the mid 1980s and mid 1990s respectively, and are interesting because they are meant to represent 'state of the art' thinking about residential communities for their respective eras. Norwood by contrast, was a product of 19th century Adelaide before the era of personal motorised transport and so its grid based street network and the compact village feel to its main street seems naturally conducive to walking and cycling. Through analysis of the application of these permeability indices to these three case studies, some suggestions for transport policy are made that may make local transport modal choices in Australian suburban areas more sustainable in future.

A primary urban transport challenge-towards sustainable transport activity

The term "sustainability" within the context of this paper adopts the position adopted in the 1987 Brundtland Report (Brundtland, 1990), which is that the needs of the present are met without compromising the environment for future generations, particularly with regard to biodiversity. Because the most significant impact of transport relates to energy usage, toxic pollution and greenhouse gas emissions from the burning of fossil fuels, this paper concentrates on these aspects of sustainability. However, there is also the issue of the "sustainability" of the health of human populations in areas heavily dependent on motorised transport for their mobility. Over reliance on motorised transport, particularly cars, is resulting in a growing problem of obesity in western societies being manifested in childhood, which is creating considerable potential for long term public health problems associated with sedentary behaviours and ultimately less "sustainable" lives for individuals so affected.

Newman and Kenworthy's (1989) seminal work, "Cities and Automobile Dependency", conducted an international comparison of around 32 cities in which it was established that Australian cities are with the exception of North American cities, amongst the most profligate consumers of gasoline on a per capita basis, and that the bulk of this consumption was due to private automobile transport. The latest statistics from ABS provide stark evidence that Australia's reliance and use of automobiles for personal travel needs (predominantly in urban areas), is growing, with the vehicle fleet increasing by 24% over the period 1991-2001 (ABS, 2001). Australia's consumption of petroleum products to meet its personal transport needs is expanding (from 15,825 million litres to 16,190 litres from 1998-2000) (ABS, 2001), despite improvements in the fuel economy of Australia's motor vehicle fleet. Although residential densities are increasing in Australia's cities, they continue to sprawl, and with the exception of inner city developments in Melbourne and Sydney, new residential development still tends to be car oriented. Perhaps the worst aspect of much of the residential development found in Australia's cities, is that a large proportion of it does not offer residents the choice to easily opt for using non-motorised modes of personal transport such as walking and cycling, and many middle and outlying suburbs continue to be poorly served by public transport.

In the long run, nothing is truly sustainable. Eventually our sun, which is already a middle aged star, will become a red giant and engulf the earth towards the end of its 10-12 billion year life span. However, if earth's resources are well managed, theoretically, life should continue to exist on this planet for about another 1500 million years. In comparison to human life spans, this may seem like an eternity, but the urgent concern is that humanity's current actions may make earth uninhabitable in a minute fraction of that time. In the early 1970s, when the first oil crises occurred (which was artificially induced by OPEC), policymakers were most concerned about the eventual exhaustion of the world's fossil fuel resources. Even now, unless new reserves of fossil fuels are discovered, even the most optimistic would have to admit that it is difficult to see how current demands for petroleum globally can be satisfied beyond the end of this century. However, since the Rio Earth Summit of 1987, a more pressing concern is the contribution of fossil fuel consumption (particularly from personal transport) towards the creation of greenhouse gases, which already is having an impact on global warming. With a growing middle class demographic profile in rapidly developing economies such as China, Malaysia, and to a lesser extent, India, apparently desperate to emulate western style consumerism, with private car ownership being the penultimate ambition, the crisis for the global environment, in terms of fossil fuel depletion, pollution and global warming, may intensify much quicker than policymakers in countries such as Australia and the United States, ever expected. While Australia is not a major player in global geopolitical terms, it nevertheless has a significant role to play as a middle ranking economic and political power. Even if Australia does adopt the very best practices in sustainable transport activities, globally, the impact will be very minor. However, a strong case can be made to say that Australia has the means to set an example, in other words, to show the rest of the world that a high quality of urban life can be achieved without excessive reliance on cars to allow a meaningful level of participation in urban life.

Research by Hughes (1993), in which energy consumption for modes of transport are compared, indicates that walking (0.15MJ/km) and cycling (0.02MJ/km) are competitive with other modes such as buses (0.35MJ/passenger.km) and cars (driver only-3MJ/passenger.km) in terms of energy efficiency. Moreover, because walking and cycling do not involve consumption of fossil fuels (at least not directly), it could be argued that these two modes are the most sustainable. Theoretically, it would seem that if the dominant modes in our cities were walking and cycling (it's currently less than 5% of journey to work trips in most Australian cities (ABS, 2000)), it would have the potential to make enormous reductions in Australia's transport energy demands, which are largely reliant on fossil fuels.

Hence, at the macro scale, the case for more sustainable transport activity can be argued convincingly. The case at the micro level in Australian urban environments is much more of a challenge. The spectrum of options for transport activity in our cities could be classified into four broad categories. The first is to minimise all transport activity; the second is to develop transport technologies that are as environmentally sustainable as possible (or encourage non-motorised transport options such as walking and cycling to be a feasible alternative to motorised transport); thirdly, transport infrastructure needs to be developed (ie mass transit, road networks), that minimise energy consumption and the generation of pollution and greenhouse gases; and fourthly, land use strategies need to be pursued that make our cities conducive to people naturally choosing sustainable transport options such as walking, cycling or public transit.

