INFRASTRUCTURE AND TRANSPORT MINISTERS

M4 Active travel — Background Report PUBLIC CONSULTATION DRAFT

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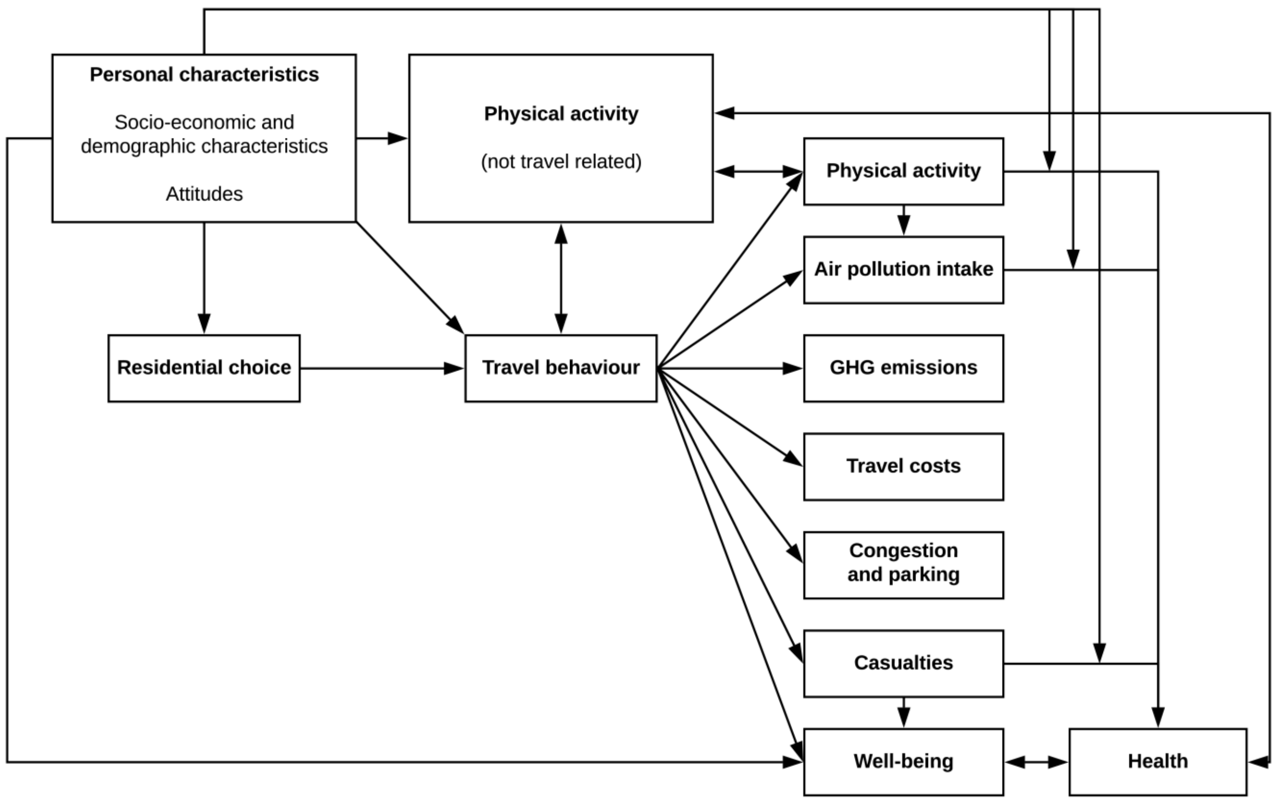
1. Introduction

Part M4 of the ATAP Guidelines provides guidance on the assessment on active travel initiatives. This report is a Background Report that supports the revised M4 draft, presenting supporting research and technical aspects. It also provides an information resource for practitioners involved in the planning and assessment of active travel. In cross-referencing between the reports, the Background Report is referred to as M4-BR.

A number of impacts are associated with active travel. Some of these impacts are related to the activity itself (e.g. health benefits due to physical activity), and others related to replacing other forms of transport (e.g. reduced environmental impacts from less car use). Figure 1 provides a conceptual framework showing the different impacts of active travel. A range of personal characteristics, such as demographics and attitudes impact on residential location and travel behaviour choices (Heinen et al., 2011), which in turn influence whether people choose active modes. The range of impacts of those choices are shown at the right-hand side of Figure 1 and include impacts on health and wellbeing, travel time, congestion, safety and the environment.

Figure 1 Active transport impacts - conceptual relationships



Source: Adapted from van Wee and Ettema (2016) with non-health impacts added.

2. Active travel patterns

This chapter provides an overview of Australian active travel patterns based on the available data sources, and provides a summary of those data sources. An excellent overview of active travel patterns can be found in DIT (2012, 2013), with this chapter providing an update of some of the data therein. The M4 draft Chapter 7 briefly discusses the effects of the COVID-19 pandemic on active travel. As further research is published on the impacts of COVID-19, it will be reflected in M4 and/or M4-BR.

2.1 Travel datasets

There are a number of datasets providing information related to walking and cycling. Table 1 provides a summary of known travel datasets in Australia that include active travel.

Standardised methods for collecting travel data vary from state to state in Australia. The only consistent, nationally collected data on travel is the ABS Census, and while this is useful there are some important limitations. Firstly, it only collects data on the Journey to Work, which only constitutes around 20% of all trips (Transport for Victoria, 2017). Secondly, it is a snapshot of one day in August, every five years. From an active travel perspective, this has a number of drawbacks. For southern states in particular, it is a winter sample, and colder, wetter weather is known to depress cycling rates (Ahmed et al., 2010).

Van Wee (2021) highlights that technology is now emerging that might provide fresh opportunities to use ‘big data’ to enhance our understanding of active travel participation.

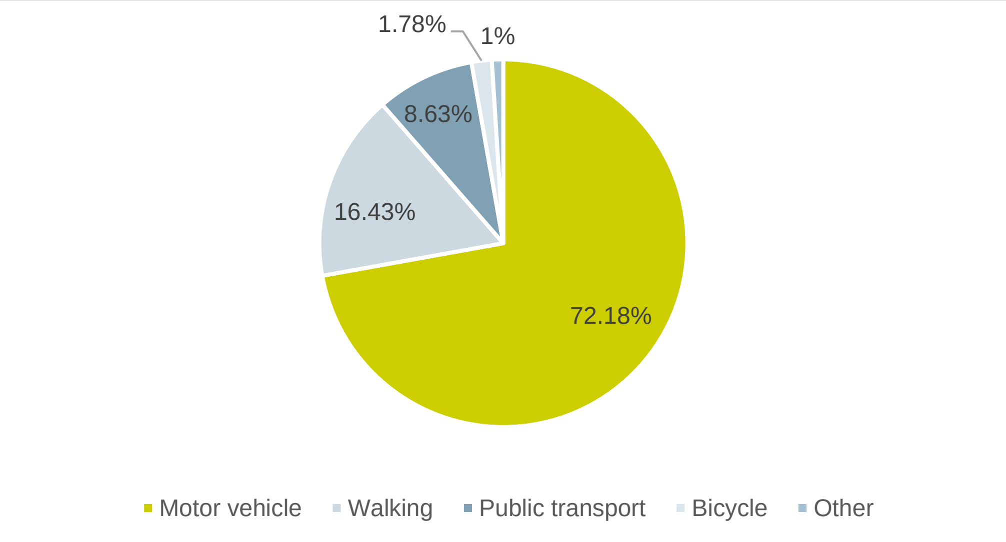
Other datasets include:

- Strava Metro (https://metro.strava.com/)
- Bicycle network (https://www.bicyclenetwork.com.au/our-services/transport-surveys-and-data/data-dashboard/)
- Data Vic (https://discover.data.vic.gov.au/dataset/bicycle-volume-and-speed)
- Queensland Government (https://www.data.qld.gov.au/dataset/tmr-bicycle-counts)
- Open Data (https://data.sa.gov.au/data/dataset/bike-cordon-counts)
- Data SA (https://data.sa.gov.au/data/dataset/bike-cordon-counts)
- Data WA (https://catalogue.data.wa.gov.au/dataset/?theme=Transport&organization=city-of-perth&tags=bicycle).

2.2 Mode share

Figure 2 provides mode share data across all trip purposes using the Victorian VISTA dataset. It shows that around 18% of all trips are by active travel: 16% walking, and 2% cycling. By far the largest number of trips are undertaken by motor vehicle (72%). In contrast, when comparing modes on the basis of aggregate trip-kilometres (see later), active travels mode share is much smaller, due to the smaller trip lengths involved compared with motorised travel. This highlights in particular the importance of walking for local neighbourhood journeys.

Figure 2 Mode share by number of trips, All purpose



Source: (Victorian Department of Transport, 2018)

Table 1 Summary of travel datasets in Australia

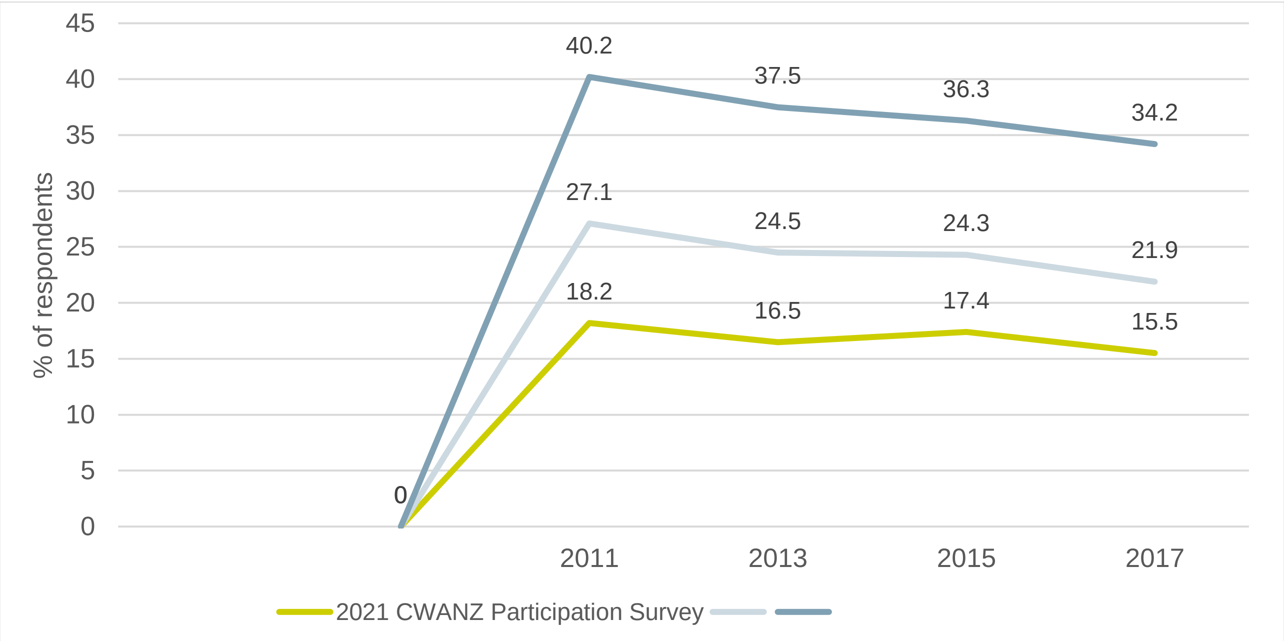
Jurisdiction	Survey name	Link	Method of collection	Journey types/additional notes
Australia	Census	https://www.abs.gov.au/census	User-input surveys	Mode of travel (including multi-modal travel), origin and destination of work, distance travelled to work (direct and network distance), Car ownership Conducted every five years, last in 2016
	National Cycling Participation Survey (NCPS)	https://austroads.com.au/network-operations/active-travel/cycling-participation	Telephone survey	A measure of participation, not travel. Year last conducted: 2021
NSW	Household Travel Survey (HTS)	https://www.transport.nsw.gov.au/data-and-research/passenger-travel/surveys/household-travel-survey-hts	Face-to-face interview	Area/s covered: Sydney GCCSA, Illawarra region, Hunter region Year last conducted: continuous since 1997
VIC	Victorian Integrated Survey of Travel and Activity (VISTA)	https://transport.vic.gov.au/about/data-and-research/vista	Travel diary	Areas covered: Metropolitan Melbourne and Greater Geelong Year last conducted: 2018
SA	Metropolitan Adelaide Household Travel Survey (AHTS)	Data not available online given that these surveys were conducted in 1986, 1999	Face-to-face interview	Area/s covered: Metropolitan Adelaide Year last conducted: 1999
ACT	Australian Capital Territory and Queanbeyan-Palerang (ACT-QPRC) Household Travel Survey	https://www.transport.act.gov.au/about-us/planning-for-the-future/household-travel-survey	Travel diary	Area/s covered: Australian Capital Territory and Queanbeyan-Palerang Regional Council area Year last conducted: 2017

Jurisdiction	Survey name	Link	Method of collection	Journey types/additional notes
NT	Darwin Region Travel Survey 2003	Not online	N.A.	Year last conducted: 2003
TAS	Greater Hobart Household Travel Survey	2019 data not released yet. About the survey: https://www.transport.tas.gov.au/roads_and_traffic_management/about_state_roads/plans_and_strategies/small_tiles/2019_greater_hobart_household_travel_survey	Travel survey	Area/s covered: Greater Hobart Year last conducted: 2019
QLD	SE QLD Household Travel Survey	https://www.tmr.qld.gov.au/Community-and-environment/Research-and-education/Queensland-Travel-Survey	Travel survey	Area/s covered: Brisbane, Gold Coast, Ipswich, Logan, Moreton Bay, Noosa, Redland, Sunshine Coast council areas Year last conducted: 2018

2.3 Participation

According to the 2021 National Cycling Participation Survey (CWANZ 2021), 82% of Australians that responded to a telephone based survey did *not* cycle in the week prior to being surveyed. As shown in Figure 3, the trend for those cycling in the previous week, month and year were all trending downward until 2019, indicating that fewer Australians, proportionally, were engaging in cycling. This contrasts with the goal set out in the 2011-2016 National Cycling Strategy to *'double the number of people cycling in Australia over the next five years'.* It also shows and upswing in 2021, which is likely to be associated with the COVID-19 pandemic (see M4, chapter 7).

Figure 3 Frequency of cycle participation



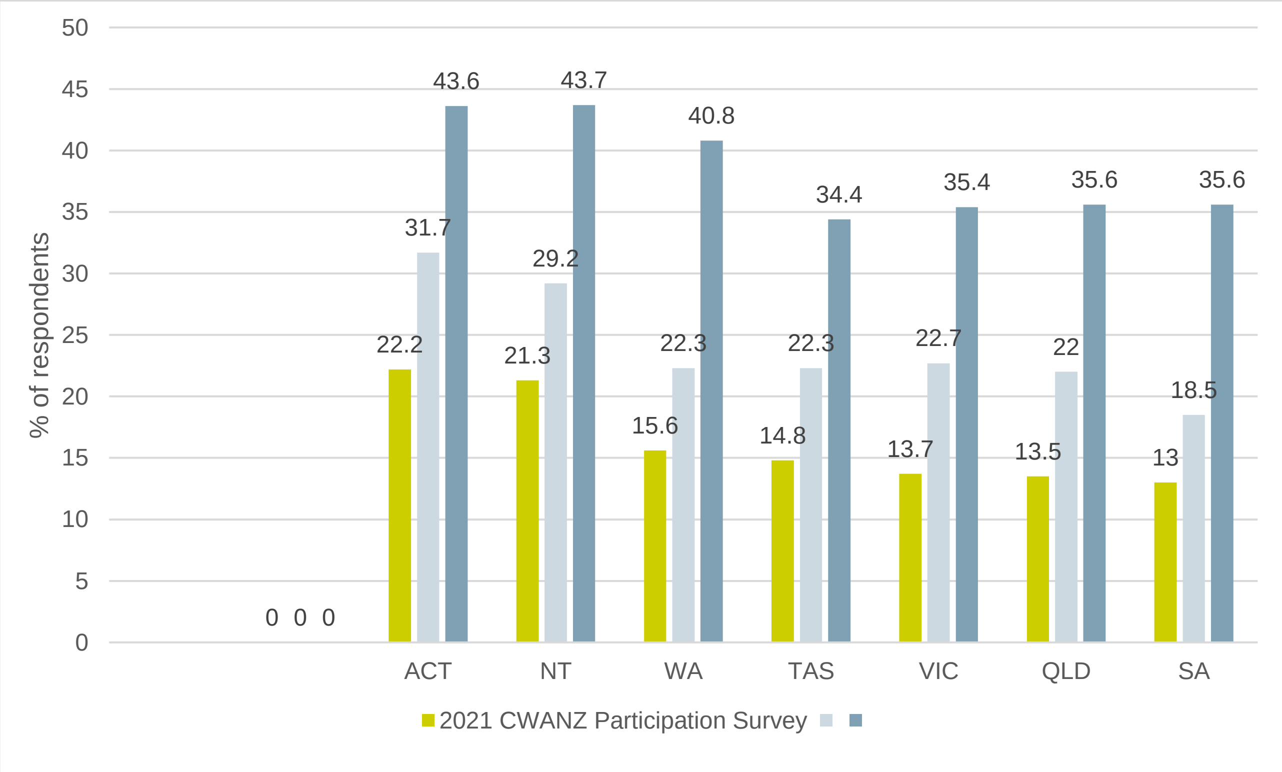
Source: CWANZ (2021)

Publication of national trip frequency estimates for walking only commenced in 2021 (CWANZ 2021), showing that, on average:

- Australians walked for at least 5 minutes on 5.3 days over the week surveyed
- The median total hours walked per week was 3.5 hours.

Figure 4, based on the same national participation survey, provides a state/territory breakdown on cycling participation levels. This shows that the Australian Capital Territory and the Northern Territory have the highest levels of cycling participation, across all three categories of frequency (last week, last month, last year). Interestingly, these jurisdictions also invest the most in active transport infrastructure (Pojani et al., 2018). New South Wales has the lowest levels of cycling participation according to the national participation survey.

Figure 4 Cycling frequency - state by state



Source: CWANZ (2021)

2.4 Trip purpose

Active travel is used for both recreation (e.g. exercise) and transport (journey to work, trips to shops, to visit friends or as part of work) trip purposes, although recreation is the most common (Australian Bicycle Council 2014, p.44, CWANZ 2021). This trip purpose outweighs cycling for transport purposes by a factor of nearly three to one[1]. Surveys of walkers and cyclists conducted in Brisbane in 2011 (SKM/PwC 2011, pp.78-79) found that on major off-road pedestrian/cycle corridors, transport trips were generally dominant on weekdays and recreational trips dominated on weekends. Estimates for Sydney contained in Aecom (2010, p.22) suggest that work trips by bicycle make up about 8% of all cycle trips. Similarly, the Victorian VISTA survey suggests that recreation is the most common cycling trip purpose in Greater Melbourne, with 30% of all trips. This is followed by commutes (26%), with education and social trips generating 12% of trips each (Transport for Victoria, 2017).