The challenge at the micro scale is considerable, however. It involves many organs of government at all three tiers (federal, state and local), working in unison to pursue policies that are consistent with the unilateral overarching aim of reducing Australia's travel related energy consumption, pollution and greenhouse gas emissions. A myriad range of policy actions will be needed to achieve this outcome. As far as urban transport is concerned, however, if policy makers want to achieve the best possible outcome over the longer term, then they will need to pursue with vigour strategies that make walking and cycling the natural choice for local trips.

Land use planning has the potential to initiate the most significant change, in terms of providing local transport networks, urban densities and the distribution of facilities that are conducive to walking. Land use planners need to understand how people derive sufficient utility to want to make a walking or cycling trip, in preference to not making a trip at all or indeed, choosing to drive or travel by public transport. The concept of utility is an economic one, but in terms of the way that it influences human behaviour with regard to modal choice or the decision to make a trip at all and what it is about trip attractors that develops trip desire in people seems to be lacking in transport research.

A considerable challenge arises in that there is enormous inertia in the existing urban environment to accept the changes that may be necessary to achieve the aim of moving towards more sustainable transport activity. Retrofitting existing urban areas is not impossible, but it has the potential to be extremely costly, particularly if radical changes are needed to roads and services infrastructure. Reurbanising at higher densities involves redevelopment which is bound to be much more costly than developing in Greenfield locations. Notwithstanding these difficulties, planners can still work to ensure that detailed improvements to local transport networks are undertaken that provide increased opportunities for increased walking and cycling in lieu of car based trips and ensure that facilities are provided in central, easily accessible locations. Moreover, careful urban design work can create more pleasant environments for walking and cycling that are more likely to encourage people to choose these modes for their local area transport requirements.

Transport modes compared

Walking

With the exception of disabled people, walking is a fundamental means of accessing locations in the urban environment for everyone. The infrastructure provided for facilitating walking in urban environments, with some modifications, can similarly facilitate accessibility for wheelchair bound persons. Walking allows people to have access where public transport, cars and bicycles cannot go, in other words, in and around buildings. The healthy human body has an amazing “all-terrain” capability that rivals the most impressive 4 wheel drive vehicle. And while one doesn’t need expensively engineered transport infrastructure to anywhere near the same extent as for motor vehicles, walkers appreciate having well defined, comfortable, visually attractive and direct pathways.

Transport planners also need to be mindful of the fact that in spite of the versatility of the walker to not be unduly constrained by the lack of a formally engineered route, the urban environment can still create some virtually impenetrable barriers to pedestrians, most often with high volume, high speed multi-lane roads, but also with buildings and property boundaries that can make walking trips impossibly circuitous. A fundamental planning consideration in catering to walkers is that generally they are not compatible with motorised modes, which means that a separate movement network needs to be provided for pedestrians. In most urban environments, this means relegating pedestrians to the nature strip along motorised traffic corridors, sometimes without even a sealed footpath, but it can also mean providing a pathway network that is independent of the road network. Other important planning considerations are that walkers will typically travel at about 5-6km/h and have an endurance of about 15-20 minutes, which equates to a range of about 2km. This means that facilities that are likely to be accessed by pedestrians, such as local shops, a transit stop or community centre, need to be limited to no more than 2km from the origin of the journey (ie normally the home, workplace or school). People will walk longer, but they’re more likely to do it to achieve a non-transport related objective such as for health or recreational reasons.

A walker does not require much space (a pathway 70cm wide allows a walker ample space) and can cope with inclines as steep as 1 in 3, although this would cause difficulty for more frail persons or those in wheelchairs or pushing prams. With the ageing of the population, increasing numbers of people are relying on motorised wheelchairs for their local mobility needs, and these people are dependent on using the pedestrian transport network for local access. Although motorised wheelchairs are reasonably versatile, they do place more onerous restrictions on the design of pedestrian networks, particularly with regard to gradients and steps. Often, in the absence of suitable pedestrian pathways, people using motorised wheelchairs will resort to using the motor vehicle road network, despite the obvious incompatibility of such slow vehicles (ie with maximum speeds of 10-12km/h) with fast motorised traffic.

Cycling

Cycling is the most energy efficient way of moving people around (Hughes, 1993). Not only is it much quicker (average speeds of 20km/h on level ground being feasible for most people without undue exertion), but because of its greater mechanical efficiency (compared to walking), it allows a vastly increased range of areas to become accessible. Table 1 compares the relative sizes of areas accessible for various modes according to the maximum practical ranges of these modes for urban trips. Since the area of accessibility increases with the square of the radius, cycling allows an enormous increase in the number of locations that can be accessed. For example, while the ratio of the maximum practical ranges for cycling versus walking is only 2.5, the ratio of accessible areas is 6.2 (ie 78.5km^2 of potential destinations compared to only 12.6km^2 for walking). This phenomenon also helps to explain why motorised forms of transport have allowed massive increases in the size of urban areas. While cycling provides a good range of accessible destinations, the car easily provides access to around 5,000km^2 while high speed mass transit can increase this reach to 31,400km^2.