2.5 Trip length across modes

Table 2 shows the average trip distance for different trip purposes and travel modes from the all-purpose travel diary data collected as part of the Victorian VISTA survey (Transport for Victoria, 2017). This highlights the journey length differences between travel modes. It shows walking distances are very similar across trip purposes. On the other hand, cycling distance does vary considerably across purpose, with work trips typically much longer (6.7km) than non-work trips (~2 – 4km).

Table 2 Average Distance (km) by Mode and Trip Purpose, VISTA

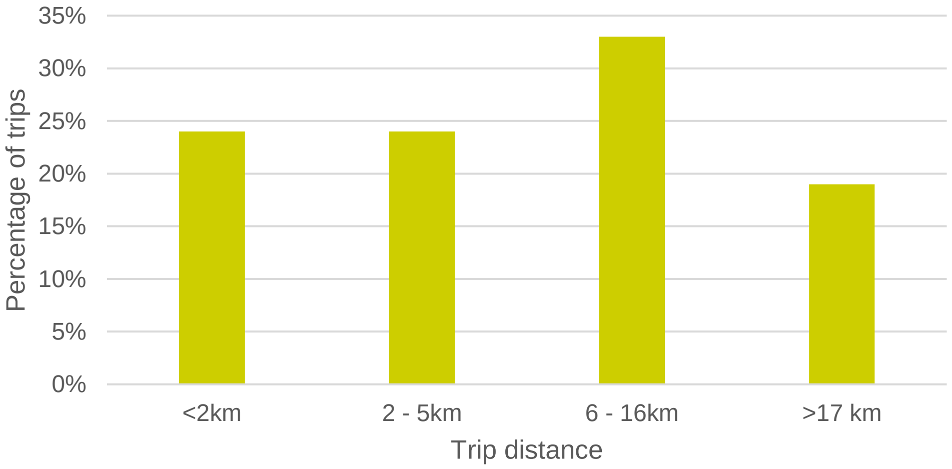
Mode	Accompany Someone	Buy Something	Education	Personal Business	Pick-up or Deliver Something	Pick-up or Drop-off Someone	Recreational	Social	Work Related	All Trips
Bicycle	2.2	2.8	2.5	4.2	3.3	1.8	5.1	5.3	6.7	4.8
Bus	7.1	6.6	10.9	18.3	11.8	9.9	11.6	15.7	11.7	10.7
Other	3.6	3.7	7.7	9.7	7.1	7.2	9.2	13.9	16.7	12.5
Train	18.6	19.3	20.5	26.5	20.7	24.0	27.3	21.7	22.4	22.3
Tram	4.0	5.3	8.0	7.8	5.6	7.1	6.3	5.4	7.2	6.7
Vehicle Driver	9.0	5.9	12.3	12.3	8.8	6.9	9.4	12.8	16.1	11.0
Vehicle Passenger	6.7	7.4	4.8	16.4	11.5	7.9	11.4	13.8	14.3	10.1
Walking	0.9	0.8	1.1	1.2	0.9	0.8	1.3	0.9	1.0	1.1

Source: VISTA survey

[1] However, this is not the same as saying that recreational trips make up 66% of all cycling trips, because recreational cycling trip frequency might be lower than transport trip frequency.

Figure 5 provides for Brisbane a trip distance profile across all modes for all weekday trips. This shows that almost 50% of trips are under 5km, indicating the potential trips that might be considered for active travel. Given that the overwhelming majority of journeys in Brisbane are by car (Zapata-Diomedi et al., 2017), Figure 5 offers an indication of the size of the opportunity to convert some of the short distance trips to active travel modes. Trips under 2km have previously been considered as being suitable for walking (DIT 2013). The NZ *Monetised benefits and costs manual* (NZTA 2020) identify that the average cycle trip, according to the New Zealand Household Travel Survey is estimated to be 3km, which is generally consistent with the household travel data provided for Victoria, shown in Table 2.

Figure 5 Trip distance, all purpose, all mode, weekday (Brisbane)



Source: Cited in Zapata-Diomedi et al. (2017)

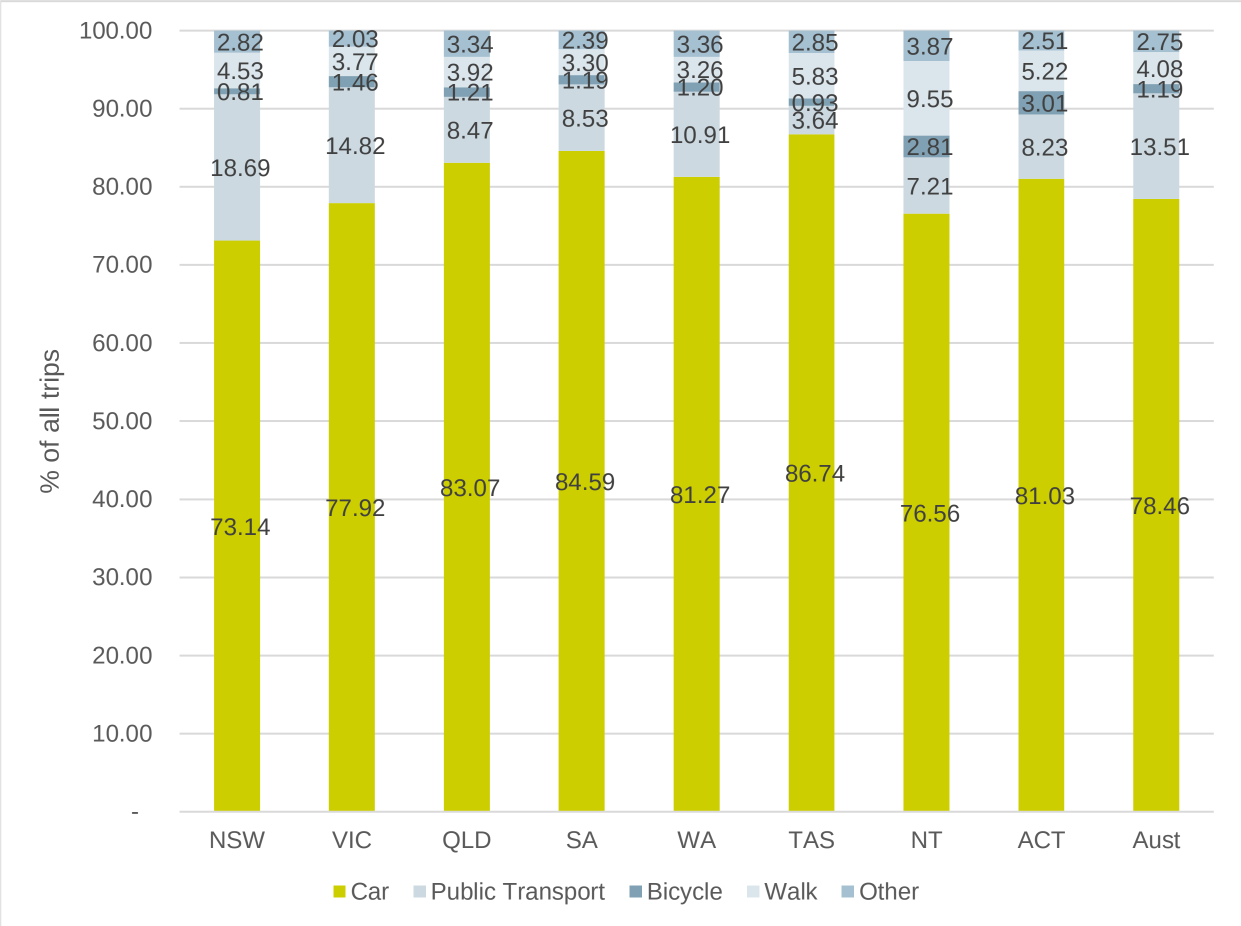
2.6 Journey to work — mode share

The remainder of the discussion in this appendix relates to journey to work travel. As discussed earlier, it is the most reliable sources of data on active travel and relates only to *journey to work.* While this is an important journey type, it typically only constitutes around 20% of trips. It plays a key role in assessing operations in peak hours.

Figure 6 provides journey to work mode share results for the different states and territories. It shows that the overwhelming majority of journey to work travel is by car, generally followed by public transport. The exception to this is Tasmania and the Northern Territory, where walking is the second most common method of transport for work. Walking ranges between 3.3% and 9.6% of trips to work. Cycling is less common than walking for commute journeys, ranging from just under 1% (0.8%) in New South Wales, to 3% in the ACT. It is important to recognise that almost all trips will include at least a component of walking, even if it is just from the car park to the final destination. In this sense, even when the data collection method does not capture it, most travellers are pedestrians at some point of the journey.

According to international comparisons in Litman (2014, p.7), Australian levels of active travel are a fraction of those in European countries and among the lowest in the developed world. By way of contrast, around 26% of trips in the Netherlands are made by bicycle, rising to over 40% in some central areas of Dutch cities (Fishman, 2016). Rates of cycling in the US are broadly similar to Australia (Buehler and Pucher, 2021). According to national cycling participation surveys, and highlighted earlier, Australian rates of cycling have been progressively reducing over recent years (Austroads, 2019).

Figure 6 Main mode of travel to work, Australia 2016

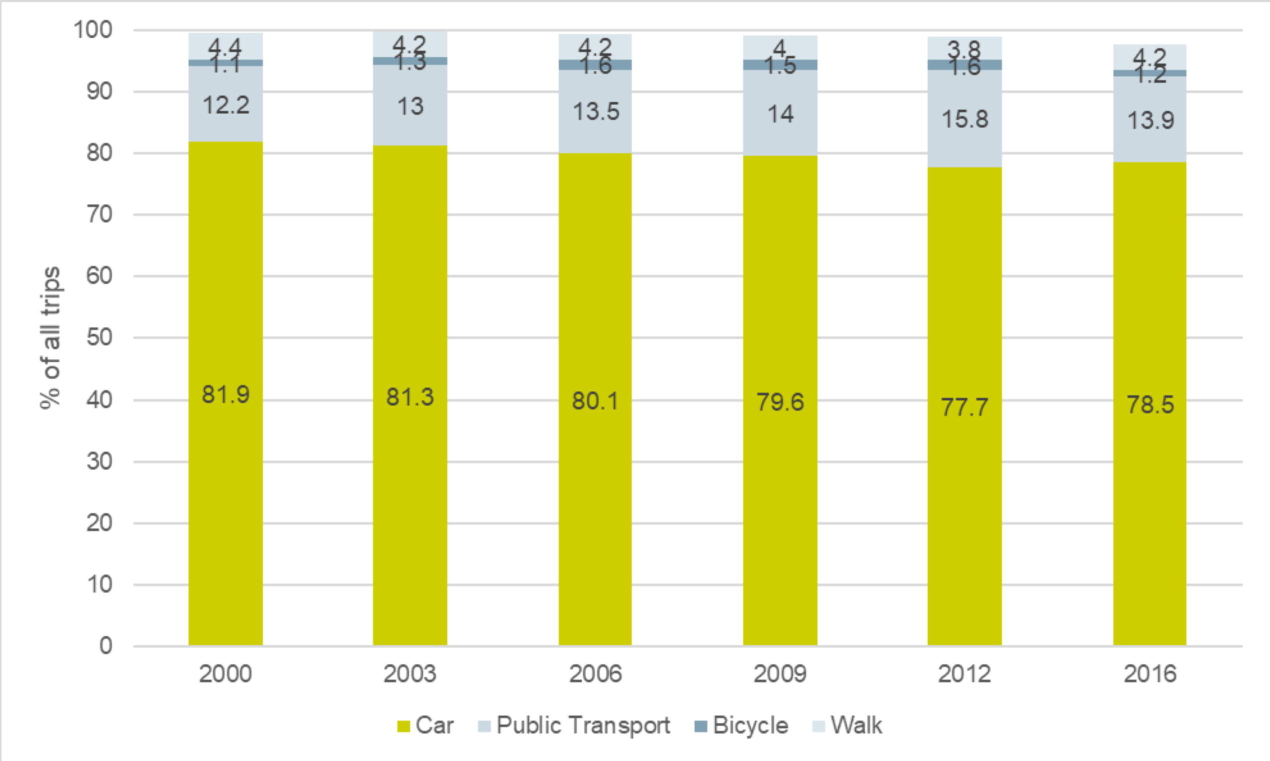


Source: Australian Bureau of Statistics (2017)

Figure 7 provides an overview of the changes over time in the proportion of trips to work by main mode. This shows that between 2000 and 2016, cycling trips as a proportion of all adult work or study trips increased from 1.1% to 1.2%, though the peak years between this period were 2006 and 2012. Walking dropped from 4.4% of all trips to work in 2000, to 4.2% in 2016.

Walking to work was highest in 2000, at 4.4%, and by 2016, accounted for 4.2% of trips to work. Overall, 5.4% of all trips in the 2016 Census were by active travel (walking or cycling). Public transport journeys have risen during this period, from 12.2% to 13.9%.

Figure 7 Main mode of travel to work or study, 2000 – 2016

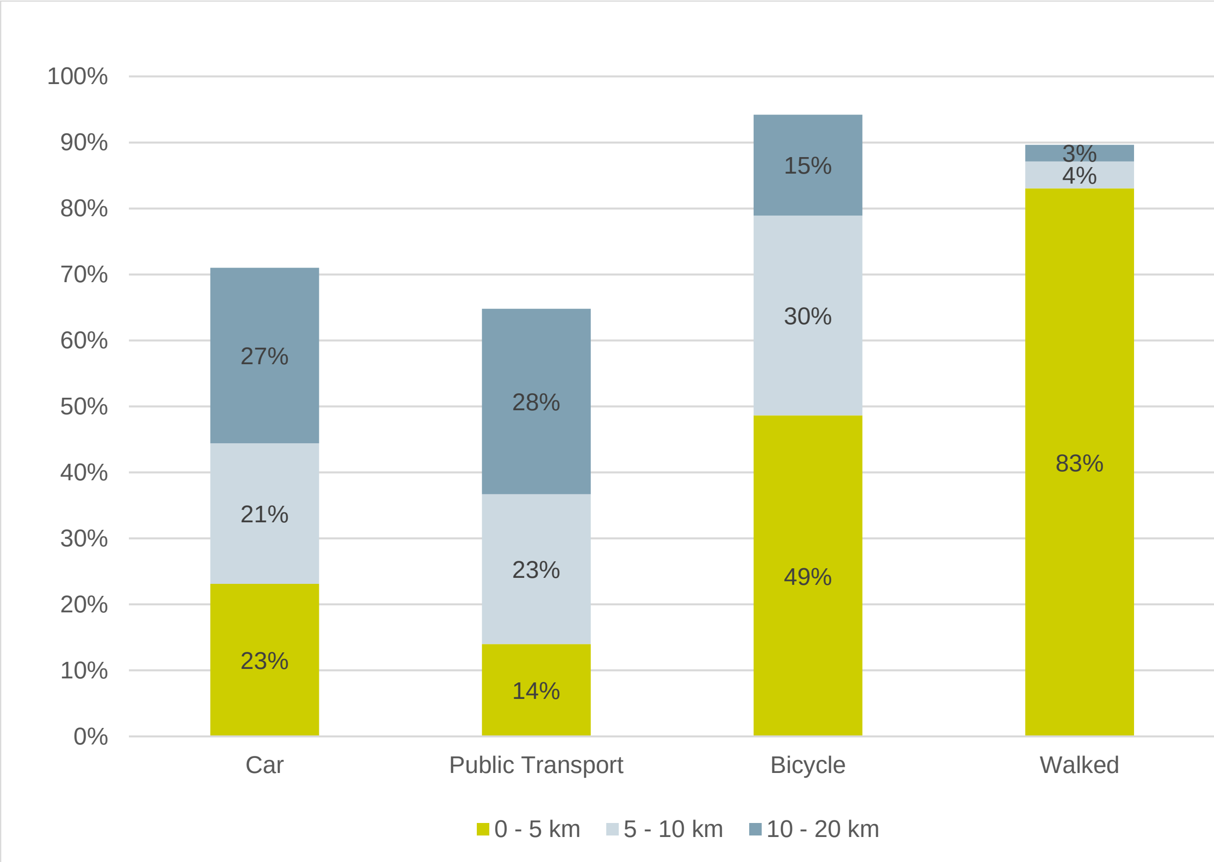


Source: ATAP Guidelines (2016) and Australian Bureau of Statistics (2017)

2.7 Journey to work — trip length

Journey to work trip length for different modes of transport is shown in Figure 8. This highlights a number of important findings relevant to the assessment of active transport. It indicates that, for trips to work, almost a quarter (23%) of car trips are under 5km, and almost half (44%) of car trips are less than 10km. This serves to highlight that although just under 30% of journeys to work by car are over 20km (and therefore not easily transferred to active travel), there is still considerable potential to grow the proportion of trips by active modes by focusing on short and medium car trips. Figure 8also shows that the majority of current walking and cycling commuting trips are less than 5 km (96% and 52% respectively).