Table 1 Transport modes compared for range and loci

Modes	AREA (km^2)	RATIO (mode accessible area/walking accessible area)	RANGE (km)	RATIO (mode range/walking range)
Walking (ideal range)	0.5	*	0.4	*
Walking	12.6	1	2	1
Cycling	78.5	6.23	5	2.5
Local transit (bus)	314	24.9	10	5
Public transit (bus/LRT)	1,257	99.8	20	10
Car	5,027	399	40	20
Express public transit	31,416	2,493	100	50

NOTES:
Area=Pi x radius^2
Assumptions are:

1. 20 minute limit for walking and cycling, with average speeds of 6km/h and 20km/h respectively.
2. 50 minutes for local transit at an average speed of 25km/h
3. 60 minutes for car at an average speed of 40km/h
4. 75 minutes for express public transit at an average speed of 80km/h

Most cycling advocates (eg Parker, 1998), would argue that local trips of 20 minutes by bicycle providing a range of about 5km at an average speed of 20km/h are entirely within the realm of possibility for persons of average fitness. The infrastructure for cycling does create additional restrictions in comparison with walking. For cyclists to maintain a 20km/h average speed, they require either dedicated specially engineered pathways or use of the urban road system. With dedicated cycle paths, attention needs to be given to minimising gradients (which reduce average speeds and tire cyclists), rough surfaces, sharp horizontal curves or anything that may inhibit timely progress such as intersections.

Cycling, however, is perhaps more restrictive as a mode of transport than walking. The populace at large have many reasons not to consider cycling as a realistic urban transport choice. An investment in equipment is required, which while extremely modest compared to motorised transport modes, can be a disincentive to people not prepared to cope with the paraphernalia needed to cycle safely (eg such as protective headwear and reflective clothing; lighting). Poor weather (such as rain, extreme heat or cold), can also inhibit even the most ardent cycling enthusiasts. Cycling in hilly terrain also requires specialised skills in changing gears to successfully negotiate gradients without having to “walk the bike”, which may deter people who are only familiar with driving automatic cars. Whilst the road rules are essentially the same for cyclists or motorists, safe cycling on public roads requires specialised techniques which are not necessarily taught in a formal sense (compared to the driver training options available to motorists), and this too may deter many from taking up cycling, particularly if it involves sharing the road with fast moving motorised traffic. Still others are deterred or excluded from cycling because of youth, old age or a lack of joint mobility or other illnesses which make cycling an unpalatable option. Many work and study places do not seriously cater for the needs of cyclist, even at the elemental level of providing safe storage, let alone in providing changing and shower facilities for cyclists.

The reality for most potential origin/destination trips in urban areas is that the urban road network does not allow for cyclists to complete a trip without a significant exposure risk to life threatening motor vehicle traffic. There are potentially many other reasons why cycling is not the natural choice of urban trips, but these are beyond the scope of this paper. However, in a city such as Adelaide, which is blessed with generally flat terrain and a Mediterranean climate, making it well suited to cycling, in the 1996 census, only 1.03% chose cycling to travel to work as the sole mode (ABS, 2000). When one considers that most local suburban areas are designed so that all dwellings are within 5km of schools, shops or open space, there would seem to be enormous potential for cycling to fill the gap between trips that can be comfortably made as a pedestrian and those trips that are better made using a motorised mode (ie local urban trips in the range from 1km-5km).

Street network permeability and sustainable transport activity in suburban areas

Street network permeability refers to the extent to which a street network provides direct trips between the origins and destinations of all trips, in other words, as “the crow flies”. It is a critically important concept relating to urban design because poor street permeability will inhibit pedestrian or cycling activity in urban areas. While a motorist will not be seriously inhibited from having to make a circuitous path to reach a destination in a local area, the very limited range of pedestrians (see table 2) (which also applies to cyclists, although to a lesser extent), when combined with the poor stamina of the human body to sustained high levels of exertion over more than half an hour, means that trip directness becomes a critical issue. An urban environment that does not provide reasonable levels of direct trip pathways can make walking and cycling impractical, even for trip origin-destination pairs that are quite close. For example, two cul-de-sac heads in a suburb may be within 100m of each other, but if the road network connecting these cul-de-sacs results in an origin-destination trip length of 2.5km, walking will probably fair poorly as a potential transport modal choice for most people, and even cycling may not be considered worthwhile for many, unless the trip has significant utility value that justifies the effort that would need to be expended.

Distance, however, is not the only criterion in considering street network permeability. Time is also critical to consider. A route may be physically direct, but if the trip path involves trying to cross an impossibly busy road or there are considerable delays with traffic signals at intersections phased to favour large traffic flows, this can be a significant disincentive to walking or cycling. Research is needed to determine at what point people decide a trip by walking or cycling (in terms of time cost expended) is not longer worthwhile, but from anecdotal evidence and personal experience, it seems reasonable to put the limit at around 30 minutes (which may be less in adverse weather conditions). If there are barriers such as busy roads that have to be crossed or delays at traffic signals, the effective range becomes dramatically compromised. For example, delays of 15 minutes in a trip for which one has budgeted 30 minutes for, halves the potential range of the trip. Transport planners therefore need to consider both the actual physical trip length and the period length of all potential trips that both pedestrians and cyclists are likely to make in planning local transport networks suitable for pedestrians and cyclists.

Street network permeability analytical transport planning tools

The concept of street network permeability (Allan, 2001) (sometimes referred to as "connectivity", as for example in Randall and Baetz's work (2001)) has the potential to provide some very useful planning tools. This section outlines distance, time and friction permeability indices for both cycling and walking. The main value of such tools is that urban designers and transport network planners can use them to analyse existing urban areas with regard to how local transport networks perform for local trips by pedestrians and cyclists. In new urban areas, the application of such tools allows an optimal local transport network to be created, at least from a functional point of view according to minimising excessive non-direct trip lengths or trip delays due to urban obstacles.

Walking and cycling distance permeability indices

The concept of urban grain (Lozano, 1990) is a useful basis for understanding what makes a local transport network permeable to pedestrians and cyclists. "Grain" refers to the size of blocks formed by the street network-a coarse grain is where the blocks are extremely large (ie 700m x 150m), whereas a very fine grain is where the blocks are small (eg 80m x 40m). A city with a very fine urban grain in its local transport network (not necessarily provided by roads geared for automobile traffic), allows a high degree of pedestrian permeability with very direct routes that may come close to the theoretical maximum. A coarse grain, by contrast, results in much less direct routes, particularly if the optimal direction for trips is across the diagonal of the blocks. However, permeability does come at a cost in land. If 16m wide streets are adopted with a fine urban grain (80m x 40m blocks) compared to 20m wide streets for the coarse urban grain (700m x 150m blocks), 46% of the urban environment is taken up with roads compared to 14%, respectively. Notwithstanding this, if higher densities are adopted and a graduated scale of street widths relative to traffic function is adopted, this drawback of fine grained streets can be minimised.

The permeability of a street network to pedestrians or cyclists could be expressed as a walking/cycling permeability distance index (PDI) (see equation 1) (Allan, 2001):

PDI = AD / DD………………………………………………………………(1)

Where DD=Direct distance between the origin and destination; AD = shortest practical distance through the network; and PDI = Walking/cycling permeability index

Note: The index should be applied separately for each mode to an area to reflect the differing modal travel performance characteristics.

A PDI of 1 would be the ideal situation that a planner would aim to achieve, which suggests a maximum degree of permeability that would allow cyclists or pedestrians to travel directly to their destination using the network. A PDI of 1.5 could be set as the limit of accessibility for a development (a PDI of 1.4 reflects the coordinate distances needed to reach the diagonal distance between two points within a grid network).

Walking and cycling time permeability indices

The permeability index could be represented in a slightly modified form to reflect the actual trip time, particularly if distance is not as much of a determining factor in the range that a person is prepared to walk or cycle. Equation (1) would be modified as in equation (2) and it would become either the Permeability Time Index (PTTI), which could be adapted for analysis of either walking or cycling modes (Allan, 2001):

PTTI = AT / DT……………………………………………………………(2)

Where AT=Actual travel time between the origin and destination (includes delays); DT = Direct travel time between the origin and destination; PTTI = Permeability Travel Time Index

Note: The index should be applied separately for each mode to an area to reflect the differing modal travel performance characteristics.

The analytical application of the PTTI would be similar to the PDI, except that it would offer a more realistic assessment of the impediments that pedestrians and cyclists would face in travel situations within urban environments. A higher PTTI of 2 for pedestrians and 1.7 for cyclists may be needed to indicate the actual types of trips pedestrians and cyclists face in urban environments, even in optimal situations. It should also be noted that where PDI=1.4, which is the most likely outcome for trips across the diagonal of an orthogonal street network, streets will need to be crossed or traffic signals waited on, which is where delays are often incurred. Hence, the PTTI is unlikely to be as low as the PDI unless the route is a dedicated pathway without any interruptions from cross streets.

A walking gait of 6km/h, a PTTI of 2 and an endurance of 20 minutes would mean that the maximum distance that could be covered would be 1km. This is determined by dividing the direct walking distance walking range over 20 minutes at 6km/h by the PTTI. For a cycling speed of 20km/h, a PTTI of 1.7 with an endurance of 20 minutes, using the same methodology, the maximum distance that could be covered would be 3.92km. Some caution is required in applying this methodology in that empirically based research of the walking behaviours of a statistically valid population in a variety of urban settings would be needed to discover how pedestrians and cyclists behave on average in terms of their travel performance. It should also be noted that while modest relief in terrain does not unduly affect a pedestrian's performance, it can have dramatic impacts on cyclists' travel performance, particularly if a cyclist has to climb a gradient continuously throughout the trip.

A further analytical tool can also be derived from the PDI and PTTI indices as shown with equations (1) and (2). A new index, the Permeability Friction Index (PFI) (equation 3) is useful for determining the extent to which a street network for a study area impedes either pedestrian or cycle travel through the network due to the need to cross streets or negotiate intersections (signalised or unsignalised):

PFI = PTTI / PDI………………………………………………………….(3)
Where PTTI = Permeability Travel Time Index, PDI = Permeability Distance Index and PFI = Permeability Friction Index
Note: The index should be applied separately for each mode to an area to reflect the differing modal travel performance characteristics.