Figure 8 Proportion of distance travelled by mode — journey to work trips

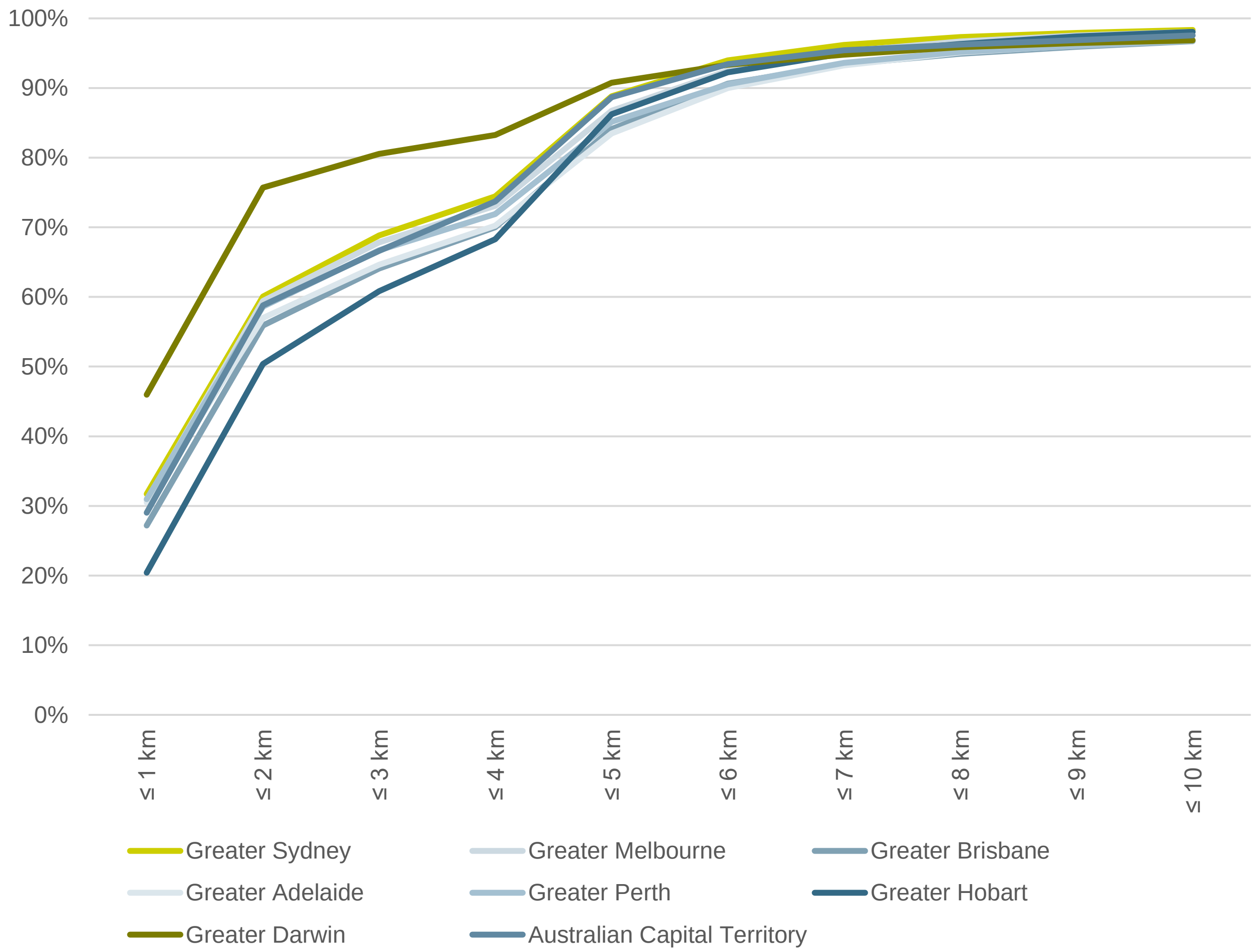


Source: Australian Bureau of Statistics (2017)

Journey to work – walking, cumulative distances

Figure 9 shows the cumulative distance to work for walking, in each Australian capital city. On average, 59% of walking trips are 2km or less, with 87% of trips less than 5km. The NZ *Monetised benefits and costs manual* (NZTA 2020) recommend 1km for the average pedestrian trip length.

Figure 9 Cumulative distance to work — walking

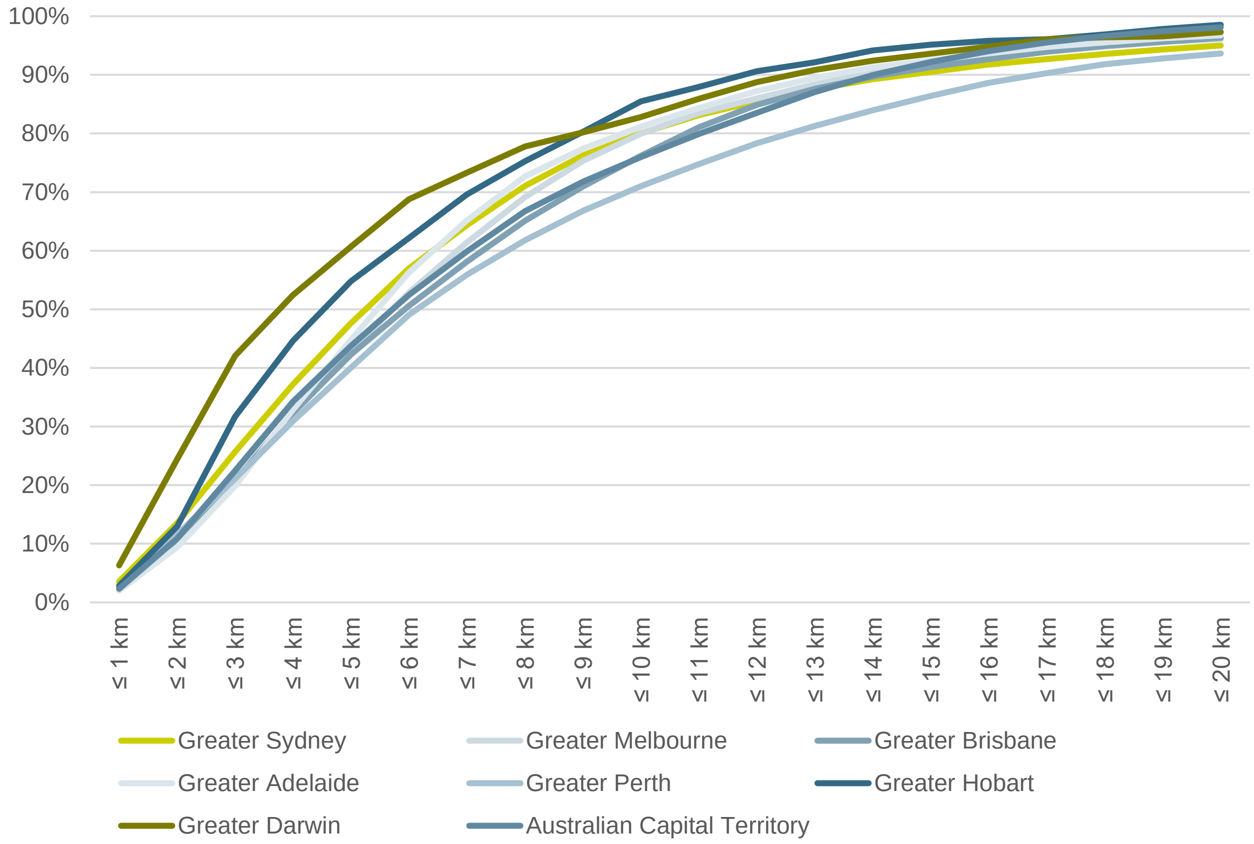


Source: Australian Bureau of Statistics (2017)

Journey to work – cycling, cumulative distances

Figure 10 shows the cumulative distance people cycle to work in Australian capital cities. It shows that around 50% of trips are within a 4 – 5km band and that about 80% of journey are under ~10km. One might expect that as the adoption of e-bikes increase in future years, the length of cycle trips may also grow, as e-bike trips are generally longer than trips on conventional bicycles (Fyhri and Fearnley, 2015, Castro et al., 2019, Fyhri and Beate Sundfør, 2020).

Figure 10 Cumulative distance to work – cycling

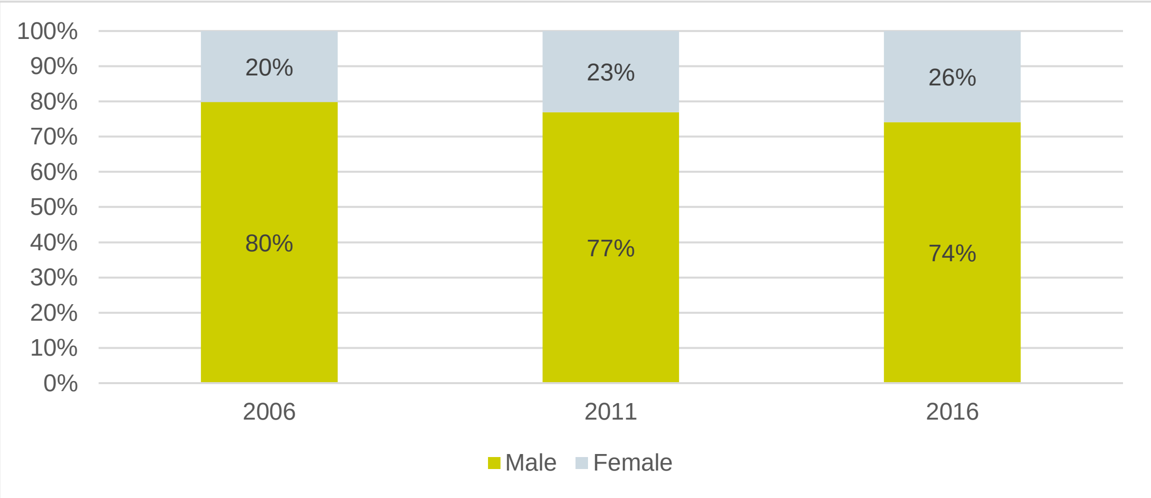


Source: Australian Bureau of Statistics (2017)

2.8 Gender, age and distance travelled of active transport users

Cycling trips to work skew towards males, as shown in Figure 11, which highlights the gender split in bike riding to work across the last three Census years. It shows a steady increase in female participation (as a proportional of all cycle trips to work) of 3% each five years. While bike commuting appears to be declining across the country, there is a steady increase in the proportion of females riding to work. Three quarters of those cycling to work continue to be male, despite constituting around 50% of the workforce.

Figure 11 Cycle commuting and gender split



Source: Australian Bureau of Statistics (2017)

In Australia, active transport participation likelihood holds a relationship to age. Table 3 provides an overview of how cycling to work varies by age group across different capital cities in Australia, as well as the overall national average. It shows that the 30–44 years of age category accounts for the highest mode share, with those aged 60+ the least likely to ride to work.

Table 3 Bicycle mode share by age group, journey to work

	Bicycle mode share				
	15-29 years	30-44 years	45-60 years	60+ years	Total
Greater Sydney	0.71%	1.04%	0.82%	0.39%	0.84%
Greater Melbourne	1.64%	2.03%	1.38%	0.75%	1.63%
Greater Brisbane	1.17%	1.64%	1.24%	0.60%	1.31%
Greater Adelaide	1.07%	1.54%	1.46%	0.93%	1.34%
Greater Perth	1.01%	1.36%	1.31%	0.79%	1.20%
Greater Hobart	1.04%	1.82%	1.36%	0.53%	1.35%
Greater Darwin	2.24%	2.55%	2.44%	1.65%	2.37%
Australian Capital Territory	2.63%	3.31%	3.30%	1.71%	3.01%
Capital city average	1.19%	1.58%	1.25%	0.67%	1.30%
Australia	1.13%	1.41%	1.14%	0.68%	1.19%

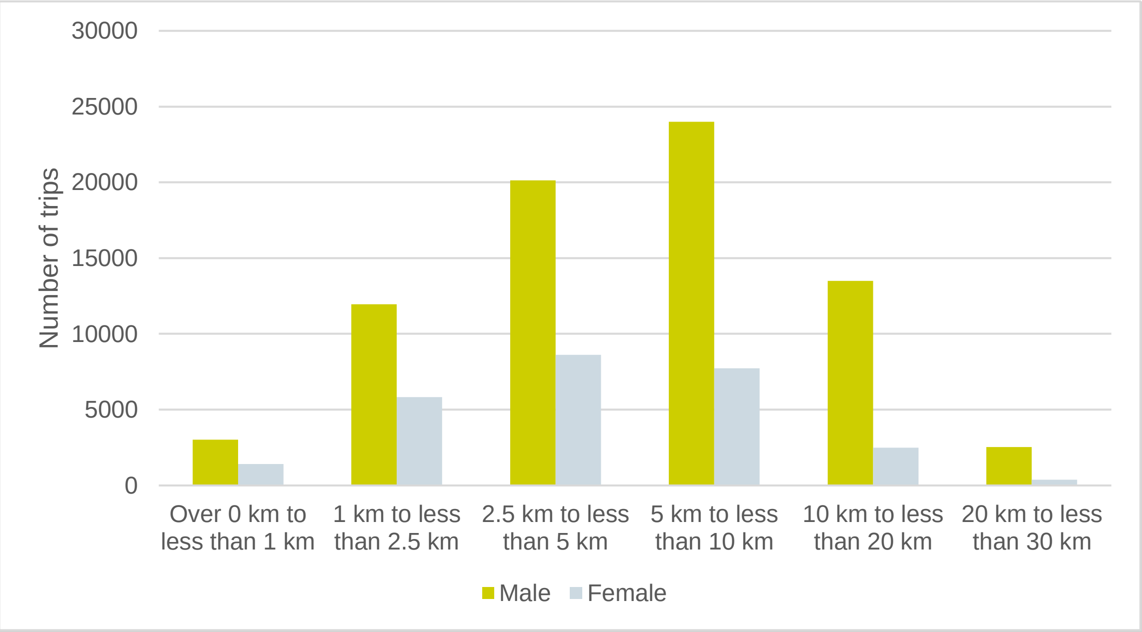
A similar table is offered in Table 4, for walking. Again, it shows considerable variation both across age categories within the same city, as well as between cities. For instance, walking is far more common within the 15 – 29 age group than it is for other age groups, across all cities. The next highest walking participation category, as a percentage, is at the other end of the age spectrum, the 60+ category. Young adults in Hobart are the most likely to walk to work, at almost 10%, followed closely by the ACT, at 8.9%.

Table 4 Walking mode share by age group, journey to work

	Walk mode share				
	15-29 years	30-44 years	45-60 years	60+ years	Total
Greater Sydney	6.29%	4.47%	3.45%	4.29%	4.63%
Greater Melbourne	5.28%	3.13%	2.35%	3.18%	3.47%
Greater Brisbane	4.94%	2.95%	2.47%	3.31%	3.39%
Greater Adelaide	3.55%	2.18%	2.14%	3.04%	2.59%
Greater Perth	3.39%	2.01%	1.94%	2.64%	2.41%
Greater Hobart	9.53%	5.91%	5.48%	5.93%	6.63%
Greater Darwin	6.90%	3.38%	3.54%	4.32%	4.47%
Australian Capital Territory	8.93%	4.36%	3.11%	3.59%	5.21%
Capital city average	5.35%	3.40%	2.71%	3.52%	3.72%
Australia	5.46%	3.54%	3.33%	4.80%	4.08%

Figure 12 shows the number of trips to work for different trip length ranges for both male and female bike riders. Despite the large difference in total trip volumes, there are clear differences in the distances men and women ride for commuting to work. The figures indicate that women are more likely to ride between 2.5 and 5 km whereas men are more likely to ride between 5 and 10 km to work.

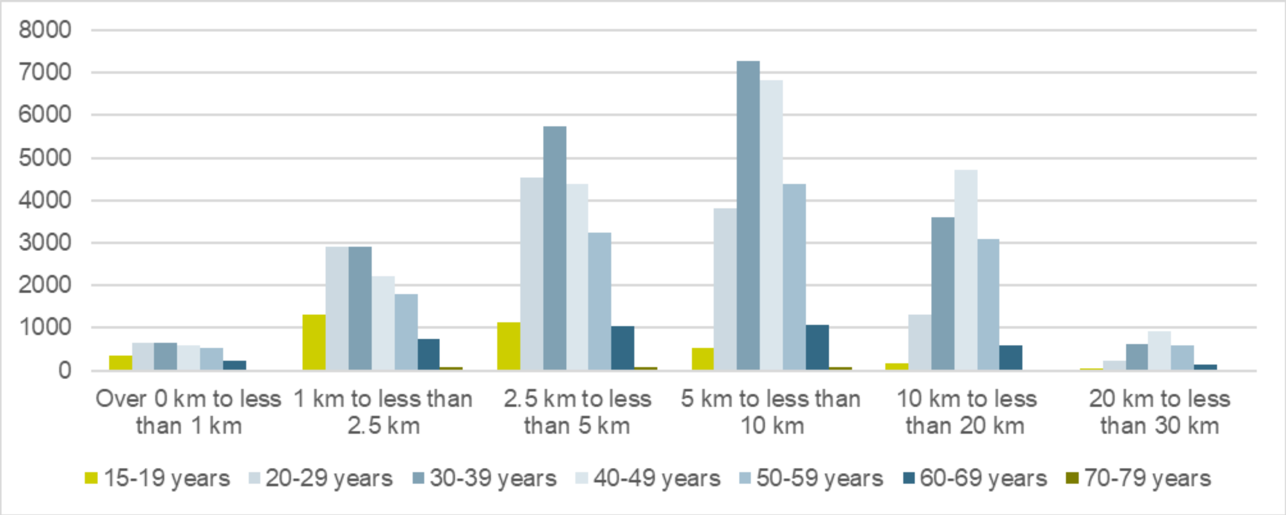
Figure 12 Cycle commutes by distance and gender



Source: Australian Bureau of Statistics (2017)

There are also clear differences in distance cycled to work for different age groups. Figure 13 shows that younger people, including those aged 20-29, are more likely to ride 2.5 – 5 km to work, while older age groups form a larger proportion of the 5 – 10 and 10 – 20 km distance bands.

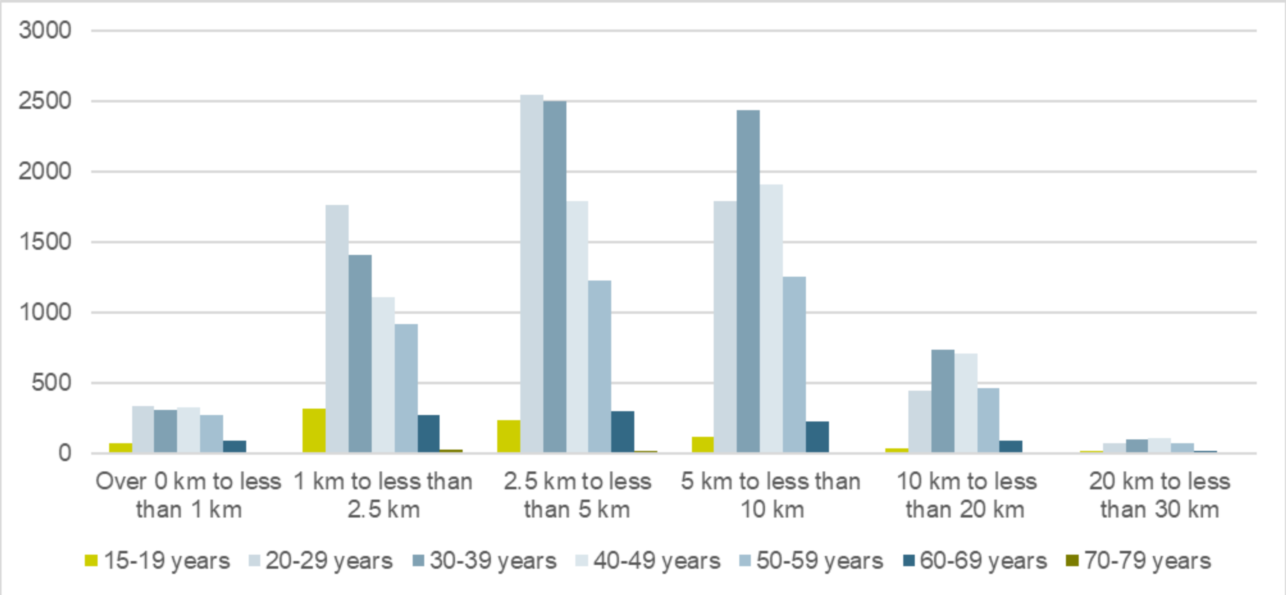
Figure 13 Bicycle trip distance by age group for journey to work – males



Source: Australian Bureau of Statistics (2017)

Figure 14 shows the same distance and age group profile as Figure 13, but for women.