Table A1 provides estimated values for the time impact of various frictional components in the urban street network (eg intersections), for pedestrians and cyclists. A PFI of 1 would be the ideal (although realistically virtually impossible to achieve), and a PFI exceeding 1.33 could be taken as the limit of acceptability for a network. However, pedestrian and cyclist tolerance thresholds to various values of the PFI would need to be determined through empirically derived research evidence. The dilemma for urban and transport planners is that while a fine grained street network is needed to maximise the performance of the PDI, a high PFI (and PTTI) may result, unless the network is exclusively restricted to a particular mode. Designing for large traffic volumes of cyclists is more problematical, since their speeds are high enough for conflict at intersections to require traffic management measures similar to those needed for motorised vehicles.

The potential for sustainable transport activity in suburban Adelaide-a comparison of three suburbs

Three suburbs were chosen for comparison: Norwood, a traditional 19th century inner city north-eastern suburb is within 1.25km of the Adelaide Central Business District (CBD); Mawson Lakes, a planned new suburb that commenced in the late 1990s on rehabilitated land is 14km north of Adelaide's CBD; and Golden Grove, a planned suburb which began in the mid 1980s on the metropolitan fringe of Adelaide, 20km northeast of Adelaide's CBD.

Norwood was chosen because its traditional 19th century fine grained grid street network approximates some of the ideals aspired to in the New Urbanism movement (Katz, 1994), with its orthogonal grid street network; the compactness of residential development; and the village nature of its shopping and community facilities clustered along Norwood Parade, a traditional "main street" environment.

Although Delfin was responsible for the urban design concepts for both Mawson Lakes and Golden Grove, their histories, design philosophies and characteristics are sufficiently different to merit comparison. The housing in both suburbs in terms of appearances and densities may be similar (ie dominated by conventional freestanding suburban cottages of 1-2 storeys on allotments ranging in size from 300m^2 up to 1200m^2), however, there are subtle differences. The dominant design theme with Golden Grove was to develop a balanced "perfect" suburban life with good access to locally provided schools, shops, open space, public transport and community facilities in an attractively landscaped setting. By contrast, the dominant design theme in Mawson Lakes was to achieve an integrated, environmentally sustainable community in which theoretically at least, to borrow Delfin's marketing mantra, one could "live, learn, work and play" without leaving the suburb. The suburb is adjacent to the University of South Australia's Mawson Lakes Campus and Technology Park (an industrial park catering to high technology companies). Both suburbs were designed to provide diversity of housing choice, including townhouses, courtyard style homes on 300m^2 allotments at one end of the spectrum to large, freestanding double storey homes on "traditional" sized allotments of 850m^2 or more. Mawson Lakes has been presented by Delfin as representing the cutting edge of residential design as demonstrated by features such as its reuse of grey water by all housing, compact allotments and narrow street widths. However, what sets it apart from most other residential developments, is its 71 hectares of artificial lakes, which paradoxically compromises many of the development's environmental objectives due to a dramatic lowering of gross residential density, the longer local trips required because of the barriers produced by the lakes and the excessive loss of water to due evaporation from the large areas of water surfaces in Adelaide's hot summers.

Table 2 provides comparative details of the study area characteristics in terms of the extent of walking and cycling, and residential and population densities. The data in table 2 suggests that high residential and population densities, together with close proximity to Adelaide's Central Business District may be important factors in influencing a local population's propensity to walk or cycle to work. Approximately 6-8 times the number of residents in Norwood walk or cycle to work compared to residents in Tea Tree Gully. Notwithstanding this, the proportion of people opting environmentally sustainable transport modes to work is exceedingly low. The ratio of cycling to walking is below the metropolitan average across all three case study areas (although only marginally less in Salisbury), and is perplexingly low in Norwood. The lack of popularity of cycling in Tea Tree Gully compared to walking as the sole mode of travel to work is understandable given the area's hilly terrain.

Table 2 Walking, cycling, development characteristics, street network and terrain compared for Norwood, Mawson Lakes, Golden Grove and metropolitan Adelaide

(source: Derived from data in ABS (2000))

Characteristic	City of Norwood & Kensington (proxy for suburb of Norwood)	City of Salisbury (proxy for suburb of Mawson Lakes)	City of Tea Tree Gully (Proxy for suburb of Golden Grove)	Metropolitan Adelaide
Walking 1	6.44%	1.38%	0.83%	2.16%
Cycling 2	1.89%	0.66%	0.32%	1.03%
Ratio of cycling/walking	0.29	0.47	0.39	0.48
Gross residential density (households/Ha)	10.73	2.41	9.65	2.09
Gross population density (Persons/Ha)	23.01	6.88	3.52	5.43
Household occupancy ratio	2.14 persons/dwg	2.86 persons/dwg	2.84 perons/dwg	2.60 persons/dwg
Street network pattern	Orthogonal fine grained grid with functional road hierarchy; generous street widths. Mature trees provide shade along most streets. Paved sidewalks on all streets. Cycle lanes on distributors and some sub-arterials.	Modified orthogonal fine grained grid with functional road hierarchy; minimal street widths. Cycle lanes on main distributors. Paved sidewalks. Connectivity for pedestrians provided with linear parks and connecting cul-de-sacs	Functional road hierarchy; cul-de-sac oriented. Streets follow terrain contours. Street widths minimal, but high speed distributors link residential precincts to centres. Paved sidewalks on distributors.. Connectivity for pedestrians provided with linear parks and connecting cul-de-sacs	Generally am orthogonal medium grained grid with functional road hierarchy. In hilly areas, roads follow contours, impeding street permeability.
Terrain	Minimal gradients	Level	Hilly with steep gradients common	Generally flat, but hilly in the northeast, east, southeast and far south
Distance from Adelaide Central Business District	1.25 km	14 km	20 km	___

NOTES:

1.Walking as the sole transport mode to work for employed persons.
2. Cycling as the sole transport mode to work for employed persons.

The Analysis

Tables 3, 4 and 5 provide comparisons of the permeability performance indices for Norwood, Mawson Lakes and Golden Grove. The indices have been determined for the most inaccessible extremes of the respective localities. An alternative analytical approach would be to map the permeability indices as contours around the key facilities in each suburb to highlight parts of the network that appear to have the potential to inhibit walking or cycling activity. Urban design solutions could then be applied to determine the impact on the permeability indices.

Some of the key findings to emerge from the application of the permeability indices in the three study areas are:

*Cyclists are much more significantly impeded by frictional components in the street network than are walkers. In Norwood, the PTTI ranged from 1.39 to 1.77 for walking versus a range of 1.51 to 3.08. The pattern is similar for both Mawson Lakes and Golden Grove, with PTTIs ranging from 1.32-1.97 (walking) compared with 1.81-4.69 (cycling) in Mawson Lakes and from 1.22-1.71 (walking) compared with 1.39-3.38 (cycling) for Golden Grove.
*The PDIs for walking and cycling were virtually identical for Norwood, which reflects this suburb's relatively fine grained orthogonal street grid pattern, presenting considerable advantages over Mawson Lakes and Golden Grove in making cycling have significant competitive advantage over walking. Unfortunately, the high PTTIs for Norwood somewhat negate this advantage.
*Mawson Lakes' permeability indices are on par with Norwood's for access to its still to be built town centre, but relatively poor for cycling if the road network is used (walking ranges from 1.32-1.76 while cycling ranges from 1.81-3.39). The disruption to the street fabric caused by the artificial lakes is the dominant reason for this. Cyclists could use the pedestrian pathways in theory, however, these are not built to accommodate the commuting speeds that bicycles can achieve.
*Mawson Lakes performs poorly with its permeability indices regarding residential access to Technology Park for both walking and cycling, which range from 1.60-1.97 for walking (PDI, PTTI) and from 1.75-4.69 for cycling (PDI, PTTI). However, the PFI is low indicating that although the route for cycling and walking is lengthy and not very direct, at least there are minimal frictional components in the street network to cause stress (PFI=1.03-1.23 for walking and 1.12-1.70 for walking). The logic of providing the lakes as a buffer between the residential and industrial areas makes sense in terms of aesthetics and the minimisation of externalities from industry located there, nevertheless, it does present a serious physical and psychological barrier to people choosing walking or cycling between the two areas.
*Mawson Lakes has abysmal access to public primary and high schools, both in terms of the actual distance required to reach them and the unsuitability of the route to pedestrians and cyclists. The connecting arterial road has a 100km/h speed limit and because the schools are on the opposite side of this road, a long circuitous journey is required to reach them. Notwithstanding this, theoretically cyclists could manage this trip since it is on level ground (up to 8km), although it would not be recommended from a road safety perspective. Realistically, the analysis in table 4 demonstrates that walking and cycling are highly dubious travel mode options to reach these destinations.
*Golden Grove provides reasonably direct walking distances as indicated by PDIs in the 1.07-1.50 range. This compares with PDIs in the 1.07-1.98 range. This is achieved through the use of pedestrian paths along linear parks and between cul-de-sac heads, or wherever necessary to ensure that walking is as direct as possible, even if maximum walking distances approach 4km. As with Mawson Lakes, the pathway network could be used by cyclists, but because it's not designed for high speed cycling, it is more appropriate to relegate cycle trips to the road network.
*Golden Grove's road network follows the contours to some extent to accommodate high speed roads (zoned for 60km/h for local distributors and 70km/h for the sub-arterial roads), but little is done to minimise the daunting relief in the terrain, with 10% gradients and changes in altitude of 30m or more

not uncommon. With less than direct paths through the street network, the hilly topography and high frictional components in the street network, it is perhaps not surprising that cyclists are a rare sight in Golden Grove. The suburb is bisected by two high speed 70km/h sub-arterial roads which while providing rapid ingress and egress to the suburb for motorised transport, have far too high a speed differential with cyclists to allow them safe passage.