Figure 14 Bicycle trip distance by age group for journey to work – females



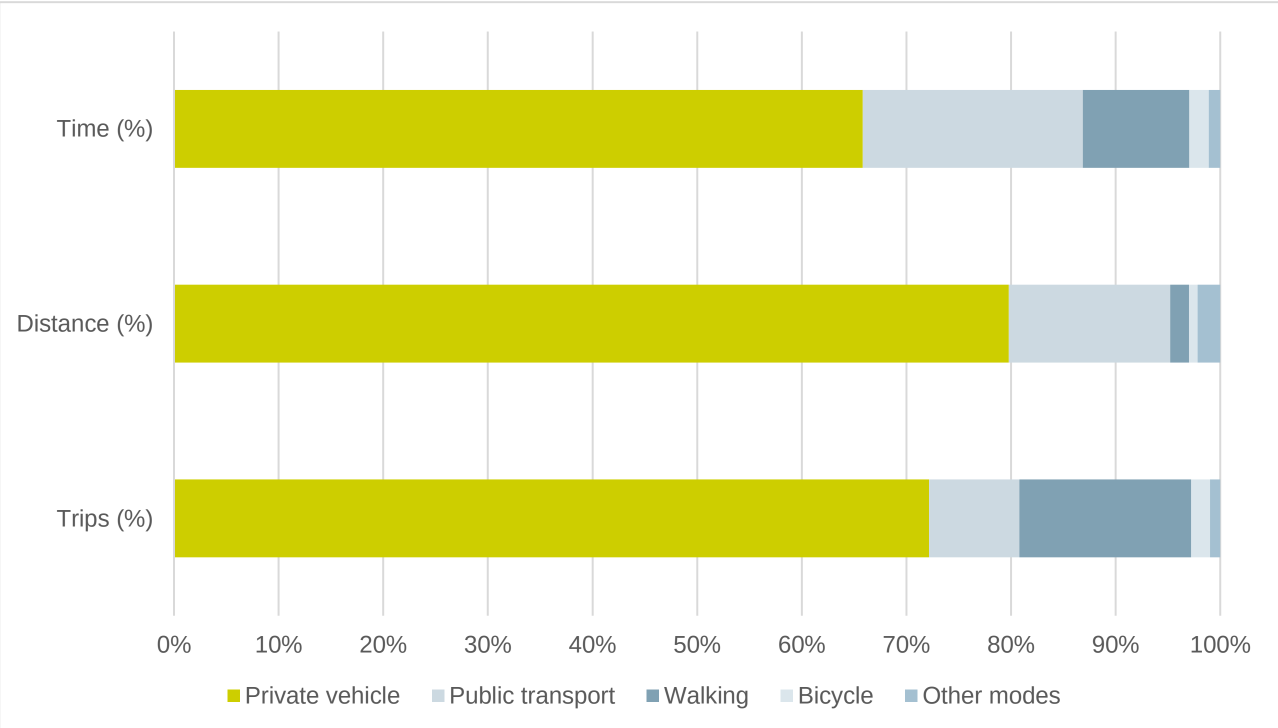
Source: Australian Bureau of Statistics (2017)

2.9 Trip duration

In most communities, active travel is a very small portion of travel distance and a small portion of trips and mode share (particularly if the walking links of motorised trips are categorised by the motorised component as some surveys do). However, active travel can be a significant portion of travel time and "exposure" to transport facilities. For example, on a typical city street, pedestrians and bicyclists may only represent 10% of trips that pass a particular point, but 50% of the total *time* people spend on that street. This is important because walking and bicycling significantly affect how people experience the public realm (shared public spaces), raising the significance of walking and bicycling conditions (safety, comfort, shade, furniture, etc.) compared to consideration from a pure transport distance or mode share perspective.

This point is illustrated in Figure 15, which provides an overview of Australia's most detailed household travel dataset, VISTA (Victorian Department of Transport, 2018), providing a breakdown of the time spent, distance travelled and number of trips (all expressed as a percentage). It reveals that while walking and cycling make up only a very small proportion of distance travelled, at 1.8% and 0.8% respectively, of all distance travelled, they account for 10% and 2% of the total amount of time spent engaged in travel.

Figure 15 All purpose travel, as a proportion of time, distance and trips



Source: (Victorian Department of Transport, 2018)

2.10 Active travel issues with travel surveys

Many travel surveys include questions regarding multi-modal travel. This helps to capture the broad ways people move throughout cities. Due to the multitude of transport mode combinations possible, these multimodal trips are often combined into a dominant or aggregate mode, typically a motorised mode. For example, a trip that includes a bike ride to a railway station, a train trip to the CBD, then a short walk to a business is most commonly aggregated into a train trip.

However, there are many examples where the aggregation to motorised transport does not accurately reflect the dominant transport mode for a given trip. For example, a 10-minute train ride followed by a one-hour walk is likely to be a recreational walking trip, however it is often aggregated to a train trip.

Analysis of the Victorian Integrated Survey of Travel and Activity (VISTA) dataset found that over 8% of all multi-modal trips aggregated the transport modes to one of the modes that was neither the longest distance travelled nor longest time spent using that mode. The majority of these trips include those that had a train or tram leg as part of the journey. For instance, if a trip included a 2km walk, a 1km minute tram ride, and a 1.5km bike ride, the aggregate mode shown in VISTA is a tram trip.

There are merits to the aggregation process, namely, that it is typically required for strategic demand models. However, it results in important information behind effectively hidden about other modes used in multi-modal trips. This poses challenges in adequately quantifying the contribution that active transport makes to the overall transport network.

It is important to be cognisant of the effect this matter may have on planning for, and consideration of, walking and bike riding. This issue highlights the competing needs for information from travel surveys, and the funding constraints that limit the number of surveys that can be undertaken.

3. Factors influencing walking and cycling

The factors that influence rates of walking and cycling are diverse. Some of these factors are shared between walking and cycling, while others are far more pronounced in one than the other. Thus, while walking and cycling are often handled within the one policy area, there are important nuances that can be lost when grouped together. For instance, while wet weather is a strong barrier to both walking and cycling, a factor like land use density influences walking and cycling differently. While land use density is important to both walking and cycling, arguably, walking is more sensitive to land use density than cycling.

3.1 Land use factors

There is a strong relationship identified in the literature on the impact of land use on active transport levels (Nieuwenhuijsen, 2020, Stevenson et al., 2016, Giles-Corti et al., 2016, Sallis et al., 2016). Recent key Australian research found that policy decisions that foster more compact city design can have a significant impact on shortening travel distances and supporting more walking and cycling (Stevenson et al., 2016). As a result, low land use densities, and single use densities can act as a barrier to active travel.

Some researchers describe the relationship between transport and land use through the use of the *five Ds* (Ewing and Cervero, 2010):

1. Density (of land use)
2. Diversity
3. Design
4. Destination accessibility
5. Distance to transit.

In a study on the factors that influence walking levels, researchers from Melbourne found that it was the presence of *destinations* (i.e. places to walk to) that had the strongest influence on walking rates (Kavanagh et al., 2007). This highlights the importance of *density*, and *diversity* of destinations when designing human settlements. Higher density, without a mix of land uses (e.g. residential only) limits the opportunities for walking and cycling (Ewing and Cervero, 2010).

Ewing and Cervero (2010), in their meta-analysis of research conducted on the built-environment travel literature found correlations between the built-environment and street network design variables and travel mode:

- Motor vehicle usage was strongly linked with measures of destination accessibility (how many different destinations can be reached for a given transport mode) and secondly to street network designs
- Shorter blocks and more intersections decreased the amount of car use, while those same features were found to increase walking
- Walking was most strongly correlated with land-use diversity, intersection density, and destinations reachable on foot
- Public transport use was found in areas with proximity to public transport systems, and street network designs
- No results could be provided for cycling use, due to a lack of research on the topic
- An interesting finding from their research was that job and population densities were weakly associated with travel behaviour, once other variables are controlled for.

The Ewing and Cervero (2010) find that certain built-environment and street layout designs are correlated to travel modes. That is, travel demand is created through the design of an area's street network, built-form, and density of land-uses. This is an important result, particularly for greenfield developments, where travel elasticity is likely to be highest while new travel patterns and behaviours emerge. This means that the specific design chosen for a greenfield development or suburb could adequately predict the resulting transport mode usage, prior to its development. This poses a challenge to traditional ways of greenfield planning, which aims to meet expected demand.

WalkScore is a website that analyses walkability via an automated analysis of nearby amenities, taking into account distance. Amenities within a 5-minute walk are given maximum points with a decay function applied to those within a 30 minute walk. Cycling levels are also influenced by land use factors. Higher density regions promote shorter trip distances, which favour active travel. Cycling levels drop off rapidly once trip distance exceeds 6km and land use policies can play an important role in promoting shorter trips.

3.2 Active travel infrastructure or appropriate facilities

The availability of bicycle infrastructure is an important determinant of people's decision to cycle (Buehler and Pucher, 2020, Pucher et al., 2010, Buehler and Dill, 2015).

Buehler and Dill (2015) undertook a meta-analysis of previous academic and grey literature[2]. It suggests a positive relationship between the provision and quality of bike networks, and cycling use. Street intersection density was found to negatively impact on cycling levels, though certain design features (such as protected intersections) reduced this. This draws parallels with Ewing and Cervero's findings (2010), particularly with public transport predictors — proximity to high-quality network and street network designs (fewer intersections). Buehler and Dill (2015) reviewed a study which found that each additional linear mile of bike network installed correlated with a 1% increase in bike use.

The provision of suitable infrastructure is likely to influence the decision to cycle through its effect on perceived safety. Increased perceived safety increases the level of cycling. Researchers have described that safety can be thought of both in terms of perceived and actual safety (Heinen et al., 2010). Numerous studies have found protected bicycle infrastructure (through its safety effect) is especially important when seeking to encourage higher levels of cycling, and this is especially important for novice or 'would be' cyclists (Mueller et al., 2018).

The quality of bicycle network is also important. Australian research has found that the proportion of females cycling can act as a proxy indicator for the quality of the bicycle network — where higher quality infrastructure is associated with less of a gender imbalance (Garrard et al., 2008). In Australia, as elsewhere, women are more sensitive to the riding environment and are more deterred from riding in mixed traffic (Garrard, 2003, Garrard et al., 2006, Garrard et al., 2007). As highlighted in section 2.8, in Australia, only around a fifth to a quarter of commuter cyclists are female, despite constituting around 50% of the workforce (Australian Bureau of Statistics, 2017). The quality of a network can be measured using the level of service concept.

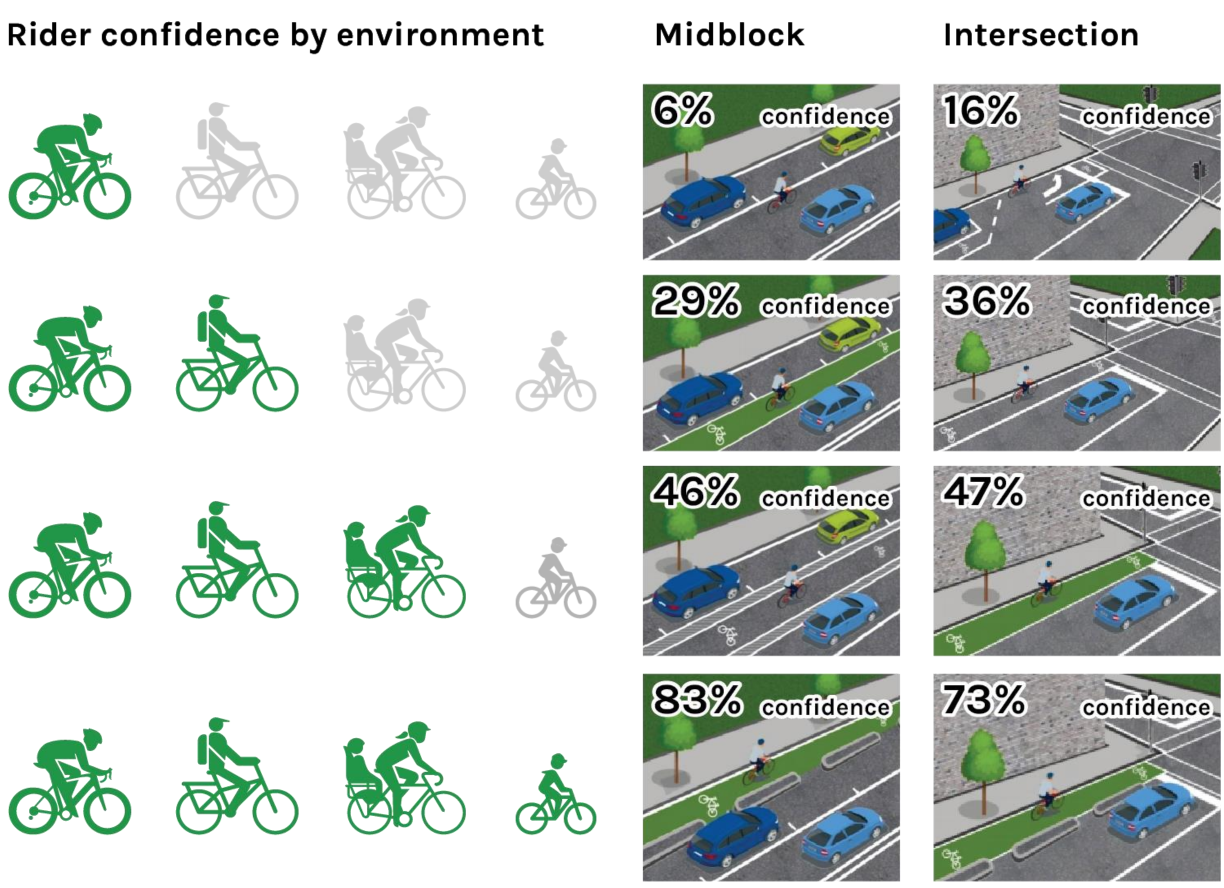
The connectedness of, and proximity to, the network was also found to be a significant factor for cycling use. While this study did not specifically draw out why connected networks was important (it spoke of improved travel time compared to car use), a more connected bike network increases access to the number of possible destinations. This study indicates that cycling use correlates with proximity to cycling networks, with usage increasing with level of protection from motor vehicles.

[2] Research that is either unpublished or has been published in non-commercial form.

Figure 16 provides an illustration of how confident people say they would feel riding on different forms of bike infrastructure, based on a stated preference survey (CDM Research and ASDF Research, 2017). Starting will no or minimal active travel infrastructure at the top of the figure, the level and quality of infrastructure gradually increases as one moves down the figure. Figure 16 shows that:

- Where there is minimal, or no active travel infrastructure, only a small minority of people feel confident to cycle. Only a small proportion of people feel confident to ride on streets with no bike infrastructure or a painted lane. Only 6% of people felt confident riding in mixed traffic (i.e. with motor vehicles)
- Most people involved in the research stated they would feel confident riding on a bike lane protected from motor vehicle traffic. When physically protected bike lanes are provided, 4 in 5 people say they would be confident to cycle.

Figure 16 Riding confidence with different infrastructure levels



Source: CDM Research & ASDF Research (2017)

3.3 Integration with public transport interchanges

3.3.1 Best practice: Dutch experience

The integration of bicycling networks and public transport interchanges can serve to support the use of both the bicycle and public transport (Austroads 2020) and help to make up for the weaknesses inherent in each mode. It is well established that integrating cycling networks with public transport hubs can significantly increase the public transport catchment by up to a factor of 15, compared to walking (Hudson, 1982). A lack of integration between active transport and public transport can therefore act as a barrier to both active and public transport use, as well as increase the proportion of rail passengers that use a motor vehicle as their access mode to the railway station, exacerbating parking issues.

The country with the most well-developed relationship between cycling and public transport is the Netherlands. Some 50% of train passengers nationally arrive at the station by bike, and this can rise to as much as 70% at some stations (Nederlandse Spoorwegen, 2018). Moreover, data from the national rail operator has found that passenger satisfaction levels are highest for those who have arrived by bicycle, and this is thought to be related to the fact that the passenger has complete independence as to when they arrive therefore minimising wait times (Nederlandse Spoorwegen, 2018). Cycling to the station also provides greater access to hub stations that offer more travel choice/journey speed. A distinct category of “bicycle-train travellers” has emerged in the transport literature due to the competition to the private motor vehicle the paired use of cycling and public transport can offer (Jonkeren et al., 2019). This has relevance to Australian cities, which can often have significant car parking issues at suburban stations, despite a large proportion of car trips to railway station being short (i.e. less than 3km), according to number plate analysis conducted by the author in conduction with the Victorian Department of Transport.

Jonekeren et al. (2019) argues there are a variety of elements to understand when trying to encourage bicycle-train travel. Firstly, not all stations attract bicycle-train travellers. Bicycle-train travellers very often do not use their nearest station, rather they take advantage of cycling’s increased catchment area to reach stations the Dutch National Railways consider as having ‘hub’ functions. According to their research, 80% of the time ‘hub’ stations were chosen over the nearest station (Jonkeren et al., 2019). These stations offer the most diverse range of connections which usually results in the fewest train transfers to reach the travellers final destination. Such stations generally also have express and intercity services and higher train frequencies. The quality of bike parking at these ‘hub’ stations is also important. ‘Hub’ stations tend to offer better and safer bicycle parking than small local stations. The increased ability to reach these ‘hub’ stations, afforded by the bicycle, is likely another factor influencing the high satisfaction levels bicycle-train travellers exhibit compared to other train travellers.

Jonekeren et al.’s (2019) second point is that the catchment effect of cycling can occur 3 - 7 km at both ends of a train journey. Whilst it is vastly more frequent to cycle the “home-end” trip to the station, cycling also occurs at the “activity-end” of journey. Most “activity-end” trips are taken on foot (average 51%), by another means of public transport (average 23%) or by bike (average 20%). Activity-end bike choice differed depending on the city. Some cities witnessed a high use (up to 65%) of folding bikes, implying bicycle-train travellers brought their bikes with them. Other cities witnessed a high use of public transport bikes (known as *OV Fiets*, or public transport bike) owned by the Dutch National Railways (up to 44%). One distinction between the Dutch and Australian experience, is that for most high demand times, regular bicycles cannot be taken on Dutch rail services, whereas in Australia, many operators allows bicycles to be taken without an additional fee.

The key theme from the Netherlands experience is that railway stations must be connected to high quality bicycle infrastructure. Cycling infrastructure should be provided to facilitate safe travel a 3 – 7 km radius from the station, and provide conveniently located, safe, and secure bike parking at public transport interchanges. The number of bicycle parking spots should be in proportion to the transport agency’s goal of the proportion of daily passengers it wishes to arrive by bicycle.

3.3.2 Australian practice

The integration of cycling and public transport is rare in Australia, both from an individual perspective, and in relation to bicycle network planning, at a government level. Bicycle networks have not been developed to support access to train stations, and it is more typical for bike infrastructure to run parallel to a rail corridor, than to offer radial connections from the station to its surrounding catchment. Table 5 shows the number of people who responded in the 2016 Census as having used a bike and a form of public transport to travel to work. These numbers constitute a small minority of overall public transport patronage, with only around one in every 200 Sydney public transport commuters integrating cycle use, rising to one in around 70 for Melbourne.

Table 5 Bike and public transport use for Journey to Work, Australian Capital Cities

	Train, bicycle	Bus, bicycle	Ferry, bicycle	Tram, bicycle
Greater Sydney	1370 (0.55%)	417 (0.33%)	246 (3.29%)	25 (0.96%)
Greater Melbourne	2095 (1.37%)	123 (0.49%)	24 (5.62%)	514 (1.01%)
Greater Brisbane	498 (1.27%)	268 (0.54%)	88 (3.74%)	0 (0%)
Greater Adelaide	132 (1.47%)	155 (0.54%)	0 (0%)	26 (0.95%)
Greater Perth	548 (2.13%)	140 (0.41%)	14 (6.57%)	0 (0%)
Greater Hobart	0 (0%)	6 (0.14%)	3 (0%)	0 (0%)

Source: Australian Bureau of Statistics (2017)

Note: Percentage is total for that mode – e.g. 0.55% of Sydney train commuters arrived at the station by bicycle.

Where the integration of cycling and public transport has occurred, it has been through the inclusion of bike parking, including secure, weather-protected bike parking. The most prominent example of this is Victoria's Parkiteer system which provides secure bike parking at over 100 Metropolitan and Regional railway stations and the Western Australian program run by the Public Transport Authority. Customer research found that around a quarter of Parkiteer users previously drove to the station and theft prevention was their main reason for joining. It is also notable that in Melbourne passengers are always permitted to bring a bike on board the train, while only folding bikes are permitted on trams and buses. In Sydney, passengers are permitted to bring bikes on board trains and light rail vehicles, while only folding bikes are permitted on buses. Other capital cities in Australia have more restrictive policies, often forbidding non-folding bikes to be taken on board a train during peak hours.

3.4 Ancillary infrastructure

Ancillary infrastructure consists of drink fountains, shade, parking and other infrastructure designed to support active travel, and are widely seen to be an important part of enhancing the user experience. The existing literature does not report itemised figures for the monetised value to the presence of such ancillary infrastructure. Nevertheless, especially for shared paths and other forms of dedicated active travel infrastructure, community surveys have found strong public support to integrating shade, drink fountains, benches and bike tool work stations within pathway developments (City of Canada Bay, 2018).

Heinen et al. (2010), in their work reviewing the literature on the factors that influence people's decision to commute by bike found that end of trip facilities at work can be important. Bike parking, lockers and showers were all positively associated with people's decision to ride. Those with more expensive bikes consider secure bike parking to be very important.

Since the time Heinen et al. conducted their review, e-bikes have emerged as a more common bicycle type, which typically are more expensive (see chapter 10). This growing trend may strengthen the degree to which safe parking is required, as well as the need for charging infrastructure (10Amp GPO standard plug) within workplace and multi-dwelling apartment bicycle parking facilities. The growth of e-bikes and heavier transport oriented bicycles[3] also require more horizontal and less vertical parking facilities in new developments.

Showers were not considered to be as important as secure parking and Heinen et al.'s review found mixed results in terms of the degree to which prospective bike commuters considered showers important. It is likely that it is somewhat context/city dependent. In a hot, hilly city (e.g. Brisbane), showers may be seen as more important than a cold, compact city like Amsterdam or Copenhagen. The growth of e-bike use may reduce the number of showers required. The review by Heinen et al. was unable to find research showing that access to showers and parking facilities influence bike mode share, although the researchers identify that there is a paucity of research in this area (Heinen et al., 2010).

Wayfinding signage can be important to enhance people's awareness and usability of active travel networks In a recent Wayfinding Masterplan for an area of Sydney, the presence of physical signage was strongly supported by the community, with 85% expressing support (City of Canada Bay, 2018). Once a coherent bicycle network has been established, wayfinding can increase people's awareness of the network. This can include directional signage, including the distance and time it takes to reach key destinations. This is important, as it is known that those who do not often cycle can overestimate how long it takes to travel by bike and underestimate how long it takes to travel by car (City of Canada Bay, 2018).

3.5 Barriers

Heinen et al. (2010) found a number of reasons that are commonly identified as 'reasons not to cycle'. The overwhelming reason, which is supported by several Australian studies on determinants of cycling is safety (Ker et al., 2011, Fishman et al., 2015c, Garrard, 2011, Fishman et al., 2011, Pucher et al., 2010). The following is a list of the key reasons Heinen et al. (2010) found in their exploration of barriers to transport cycling include (some of which overlap):

- Too dangerous
- Too much traffic
- Bad weather
- Personal factors (too busy)
- Lack of daylight
- Inconvenience
- Lacking sufficient fitness
- Uncomfortable
- Cycling as an uncommon mode, and
- Difficulties with trip chaining.

Some of these reasons, which have been provided to researchers from those that do not cycle, can be addressed through intervention, while others cannot. For instance, 'too dangerous' can be ameliorated to some degree through enhanced bicycle infrastructure networks. Other reasons, such as 'bad weather' may

[3] In past decades, most bicycles in Australia have been relatively light (e.g. under 14kg). More recently, there has been a growth in bicycles in which low weight has not been a priority, with a preference for higher carrying capacity, racks and baskets. These bikes are heavier, and make vertical parking (e.g. attached to a wall) less practical.

be more difficult.

In many cases, the inverse of a barrier can be a facilitator. For instance, while too dangerous is cited as a reason for not cycling, measures to enhance safety and separation between bicycles and motor vehicles is a facilitator of cycling.

The barriers may also be cultural.

It is also interesting to note that, while 'convenience' is given by existing cyclists as one of the reasons they choose to cycle, 'inconvenience' is one of the reasons given as a barrier to cycling by those that do not (Heinen et al., 2010). So perceptions vary from person to person.

Personal security can also have an influence on people's decision to walk or cycle. Travelling on isolated shared paths, particularly at night can be a deterrent to active travel, and this is likely to be more pronounced for women (Ravensbergen et al., 2020).

The relative attractiveness of active travel compared to other modes (e.g. motor vehicle) is another important influence on whether people walk or cycling. These might be described as indirect barriers. For instance, in a study of Brisbane residents, the researcher asked respondents why they don't use the Brisbane bike share program. The top reason identified was that it was 'easier to drive' (Fishman, 2019). This highlights an important finding for those interested in growing the role of active travel — that overcoming barriers to walking and cycling may need to address the relative attractiveness of active travel compared to other modes that might be available. What is clear from the transport literature is that people do not make travel choices in isolation; they weigh the pros and cons of the different modes available and make a decision, based at least in part on time, cost and safety considerations (give refs). For example, if motor vehicle travel is time competitive, has few variable costs (e.g. parking, tolls etc) and feels safe, it will be the dominant mode, and a mode such as cycling is likely to play only a marginal role.

Applying *utility theory* to the decision to use active modes, it can be assumed that when presented with a mode that involves an increase in time, cost or effort, there will be reduced probability of using this mode. This explains why cycling shows a rapid drop off in participation once trip distance exceeds 6km. For instance, using ABS Census data, between 67% and 80% of journey to work cycling trips are less than 8km. Figure 10 in chapter 2 shows the cumulative rate of cycling commutes over distance in each capital city of Australia. For most cities, the largest proportion of work trips are around the 4 – 5 km mark.

3.6 Measuring pedestrian level of service

The level of service concept is useful when considering the attractiveness of walking and cycling as modes of travel. In relation to walking, the pedestrian level of service (PLOS) is a concept used to determine the walkability or trip quality based on the characteristics of a pedestrian environment such as comfort, safety, and amenity. Note that this differs from measures such as the Fruin level of service (LOS) which consider speed-flow-density relationships only and are used for space proofing infrastructure such as rail stations, stadiums and buildings.

A review paper by Raad and Burke (2018) considered 58 PLOS studies between 1971 and 2016 to identify the main approaches being used to identify PLOS (and thereby understand barriers and facilitators to walking). Factors can be geometric (e.g. signage, lighting, bollards, parking) and non-geometric (e.g. safety, attractiveness, comfort) in relation to the pedestrian environment or the traffic system.

There is not a standardised approach to grading PLOS. There have been different methodologies to grading PLOS and these were designed to fit certain pedestrian contexts. The review by Raad and Burke (2018) categorised these as streets, footpaths, intersections, and mid-block crossings.

It must also be acknowledged that an individual's propensity to walk is governed by more than geometric factors, with neighbourhood characteristics playing an important role, including the diversity of destinations (e.g. see Kavanagh et al., 2007) (see section 3.1 above). The landmark study by Kavanagh et al. found that among the most important determinants of whether someone walks, or rather how much they walk, was whether there are places/destinations within a walkable distance. Mixed use areas that have a combination of different land uses, such as shops, parks, and houses encourage walking, while single use zoning can starve an area of walkable destinations, and thereby reduce the propensity for walking (Stevenson et al., 2016, Sallis et al., 2016, Giles-Corti et al., 2014).

When people live in a place that is purely residential, and this area covers say a 2km catchment, it means there are few destinations for them to walk. This results in less walking. The finding from the research is that it is not only about the quality of the footpaths or crossing points — it is whether people actually have destinations within their area to walk to.

The review by Raad and Burke (2018) found that for streets and footpaths, the most common factors influencing PLOS included footpath width, obstructions, pedestrian flow, and motor vehicle speed. For intersections and mid-block crossings, common PLOS factors were very much focused on street design that governed a crossing's traffic volume, dimensions, markings, and number of traffic lanes.

There has been an increasing policy and planning interest in walking provision, with 25 of the 58 studies considered by Raad and Burke (2018) published between 2012 and 2016. While the review recognises the benefits in building relatively objective PLOS assessments for particular pedestrian environments, it argues that assessing the level of service of pedestrians is less developed than other travel modes and more research to discern better methods on PLOS is recommended.

Austroads guide

The Austroads *Guide to Traffic Management Part 4: Network Management Strategies* (Austroads 2020) provides a list of key considerations in assessing PLOS, summarised here in Table 6. The PLOS assessment allocates grades between A-F, where A indicates most suitable and F indicates least suitable. An advantage of letter grading is that it can be more easily interpreted by stakeholders. Table 6 adapts Austroads' PLOS framework and summarises the key factors used to measure PLOS.

Table 6 Factors used to measure Pedestrian Level of Service

Level of service needs	Level of service factors	Service measure values
Mobility	Footpath congestion	Freedom of movement on desired path. Congestion is where there is limited speed and restricted ability to pass obtrusions (e.g. other users, parked cars, rubbish bins). Footpaths in busy areas should be wide enough for everyone to use, including pedestrians in a wheelchair or with a pram.
	Gradient of path	The provision of accessible path routes by considering flat to gentle gradients. Poor service is reflected by the lack of or unacceptable design of gradients. Examples include very steep gradients, long stretches of stairs, and not providing ramps or stairs which thereby obstructs pedestrians – especially those with limited mobility.
	Crossing delay or detour	The amount of delay/detour for pedestrians to cross where there is demand to cross, ranging from minimal to significant. Increase in delays and detours can affect values such as speed and travel time.
Safety	Exposure to vehicles at mid-blocks	Service considers the amount of separation between pedestrians and motor vehicles. Poor service is reflected by restricting separation. Excellent service may consider clear separation including a buffer between pedestrians and motor vehicles, such as a nature strip and/or bicycle lane.
	Exposure to vehicles at crossings	Service considers the type of crossing facility and its suitability depending on motor vehicle environment (e.g. major arterial road, residential street).

Level of service needs	Level of service factors	Service measure values
		Poor service is reflected by uncontrolled or no crossing facility in a high volume and high-speed motor vehicle environment (e.g. major arterial road). For busy motor vehicle environments, excellent service may consider fully protected crossings (e.g. signalised intersections) or regulated crossings (e.g. zebra and pelican crossings).
	Trip hazards	Footpaths should be well-maintained, with no or limited pavement defects, and hazards that may impact on safety. Poor service is reflected by footpath defects (e.g. tree roots, potholes, uneven surfaces), and number of hazards obstructing the footpath (e.g. street furniture, trees, garbage, parked cars). Excellent service may consider tactile indicators, good drainage, clear of debris, and minimal pavement defects.
Access	Crossing opportunities	Allowing pedestrians to cross the road safely and freely at any location along the road, such as a low speed shopping strip or shared zone. Excellent service may consider making provisions for crossing within 25m from an origin. Poor service is regarded by making pedestrians walk much longer to safely cross the road (e.g. a sub-arterial road where pedestrians may need to walk 200m to avoid a physical obstruction such as a fence to cross safely).
	Level of disability access	The provision of appropriate wheelchair access and meeting Disability Discrimination Act (DDA) requirements.
Information	Traveller information available including signposting	Service considers making traveller information available to pedestrians. Excellent service make implications for complete and clear signposting for navigation, and the nature of pedestrians and the area (e.g. a tourist area would require more information than a local neighbourhood).
Amenity	Footpath pavement conditions	The provision of sealed, smooth, and non-slip pavement surface that is comfortable and well-maintained for pedestrians to walk on.
	Comfort and convenience features	Features which offer added comfort and convenience (e.g. shelter, noise protection, benches).
	Security	Level of security (e.g. adequate lighting, security personnel presence, security cameras, no or limited history of criminality of disturbance, sufficient number of pedestrians, etc.).
	Aesthetics	The provision of a clean and aesthetically pleasing pedestrian environment (e.g. greenery, view, design, artwork, etc.). Poor service is reflected by uncleanliness (e.g. graffiti, garbage, etc.).

Source: Adapted Austroads (2020) Table C2 1.

4. Demand estimation

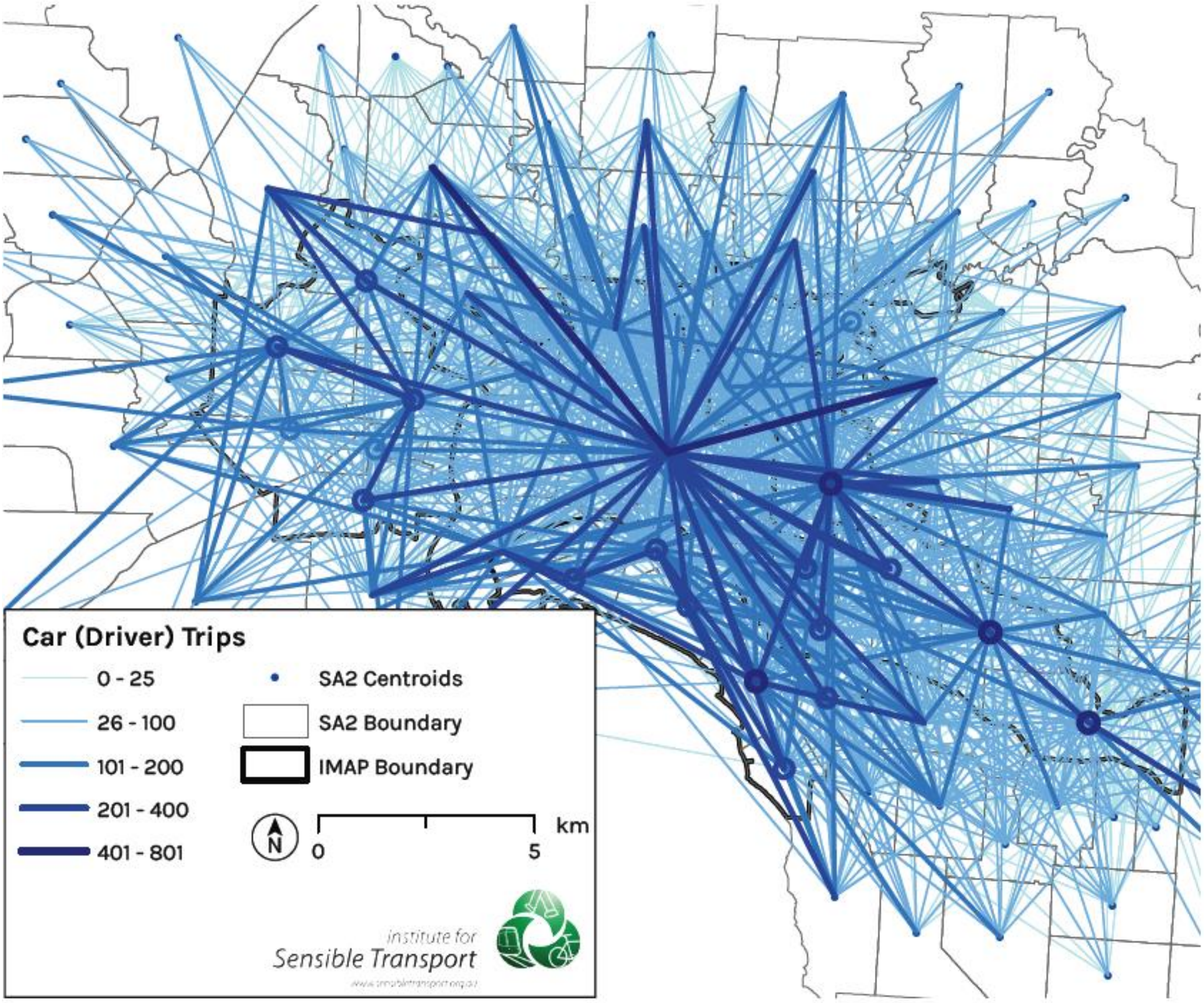
4.1 Demand elasticities

An extensive review of the North American literature on active travel elasticities was conducted by Handy et al. (Handy et al., 2014b, Handy et al., 2014a). The elasticities are summarised in Table 7 and Table 8 for a range of different measures of active travel infrastructure quantity or quality. For example Table 7 shows that a 1% increase in the percentage of streets with bike lanes results in a ~0.35% increase in trips to work by bike (Marshall and Garrick, 2010). Table 8 reports elasticities for walking between 0.09 and 0.27.