Table 3 Permeability performance indices for Norwood

	Magill Rd/Fullarton Rd (North west quadrant of suburb)	**Fullarton Rd/Kensington Rd** (South west quadrant of suburb)	**Kensington Rd/Portrush Rd** (South east quadrant of suburb)	**Magill Rd/Portrush Rd** (North east quadrant of suburb)
Norwood Public Primary School				
Direct Distance	825m	1210m	1200m	915m
PDI (walking)	1.33	1.40	1.40	1.42
PDI (cycling)	1.33	1.40	1.40	1.42
PTTI (walking)	1.52	1.71	1.77	1.75
PTTI (cycling)	1.74	2.16	2.71	1.51
PFI (walking)	1.14	1.22	1.26	1.23
PFI (cycling)	1.31	1.54	1.94	1.06
Norwood Town Hall	**(1)**			
Direct Distance	1350m	1400m	800m	775m
PDI (walking)	1.37	1.36	1.31	1.35
PDI (cycling)	1.37	1.36	1.31	1.35
PTTI (walking)	1.63	1.64	1.59	1.71
PTTI (cycling)	2.05	2.25	2.25	1.90
PFI (walking)	1.19	1.21	1.21	1.27
PFI (cycling)	1.50	1.65	1.72	1.41
Marryatville Public High School				
Direct Distance	2450m	2000m	400m	1420m
PDI (walking)	1.35	1.00	1.00	1.20
PDI (cycling)	1.35	1.00	1.00	1.20
PTTI (walking)	1.75	1.39	1.75	1.76
PTTI (cycling)	2.67	1.83	3.08	2.55
PFI (walking)	1.30	1.39	1.75	1.47
PFI (cycling)	1.98	1.83	3.08	2.13

NOTES:

PDI=Permeability Distance Index; PTTI=Permeability Travel Time Index; PFI=Permeability Friction Index
Streets represent extreme edges (ie least accessible) parts of the suburb.

1. Norwood Town Hall is the heart of the “main street” shopping district and the focus for public transport routes serving the suburb.
2. Average speeds of 6km/h for walking and 20km/h for cycling assumed. Gradient for cyclists is assumed not to affect their speed because the effect is cancelled out on the return trip providing the cyclist travels at the maximum drag limited speed on downgrades. See table A1 for assumptions about how travel time is degraded by a street network’s frictional characteristics.

Table 4 Permeability performance indices for Mawson Lakes

	Mallard Crescent (Western edge of suburb)	**Glen Court** (Northern edge of suburb)	**Windemere Crescent** (Southern edge of suburb)	**McKinlay Court** (Eastern edge of suburb)
Mawson Lakes Proposed Town Centre				
Direct Distance	1235m	680m	790m	300m
PDI (walking)	1.20	1.26	1.23	1.60
PDI (cycling)	1.20	1.26	1.44	2.00
PTTI (walking)	1.32	1.38	1.42	1.76
PTTI (cycling)	1.81	1.89	1.97	3.39
PFI (walking)	1.10	1.10	1.15	1.10
PFI (cycling)	1.51	1.37	1.37	1.70
Public Schools- Para Hills West Primary; Para Hills High	**(1)**			
Direct Distance	4650m	3940m	4200m	3440m
PDI (walking)	1.72	1.87	1.73	1.86
PDI (cycling)	1.72	1.87	1.73	2.07
PTTI (walking)	_	_	_	_
PTTI (cycling)	2.17	2.29	2.22	2.55
PFI (walking)	_	_	_	_
PFI (cycling)	1.26	1.22	1.28	1.23
Technology Park				
Direct Distance	1280m	1540m	800m	800m
PDI (walking)	1.72	1.60	1.80	1.85
PDI (cycling)	2.55	1.71	3.65	2.98
PTTI (walking)	1.80	1.66	1.86	1.97
PTTI (cycling)	3.46	2.26	4.69	3.81
PFI (walking)	1.05	1.04	1.03	1.06
PFI (cycling)	1.36	1.32	1.28	1.28

NOTES:

PDI=Permeability Distance Index; PTTI=Permeability Travel Time Index; PFI=Permeability Friction Index

Streets represent extreme edges (ie least accessible) parts of the suburb.

1. There is a private school (Endeavour College) within Mawson Lakes, however, Para Hills West is where the nearest public primary and high schools are located.
2. Public transport routes are currently focused on the University of South Australia's Mawson Lakes Campus, 400m east of the town centre and Technology Park.
3. Average speeds of 6km/h for walking and 20km/h for cycling assumed. Gradient for cyclists is assumed not to affect their speed because the effect is cancelled out on the return trip providing the cyclist travels at the maximum drag limited speed on downgrades. See table A1 for assumptions about how travel time is degraded by a street network's frictional characteristics.

Table 5 Permeability performance indices for Golden Grove

	Sherbrook Court (North eastern edge of suburb)	**Valour Court** (Northern edge of suburb)	**Ranelagh Court** (North eastern corner of suburb)	**Seville Place** (Eastern edge of suburb)	**Laurina Court** (Southern corner of suburb)
Golden Grove Village (1)					
Direct Distance	600m	910m	3140m	1940m	1020m
PDI (walking)	1.27	1.19	1.07	1.22	1.27
PDI (cycling)	1.27	1.80	1.07	1.22	1.98
PTTI (walking)	1.64	1.49	1.22	1.42	1.52
PTTI (cycling)	2.10	2.53	1.39	1.43	3.38
PFI (walking)	1.29	1.25	1.14	1.16	1.20
PFI (cycling)	1.65	1.41	1.30	1.17	1.71
Golden Grove Public High School (2)					
Direct Distance	1300m	1400m	3460m	2160m	970m
PDI (walking)	1.09	1.40	1.14	1.18	1.49
PDI (cycling)	1.09	1.77	1.14	1.18	1.81
PTTI (walking)	1.34	1.60	1.23	1.30	1.61
PTTI (cycling)	1.73	2.54	1.48	1.53	2.60
PFI (walking)	1.23	1.14	1.08	1.10	1.08
PFI (cycling)	1.59	1.44	1.30	1.18	1.44
Golden Grove Public Primary School					
Direct Distance	2080m	1080m	2000m	660m	930m
PDI (walking)	1.29	1.39	1.42	1.50	1.35
PDI (cycling)	1.45	1.67	1.42	1.50	1.41
PTTI (walking)	1.50	1.71	1.51	1.55	1.49
PTTI (cycling)	2.47	2.37	1.59	2.24	2.40
PFI (walking)	1.16	1.23	1.06	1.03	1.10
PFI (cycling)	1.70	1.42	1.12	1.49	1.61

NOTES:

PDI=Permeability Distance Index; PTTI=Permeability Travel Time Index; PFI=Permeability Friction Index
Streets represent extreme edges (ie least accessible) parts of the suburb.