4.2 Origin-destination mapping

The mapping of trips on an origin-destination basis has long been important for understanding travel. Origin-destination data comes from household travel surveys and the ABS Census for Journey to Work. The mapping of active travel trips on this basis assists in identifying areas that are the largest generators and attractors of trips, and potential active travel problems areas. Figure 17 shows the origin-destination matrix for car trips in inner-Melbourne.

Figure 17 Car Trip Origin-Destination Matrix (ABS Census Journey to Work)



Source: Davies et al. (2019)

Table 7 Elasticity of demand for cycling infrastructure

Study	Infrastructure Measure	Cycling measure	Elasticities	Results	Region and notes
Marshall and Garrick (2010)	% of citywide street lengths with bike lanes	% cycle commute	0.3490 to 0.3621 for impact of percent of citywide street length with bike lanes on percent commuting by bicycle -0.0036 to -0.0104 for impact of percent of citywide street length with bike lanes on percent commuting by driving	Elasticity calculated based on expected changes in mode shares for increase from 50 to 100% of street length with bike lanes as shown in Table 3 in cited paper. Calculated for three network types. e.g. elasticity biking for tributary tree network = [(2.59 - 1.92)/1.92] / [(100 - 50)/50]	Based on census block group data for 24 medium sized Californian cities.
Dill and Carr (2003)	1 Miles of bike lane per sq. mile 2 Average state spending of federal funds per capita on bicycle and pedestrian facilities (1990-1999); not adjusted for inflation	% cycle commute	0.323 for impact of miles of bike lanes per sq. mile on percent commuting by bicycle 0.321 for impact of average state spending of federal funds per capita on bicycle and pedestrian facilities on percent commuting by bicycle; elasticity should be adjusted for inflation to reflect value of current dollar relative to 1990-99 dollars.	Elasticity calculated based on regression coefficients (β) in Model 4 (see Table 3 in cited paper), average measure of infrastructure (xo) and average % commuting by bicycle (yo): β * xo/ yo 1 β=0.998, xo=0.34, yo=0.01055, elasticity = 0.323 2 2. β=1.021, xo=$0.33 yo=0.0105, elasticity = 0.321	Based on aggregate data of 33 of the largest U.S. cities, excluding New York City

Source: Handy et al (2014b)

Table 8 Elasticity for walking based on footpath characteristics and pedestrian environment quality

Study	Footpath characteristics or pedestrian environment quality variable	Walking or vehicle travel measure	Elasticity	Region and notes
Cervero and Kockelman (1997)	Average footpath width: based on sample of 20 block faces within each neighbourhood	Non-private vehicle choice for non-work trips	0.09	Region-wide household survey, for 50 neighbourhoods in SF Bay area
Rodríguez and Joo (2004)	Footpath coverage: percentage of shortest route to campus with footpath	Walk mode choice (commute trips)	1.23	Survey of UNC students, faculty staff
Fan (2007)	Footpath length: ratio of footpath length to total street length within block group	Daily walking time per person	0.12	Region-wide household survey in Triangle region of North Carolina
Ewing et al (2009)	Footpath coverage: mileage of footpath per centerline mile of streets within neighbourhood	Walk mode choice	0.27	Region-wide household survey in Portland, OR, for 52 mixed-use neighbourhoods in Portland, OR
Cervero and Kockelman (1997)	Walking quality factor	Non-private vehicle choice for non-work trips Non-private vehicle choice for work trips	0.18 0.12	50 case study neighbourhoods in SF Bay area

Source: Handy et al (2014a)

4.3 Cycling volumes by location

Another important source of information is the actual number of trips at any given location, and how that varies across an area. Figure 18 provides an example of how this information can be presented, in this case for Melbourne (Davies et al., 2019). This information is important as a benchmark for identifying problem locations in the network, and for calibrating active travel network demand models.

The example is taken from work modelling existing cycling levels across inner Melbourne (Davies et al., 2019), as part of an exercise to forecast how this baseline level of cycling might change following the introduction of a more extensive cycling network.

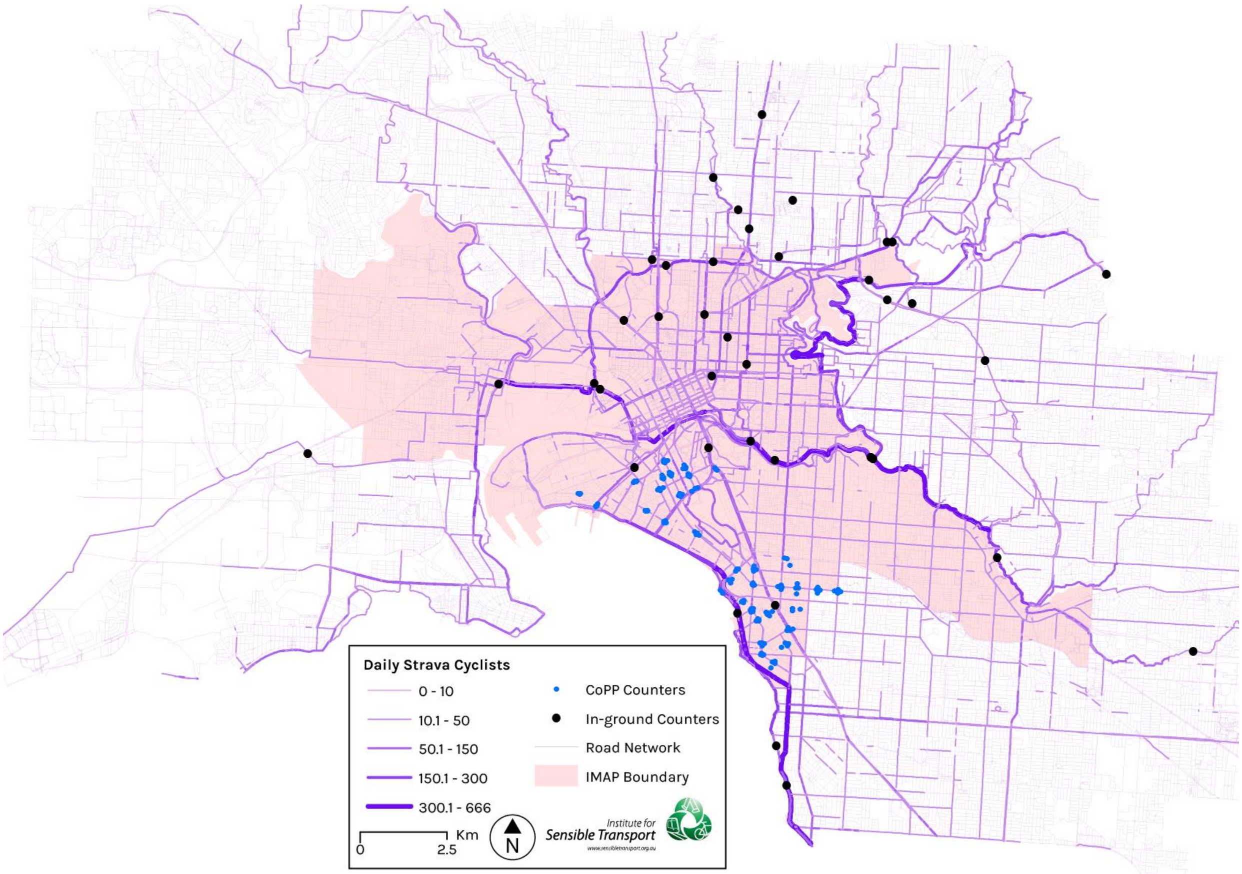
To determine active travel levels across the network, two different data sources were used:

Strava Metro and physical in-ground bike counters were used to estimate *all* cycling activity.

- Physical in-ground counters: These capture all cycling activity at the locations they are installed.
- Strava Metro data: This is a fitness-based dataset that records the path taken by cyclists undertaking fitness or recreation trips.

A regression analysis is then used to determine the differences between the Strava Metro recorded activity where it intersects with the in-ground cycling counter activity. This is then extrapolated across the network. Previous studies have found it to be a reliable estimate, with statistical correlation above $R^2 = 0.75$. The resulting output provides a reliable estimate of how cycling volumes vary across the network. Further details can be found in Davies et al. (2019).

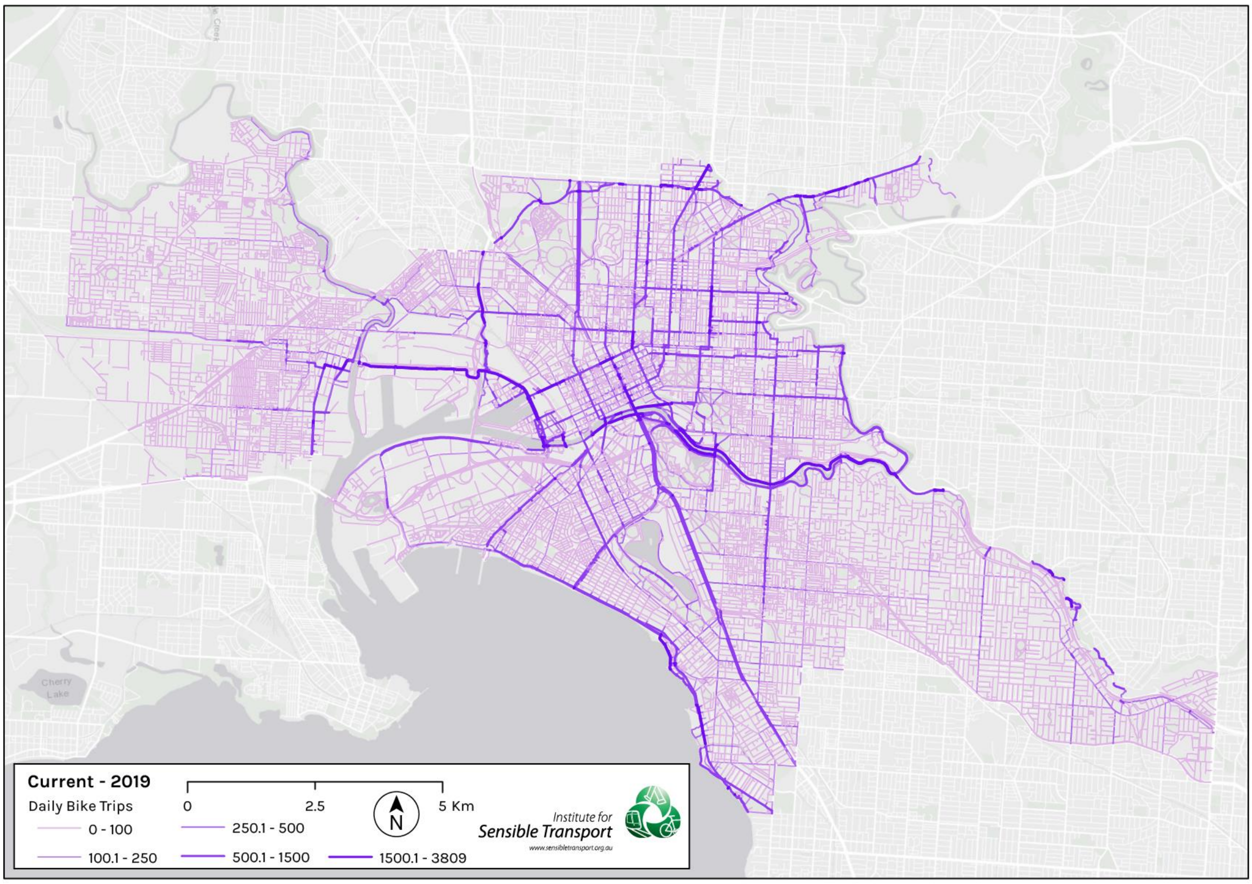
Figure 18 Estimating Cycling Activity - Strava



Source: *Davies et al. (2019)*

The Strava data and physical count data are used to provide an estimate of all cycling across a network, as shown in Figure 19. The regression model used to enable this estimate can be found in Davies et al (2019).

Figure 19 Estimating all cycling activity



Strava is just one example of how *big data* can be used to estimate cycling volumes, and similar activities can also be done for pedestrian volumes, using datasets such as DSPARK.

4.4 Identifying latent demand — the Bike Use Propensity Index

High quality bicycle infrastructure in built up areas can be expensive and government budgets are limited. It is therefore important, when planning a future cycling network, to determine spatial variation in the latent demand for cycling. Through peer reviewed research (see Fishman, Washington, Haworth, & Watson, 2015), a number of Census collected variables have been isolated, in order to provide a heat map of latent demand for cycling, known as the Bike Use Propensity Index.

The Institute for Sensible Transport developed the Bike Use Propensity Index to identify spatial differences in latent demand for cycling in a city or region. The Index is based on seven Census collected variables that are statistically significant predictors of bike use (see Fishman, Washington, Haworth, & Watson, 2015). In sum, these maps provide a clear illustration of the spatial variation in propensity to cycle. In this section, we use the results from a recent application of this methodology, for a bike network prioritisation tool developed by the Institute for Sensible Transport for Transport for NSW (Davies et al., 2020).

The Propensity Index can help guide areas for future investment in cycling infrastructure by identifying the areas where the greatest uptake in cycling is likely to occur. Actions focusing on high propensity areas are likely to include infrastructure projects, but should also consider behaviour change initiatives and other support programs to encourage greater cycling uptake.

Forecasting trips for new infrastructure may be aided by understanding areas of bike use propensity. This is a further aided by integrating origin-destination patterns (see section 4.2) with propensity. As the technique relies on ABS Census data, it can be used for any Australian city or town and provides a useful indication of the potential (at its broadest level) for conversion of trips to active travel. Importantly, the analysis can be cut by maximum trip distance, given that the probability of shifting a trip to active travel is closely related to trip distance (Fishman et al., 2018).

4.4.1 Methodology

A propensity to cycle score (latent cycling demand) is calculated for each Statistical Area 1 (SA1) to Destination Zone (DZN) path, weighted by the likelihood of that journey to occur based on distance (NOTE: this embeds a ‘directness’ measure, too). The Index consists of seven factors, including four residential factors, mapped to SA1s (Figure 20), and three destination factors, mapped to DZNs (Figure 21) based on the latest available Census data (Australian Bureau of Statistics, 2017):

6. Origin factor 1 – Residential Population per hectare
7. Origin factor 2 – Young population (aged 15-34) per hectare
8. Origin factor 3 – Low car (zero or one car) households per hectare
9. Origin factor 4 – Cycling journey to work as an origin per hectare
10. Destination factor 1 – Employment population per hectare
11. Destination factor 2 – Short car trips (under 7km) as a destination per hectare
12. Destination factor 3 – Cycling journey to work as a destination per hectare.

In each case, the area weighted numbers are scaled with a logarithmic function to create a raw ‘score’ on each factor. This will be roughly from zero to five, but as this is a raw score, it is possible for dense areas to have scores higher than five. This is an intended function of the metric; however, the logarithmic function decreases the rise in score as the area weighted score goes up, with the total score based on an average of the factors (sum of all divided by count).

This creates a score (roughly zero to five) on each SA1 as its propensity for a cycling origin, based on demographic features (see Figure 20); and a score (roughly zero to five) on each DZN as its propensity for a cycling destination, based on demographic features.

These scores are then routed along the network, and summed to give an overall score to each network component on the degree to which the link would serve the latent demand for cycling infrastructure, thereby facilitating growth in cycling. Figure 22 uses an abstracted network of the Sydney catchment to show how these scores will be run across a Principal Bicycle Network (PBN). This can be thought of as corridors of propensity to cycle. Figure 22 links these corridors of propensity with the PBN.

Geographic areas that rank in the bottom quintile receive a score of 0.2 for that attribute, while those in the top quintile receive 1.0, as shown in Table 9. The mapped values are aggregates of the attributes’ scores.

Table 9 Ranking system and Index categories

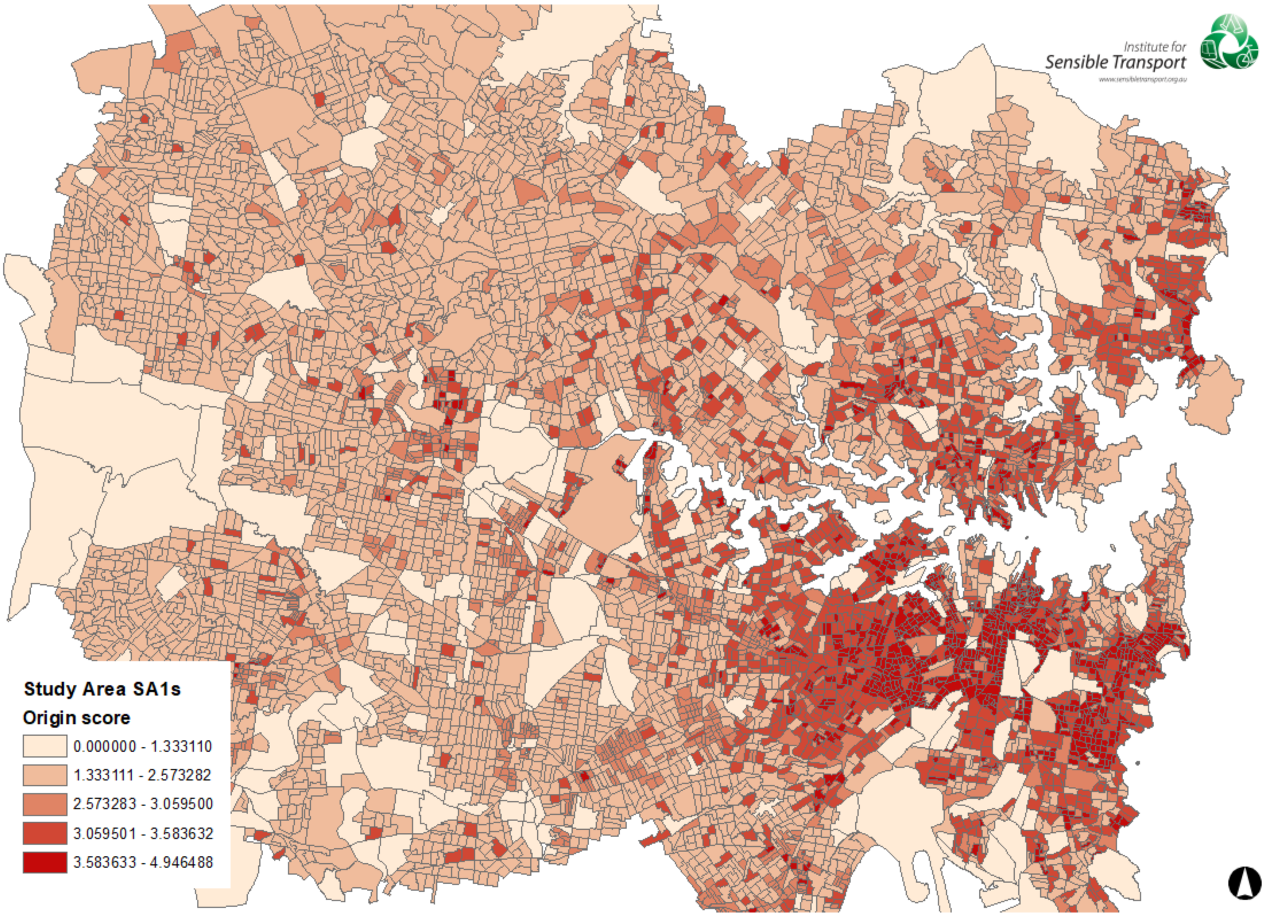
Quintile	Index Score
5	1.0
4	0.8
3	0.6
2	0.4

1	0.2

It is also important to recognise that SA1's that receive very high Index scores will have scored highly across all the variables included in the Index. In almost all cases, an SA1 that scores above 4.5 (out of 5) will have been in the top quintile in at least five variables.

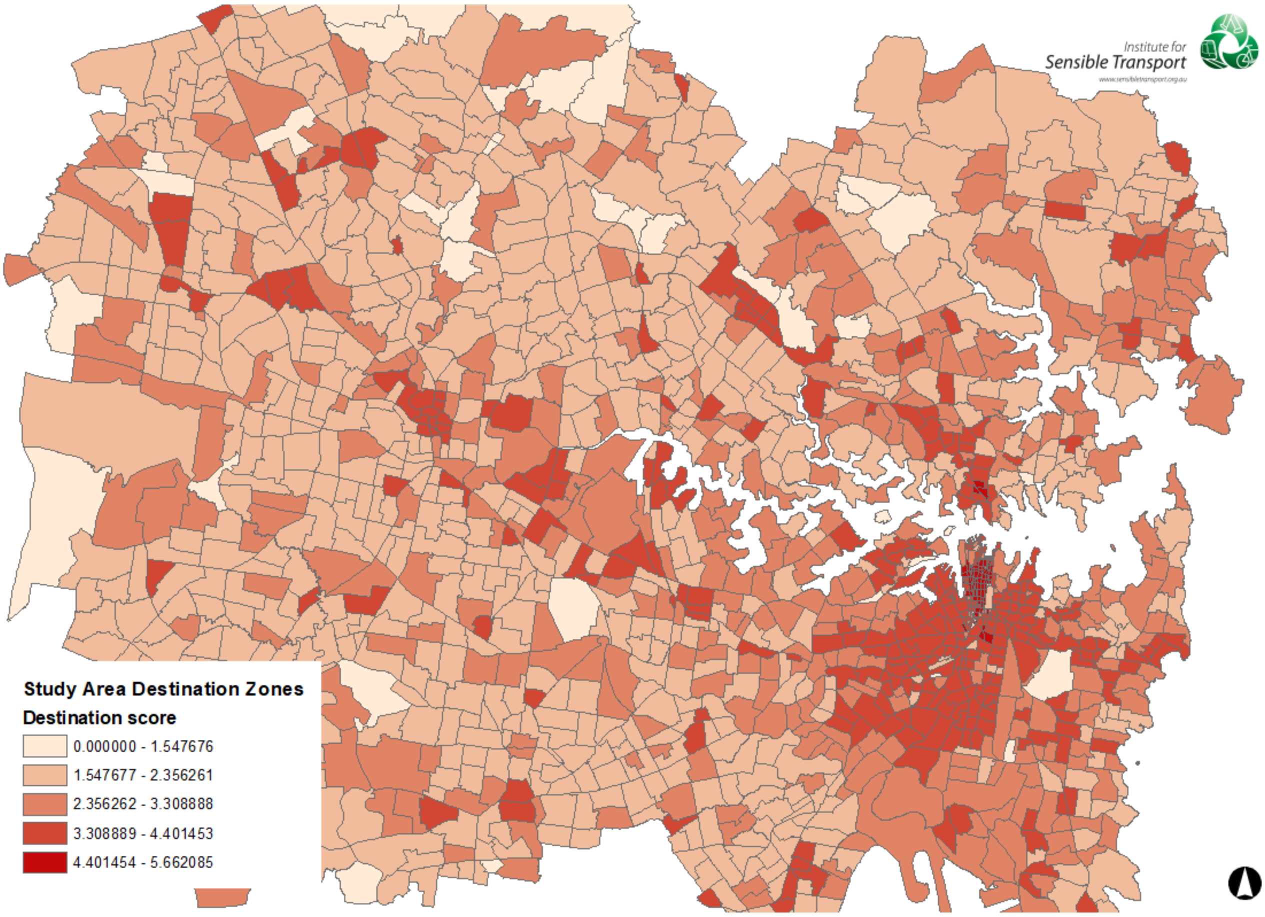
The propensity to cycle at the destination level is shown in Figure 21.

Figure 20 Propensity to Cycle Index, SA1 areas, with origin score



Source: Davies et al. (2020)

Figure 21 Propensity to Cycle Index, SA1 areas, with destination score



Source: Davies et al. (2020)

Figure 22 Propensity Index run across an abstracted cycle network

Source: Davies et al. (2020)

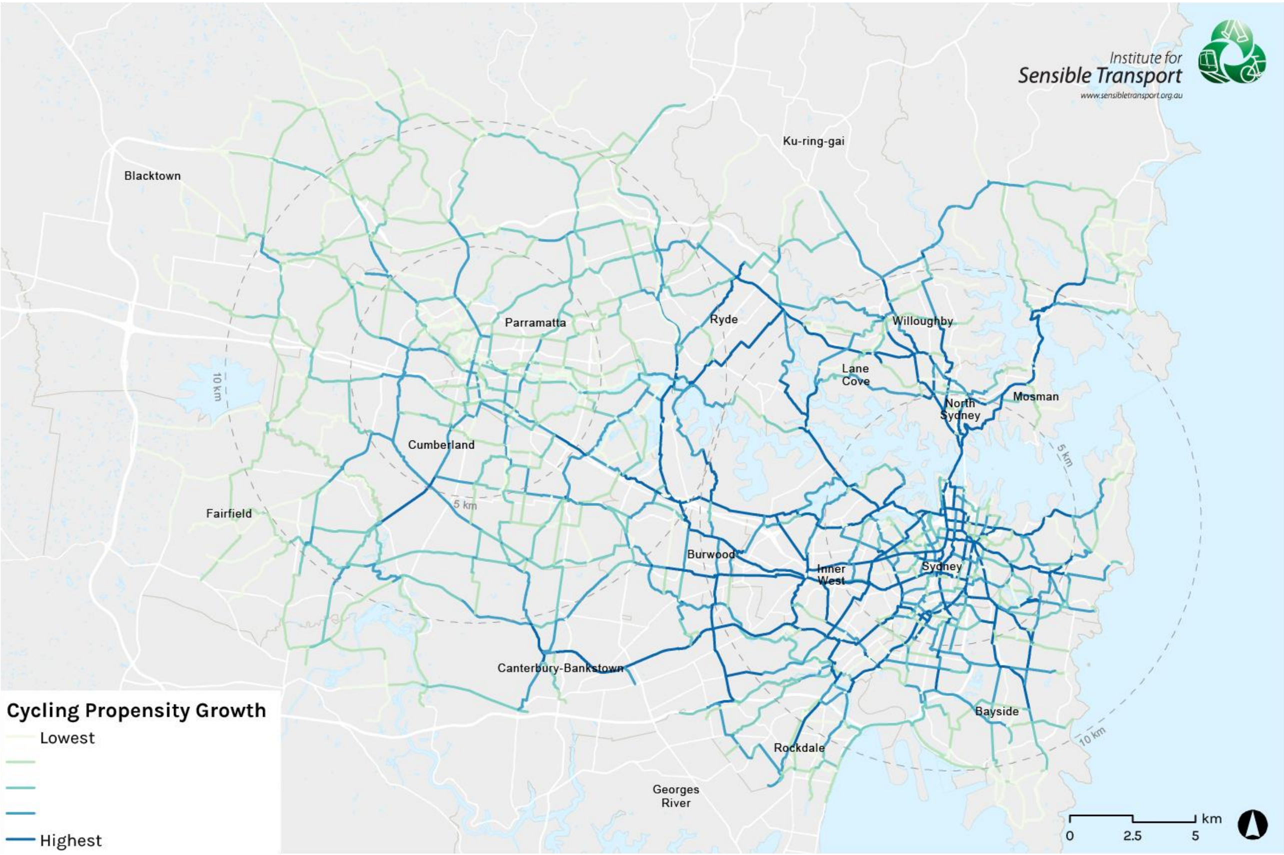
4.4.2 Mapping potential for ridership growth

The following steps were undertaken to produce Figure 22 and Figure 23. The objective of this exercise was to understand where demand may be generated once the network is complete, and to prioritise those links that are shown up as having high propensity for cycling. The purpose of this factor is not to forecast growth, but to highlight the *relative* potential for riding uptake across the study area. This is based on demographic characteristics that tell us how far people are willing to cycle for transport, what makes an attractive destination and what makes an attractive origin for a potential cyclist. The following provides a brief explanation of the steps taken in this process:

- Outline the potential origins and destinations in the network. We use ABS Statistical Area Level 1s (SA1s) for origins, and Destination Zones (DZNs) for destinations.
- For each origin, we assign an attractiveness factor based on population per hectare, young population (15-34) per hectare, low car (zero or one) households per hectare, cycling journey to work origin trips per hectare.
- For each destination, we assign an attractiveness factor based on employment per hectare, short car trips (under 7km) per hectare, cycling journey to work destination trips per hectare.
- We then have over 10 million potential trips between 6,850 SA1s and 1,500 DZNs in our study area.

- Each of these trips is assigned an *origin* attractiveness, and a *destination* attractiveness score.
- They are also assigned a probability based on the distance between the SA1 and DZN based on the distribution of current cycling to work distances from the Census. This is because we know there is a *distance decay*, where people's likelihood of cycling drops sharply beyond ~7km.
- These 10 million trips are then routed through the PBN and the combined attractiveness score is multiplied by its probability for a total likelihood score for each trip.
- The routing algorithm uses the 'shortest path' – as such the routes with the highest directness are also favoured.
- Each of these scores is then added up on each PBN segment to give it a propensity to cycle score.
- Links with the highest scores are most probable in terms of trip length, score high on directness, are the most attractive at the origin and the most attractive at the destination.
- The map shown in Figure 23 shows in dark purple, and through thickness, the highest propensity to cycle scores.
- Geographically, we can see that there are numerous key corridors identified with relatively strong propensity for cycling growth.

Figure 23 Propensity Index, linked to principal bicycle network



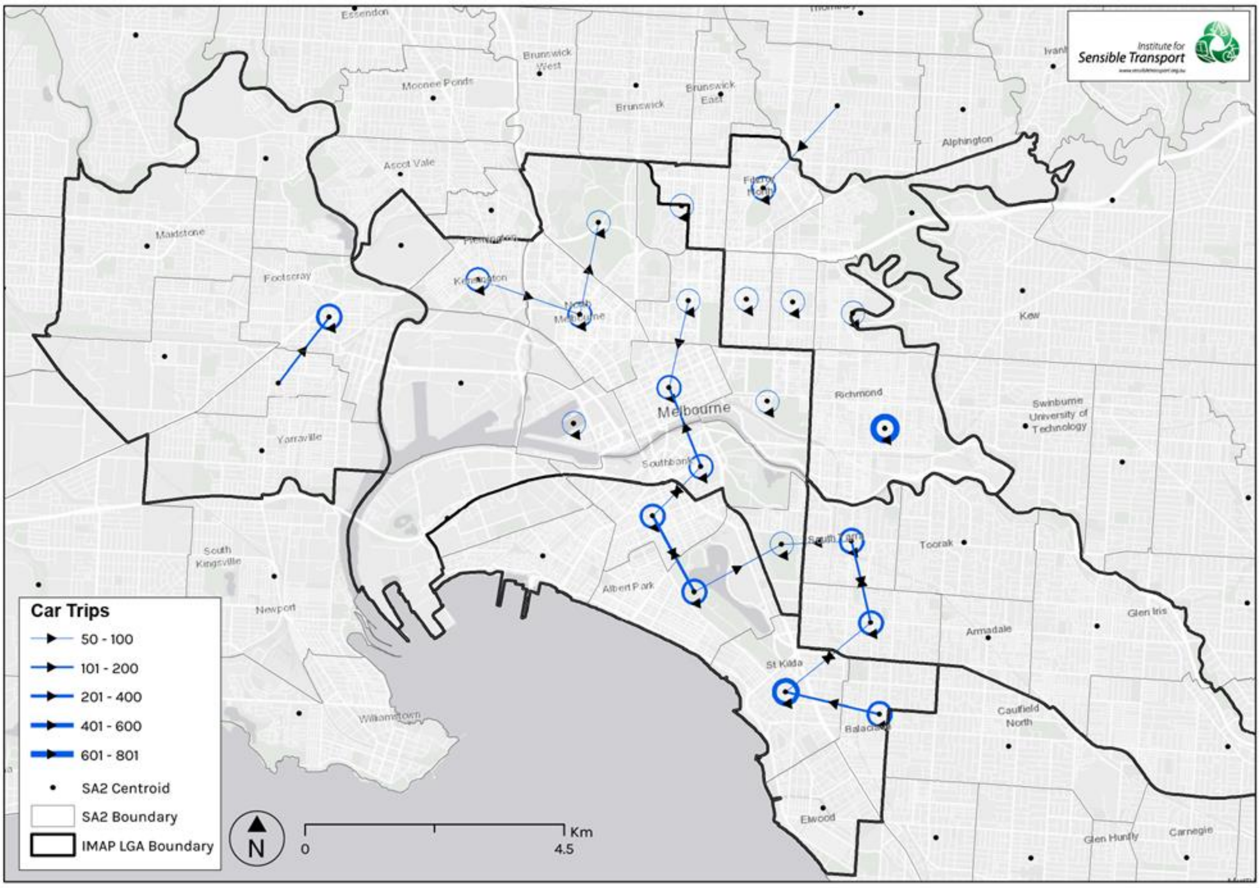
Source: Davies et al. (2020)

Those interested in understanding the network prioritisation tool developed for TfNSW are encouraged to contact TfNSW.

4.5 Propensity to switch short car trip

From a bicycle network planning perspective, it can be useful to examine where there are concentrations of short distance car trips within a city. Figure 24 shows the suburbs of inner Melbourne with high numbers of car commutes of 5km or less from ABS Census data. Where a circle is shown, it indicates trips that start and finish within the given SA2 boundary, while the thickness indicates number of trips. Richmond is the standout – with very high numbers of short distance car trips at peak hour. Similar opportunities are also expected to apply for trips for other trip purposes.

Figure 24 Areas with greatest capacity for converting short car trips



Source: Davies et al., 2019

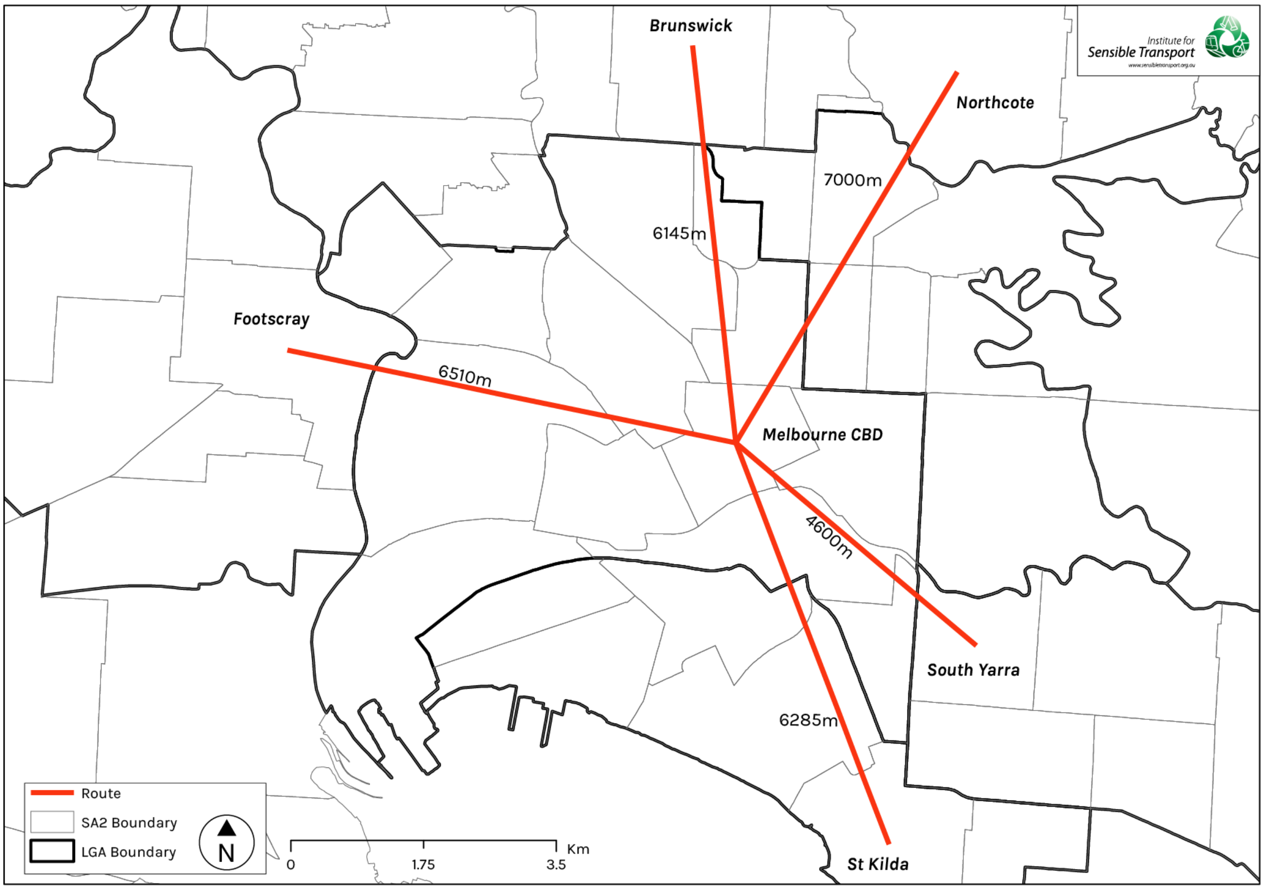
4.6 Time competitiveness analysis of mode choice

Time competitiveness is a critical component in people's transport mode choice. A time competitiveness analysis is therefore instructive to consider the degree to which cycling is time competitive with other modes.