1. The Golden Grove Village has a public transport interchange in addition to a sub-regional shopping centre.
2. Community facilities are located adjacent to the High Schools Precinct.
3. Average speeds of 6km/h for walking and 20km/h for cycling assumed. Gradient for cyclists is assumed not to affect their speed because the effect is cancelled out on the return trip providing the cyclist travels at the maximum drag limited speed on downgrades. See table A1 for assumptions about how travel time is degraded by a street network's frictional characteristics.

Conclusions and policy implications

The development of the various indices described in this paper provide a range of useful analytical tools for analysing the travel performance and the planning of local transport networks suitable for pedestrians and cyclists in new and existing urban areas. Traditional neighbourhood areas with fine grained orthogonal street patterns and high residential densities have the best travel performance for walking, although newer suburbs such as Mawson Lakes and Golden Grove are not far behind. All three suburbs do not perform particularly well with regard to catering to cyclists in terms of providing rapid, unobstructed routes to key suburban facilities such as local shopping centres, schools, community centres and public transit interchanges.

It would seem that design responses with respect to these case studies are needed that allow cycling to be a more competitive mode than this research currently suggests it is (and which is confirmed by the popularity of walking over cycling in the journey to work in the 1996 ABS Census). The use of these indices indicates that providing a direct journey with as minimal disruptions as possible is absolutely critical in residential subdivision design, particularly if direct origin/destination lengths are already at the limit of most people's endurance of how long they are prepared to walk or cycle. Where paths are provided, many are not up to the standard to allow commuter cycling to be safely undertaken in terms of geometric road standards and lighting. Golden Grove is probably hampered too much by its hilly terrain and large distances from employment centres for commuting cycling to ever be popular, however, in Mawson Lakes, critical cycling network links could be retrofitted that minimise this problem. It would seem that not much can be done to improve the situation for cyclists in Norwood. Nevertheless, further research is needed to determine why cycling is much less popular than walking in the journey to work (although it is 85% more popular than in Adelaide in general).

In Mawson Lakes and Golden Grove, walking is still feasible for all but the most distant residences, however, in the examples explored in this research, it could be argued that most are at or beyond the threshold when many would choose to drive rather than cycle or walk. Moreover, Golden Grove's high speed sub-arterial roads effectively sever the suburb into quadrants, providing minimal opportunities for pedestrians or cyclists to cross safely. Additional crossing points (possibly grade separated), should be provided, if improved street network permeability is to be achieved in Golden Grove. Mawson Lakes is more problematical, since its lakes present a barrier to direct access with Technology Park. It may be worth considering a bridge or causeway across the lake that would improve access, not only for pedestrians but also for cyclists.

All three case studies are examples of "best practice" in metropolitan Adelaide in terms of balanced residential suburban design. The transport network design bias does seem to favour a hierarchy of priority with private cars at the top of that list, followed by public buses, pedestrians and lastly cyclists. If policy makers are serious about favouring more sustainable transport modes, then urban transport planning has to give maximum priority to cyclists and pedestrians. The use of the permeability indices described in this paper would assist in understanding how the permeability of the road network constrains pedestrian and cycling activity in urban areas. It is by far from being the only consideration, since land use decisions (including the location of facilities), urban design and community attitudes/behaviour and the relative attractiveness of other transport modes are also potentially significant. Nevertheless, appropriate design of the network, apart from the allocation of land uses, is one of the most fundamental tasks in any transport planning task, particularly if policymakers are trying to encourage a shift in the community towards sustainable modes of transport such as walking and cycling.

Appendices

Table A1 Friction components used in determining the PTTI

Time delays-walking	Time (seconds)
Crossing of a minor side street	15
Crossing a roundabout	30
Crossing a local street or suburban distributor	30
Crossing a sub-arterial road	60
Crossing an arterial road	90
Crossing a signalised pedestrian crossing	60
Crossing a signalised intersection with no turn arrows	60 (each direction)
Crossing a signalised intersection with turn arrows	90 (each direction)
Time delays-cycling	
Crossing of side streets on through road	No delay
Roundabouts	30
Unobstructed left turn into intersection	15
Crossing intersection of a minor local street	30
Delay due to a signalised pedestrian crossing	60
Crossing a signalised intersection with no turn arrows	60 (each direction)
Crossing a signalised intersection with turn arrows	90 (each direction)

Note: Each origin destination trip link is analysed to determine the aggregate delays which are then added to the minimum actual time required to complete a trip.
Delays are estimates only.
Signals-traffic lights.

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