Time competitiveness analysis involves estimating and comparing travel times by mode for various routes. This provides an indication of when bicycle travel is faster than competing transport modes. Such information has the potential to influence the way bicycle network planning is undertaken, to identify corridors where bicycles are most competitive against other modes of transport to provide the most mode shift towards bicycle use. The approach has been used by inner Melbourne councils in their planning.

The approach was investigated by Davies et al. (2019) as part of a modelling activity to understand future bike use in inner Melbourne. A validation exercise was undertaken to test four inputs: bicycle mode share, infrastructure quality score, and line propensity score, distance) for estimating future cycling volumes. The analysis considered five routes with similar line propensity scores, infrastructure quality scores, and all within a cyclable distance. The selected routes are shown in Figure 25.

Figure 25 Five route analysis - time competitiveness



Source: Davies et al. (2019)

The results showed no significant correlation between propensity to cycle, infrastructure quality, distance and the mode share of bicycle trips. Further analysis was then undertaken using the 'time competitiveness' between bicycle travel and the dominant mode share for that same route, shown in Table 10. The outcome of this analysis can be seen in the 'Bike Time Ratio' column on the far-right hand side of Table 10. For each of these five routes, public transport was the dominant mode of travel and was used as the comparative mode for this analysis. Google Maps was used to calculate the time for each of the routes. Where the Bike Time Ratio is 1, it indicates that bicycle and public transport take exactly the same time. Where the Ratio is below 1, bicycle travel is faster, while if it is above 1 public transport is faster.

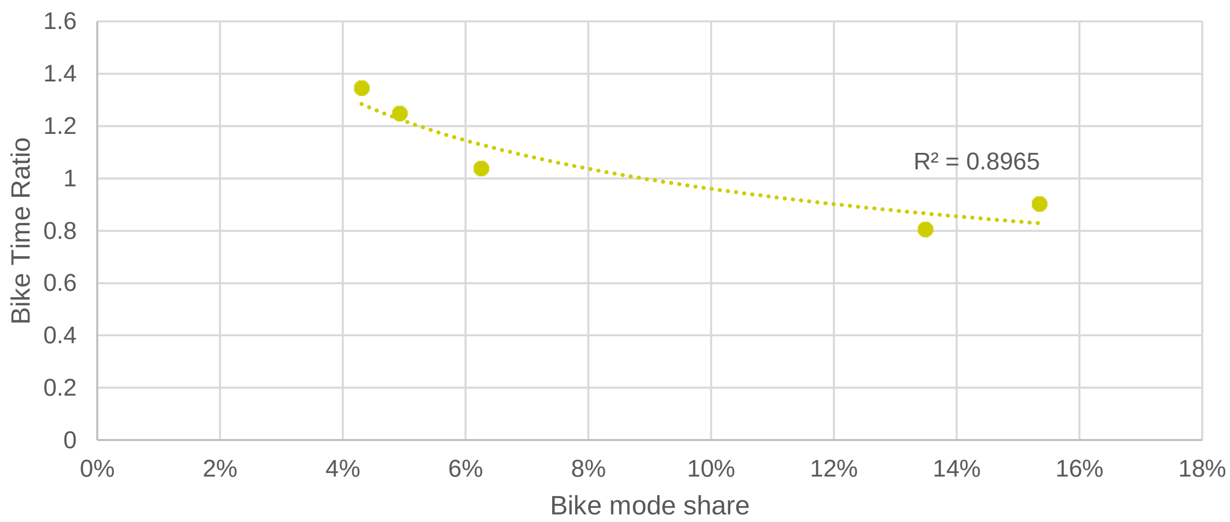
Table 10 Five route analysis

Origin SA2	Destination SA2	Propensity Score	Bike mode share (JtW)	Route confidence rating	Distance (m)	Bike Time Ratio
South Yarra - East	Melbourne	4.82	4.92%	3.62	4600	1.25
Brunswick	Melbourne	4.73	15.34%	3.15	6145	0.90
St Kilda	Melbourne	4.74	6.25%	2.54	6285	1.04
Northcote	Melbourne	4.41	13.49%	2.99	7000	0.81
Footscray	Melbourne	4.24	4.30%	3.94	6510	1.35

Source: Davies et al. (2019)

There was a significant correlation (R^2=0.88) between the time competitiveness of bicycle travel and public transport, as shown in Figure 26. This means that when public transport is faster, it depresses the mode share for cycling (e.g. South Yarra – East in Table 10), and when bicycle travel is faster than public transport, the bike mode share is amplified (e.g. Northcote to Melbourne). This finding has the potential to influence the way bicycle network planning is undertaken, to identify corridors where bicycles are most competitive against other modes of transport to provide the most mode shift towards bicycle use. As a result of this analysis, time competitiveness was factored into the Bicycle Network Model produced for inner Melbourne councils (Davies et al., 2019).

Figure 26 Time Competitiveness and mode choice, Journey to Work



Source: Davies et al. (2019) based on Census data (Australian Bureau of Statistics, 2017) and VISTA data (Transport for Victoria, 2017).

4.7 Monitoring increases

4.7.1 Sydney cycleway ridership increases

The City of Sydney has installed a number of new protected cycleways in the past 10 years. The City has undertaken pre- and post-installation counts of ridership along the upgraded sections, and other parts of the cycling network generally. The results provide a helpful case study for understanding the potential uplift of ridership for central and inner-city areas.

Table 11 provides a sample of cycling infrastructure upgrades where at least five years of post-upgrade data is available. These routes have seen, on average, a growth of 331% in daily ridership five years after upgrade. Growth in daily ridership varies, depending on the infrastructure's CBD or inner-city location. CBD sites (Kent, King, and Liverpool Streets) saw an average increase of 1,000 daily riders while the remaining inner-city locations saw an average daily increase of 331 riders.

Further analysis would be required to determine the extent that the growth comes from new riders or riders changing the course to take advantage of the new infrastructure. This could be undertaken at a high-level through monitoring changes in Census Journey to Work rates or through household travel surveys. Micro-analysis could be undertaken using intercept surveys at hold points for cyclists, such as signalised intersections.

While Table 11 is a small study sample, it is helpful for showing the potential growth in cycling activity for an inner-city cycling infrastructure upgrade.

Table 11 Sydney Cycleway Impacts

Location	Pre-install daily cycling activity	+ 5 years daily cycling activity	Growth 5 years after install	Growth in daily bike riders
Castlereagh St	269	832	309%	563
Kent St / Druitt St	170	805	474%	635
King St / Kent St	654	1770	271%	1116
Liverpool St / College St / Wentworth St / Oxford St	687	1740	253%	1053
Bourke Rd / Maddox St	139	502	361%	363
Gardeners Rd / Bourke Rd	124	331	267%	207
Mandible and Bowden	59	227	385%	168
William St / Bourke St	122	432	354%	310
Wellington ST/ George St	201	607	302%	406

Source: Based on City of Sydney data (https://experience.arcgis.com/experience/7fe4798902f64068819586a1035e26ba)

5. Safety

5.1 Crash risk per distance travelled

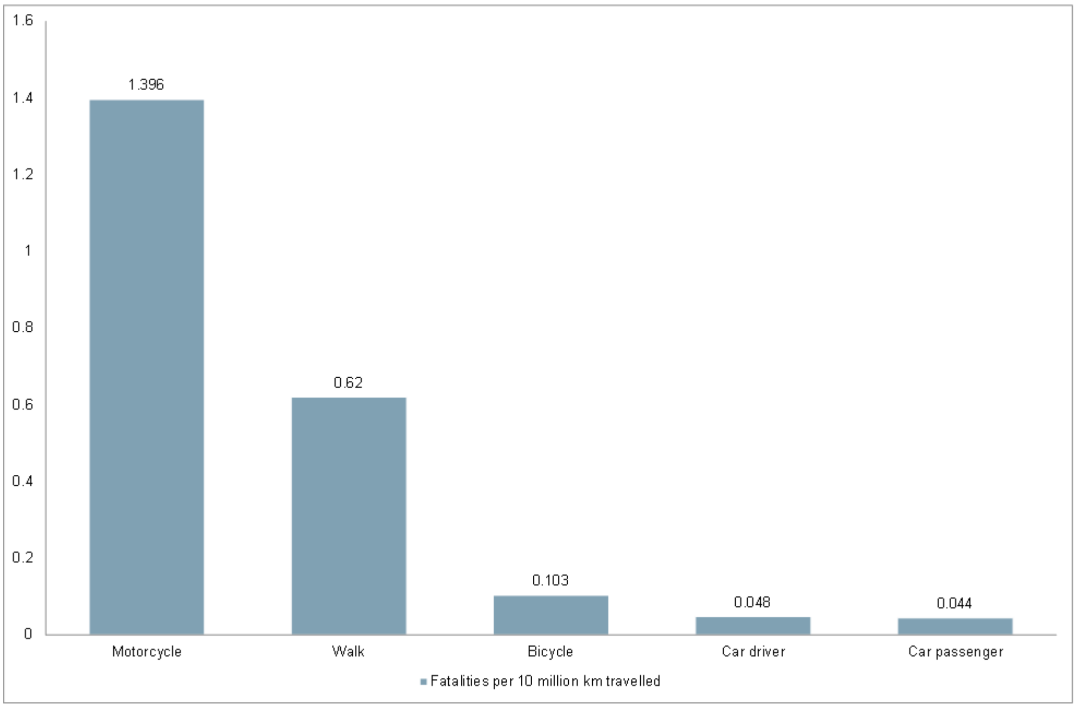
Pedestrians and cyclists are more vulnerable to physical injury from collisions, in comparison to motorised forms of transport (Götschi et al., 2015). A kilometre of walking or cycling holds greater risk of road trauma compared to a kilometre of motorised transport.

Austroads (2010) provides the basis for a comparison of relative risk across modes. Table 12 and Figure 27 presents fatality rates (deaths per 100 million km), and Table 13 presents rates of serious injury (serious injuries per 100 million km). These show that, on a per kilometre travelled basis: [4]

- Fatality rates for walking and cycling are higher than car driving and travelling as a car passenger, but lower than motorcycle travel (which involves the highest risk)
- Fatality rates for walking and cycling are 2 and 12 times those for car drivers respectively
- A similar pattern is observed for serious injury risk.

Table 14 reports more recent data on crash risk for Melbourne. Table 15 shows statistics on cyclists killed in Australia. Active travel risk is up to eight times riskier than private motor vehicle travel. Pedestrians are at higher risk than cyclists. For cyclists, most fatal crashes involve a collision with a motor vehicle.

Figure 27 Fatality rates by mode



Source: Austroads (2010)

[4] The relative differences are expected to be partly due to the different standard of infrastructure provided across modes.

Table 12 Fatality rates for motorists and active travellers, Australia (2002 to 2006)

User description	Estimated annual travel (10 million km travelled)	Fatalities annual average	Fatality rate per 10 million km travelled
Motorcyclist	96	134	1.3960
Pedestrian	271	168	0.6200
Bicyclist	124	24	0.2000
Car driver	11 866	572	0.0480
Car passenger	5611	247	0.0440
Rail passenger [(a)]	-	-	0.0082
Bus passenger [(a)]	-	-	0.0082
Total car	17 477	819	0.0470
Total car and motorcycle	17 573	953	0.0540
Total active travel	505	192	0.3800

Note: Excludes Queensland due to inconsistencies in data categories.

(a) Rail and bus passenger risk has been estimated separately by reference to BTRE (2003) which estimated fatality risk for bus and rail passengers as being 17% of the risk for car occupants.

Source: Estimated from Austroads (2010) p.8, other than for (a)

Table 13 Serious injury rates for motorists and active travellers Australia (2002 to 2006)

User description	Estimated annual travel (10 million km travelled)	Serious injuries annual average	Serious injury rate per 10 million km travelled
Motorcyclist	61	1171	19.197
Pedestrian	152	926	6.092
Bicyclist	88	440	5.000
Car driver [(a)]	7419	6264	0.844
Car passenger [(a)]	3471	2057	0.593
Total car	10 890	8321	0.764
Total car and motorcycle	10 951	9492	0.867
Total active travel	240	1366	5.692

Note: Excludes Queensland and New South Wales due to inconsistencies in data categories.

(a) See note to Table 16.

Source: Estimated from Austroads (2010) p.8

Table 14 Risk of road death and injury per 100 million km travelled by transport mode, Melbourne

	Melbourne	
	Deaths	Injuries
Walking	7.6	108.6
Cycling	1.4	79.8
Vehicle driver	0.2	7.3
Vehicle passenger	0.2	7.1
Bus passenger	0.1	0.7
Train, tram or subway passenger	0.1	0.2
Other (incl. motorcycle)	16.5	485.1

Source: Stevenson et al (2016)

Table 15 Cyclists killed in road crashes, Australia, 1997 to 2004

Event	Counterpart	% of cyclist deaths
Collision with	Pedestrian	1
	Pedal cycle or other motor vehicle	0
	Car, pick-up truck, van or other motor vehicle	64
	Heavy transport vehicle	22
	Railway train or railway vehicle	1
	Fixed or stationary object	4
Not a collision		5
Unknown		3
Total		100

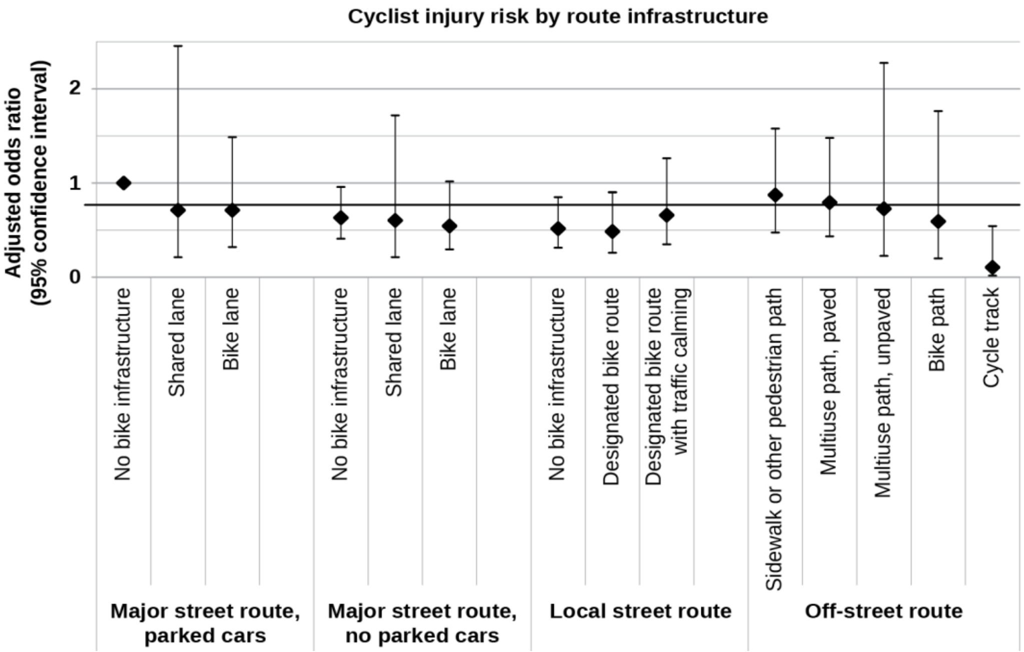
Source: ATSB (2006) p.4

5.2 Crash risk by facility type

The rate of injury and fatality to cyclists is very much related to the type of infrastructure being used (Anne Harris et al., 2013, Teschke et al., 2012). Indeed Teschke et al. (2012) found that the probability of a crash rose by a factor of ten when riding on an arterial road with parked cars compared to a protected bike lane.

Figure 28 provides an indication of how the chance of a cycling injury varies by infrastructure type. In this example, the reference category is a busy street with no bike infrastructure and parked cars (i.e. odds ratio of 1). Anything below one means less risk of an injury. It shows that a local (small, quiet) street, even when it does not have any bike infrastructure presents half the risk of injury, compared to a major street with parked cars and no infrastructure. The results shown in Figure 28 are supported by earlier work by Reynolds et al. (2009, p. 15), which, in a meta-analysis of the data found that *'clearly marked bike specific facilities were consistently shown to provide improved safety for cyclists compared to on-road cycling with traffic or off-road with pedestrians and other users'*

Figure 28 Cyclist injury risk by infrastructure type



Source: Reproduced from Teschke et al. (2012)

Table 16 shows the crash rates for different bike infrastructure typologies in inner-Melbourne. This was done by estimating total bike activity on streets within Melbourne, using *Strava Metro* and physical count data (see section 4.3) and comparing police-recorded crashes for different infrastructure types. The results in Table 16 show that separated bike infrastructure can be more than twice as safe as no infrastructure. Low-traffic and low-speed bicycle boulevards (for example Canning Street or Napier Street in Melbourne) are safest of all, with only 0.3 crashes per 100,000 cycling kilometres travelled (Davies et al., 2019).

Table 16 Cyclist crash rates by infrastructure type, Inner-Melbourne

Infrastructure Type	No bike infrastructure	Painted Lane	Buffered Lane	Separated	Bike boulevard[5]
Crashes per 100K KM	1.2	0.8	0.8	0.5	0.3

Source: Davies et al (2019).

5.3 Unit crash costs

For use in project appraisal, crash risks are converted to unit crash costs by factoring by suitable values of statistical life. Unit crash costs estimated on a per distance basis are shown in Table 17 across transport modes. The active travel crash cost estimates are based on crash exposure risk calculated separately for driver and passengers, and hence should not need to be adjusted for vehicle occupancy.

Two sets of crash costs are shown in Table 17: the more recent inclusive willingness to pay approach; and the older hybrid human capital approach used in Australia for many years and that derives from research carried out by BITRE. The ATAP Guidelines favour the inclusive willingness to pay approach.[6].

Table 17 Crash costs by mode per vehicle km (2021 dollars)

Mode	Crash cost per veh km	
	Inclusive willingness to pay approach	**Hybrid human capital approach**
Car/ motorcycle	$0.28	$0.15
Cyclist	$1.27	$0.65
Pedestrian	$1.92	$0.89
Total active travel	$1.60	$0.79
Train	$0.05	$0.03
Bus	$0.05	$0.03

Source: Estimated from Austroads (2012), Austroads (2010), BTRE (2006), BTRE (2003)

Note: If information is available on variation in unit crash cost by road type, this could be used to scale this figure accordingly

[5] Bicycle boulevards are streets with low motorised traffic volumes and speeds, designated and designed to give bicycle travel priority.

[6] The value of statistical life incorporated in the willingness to pay estimates in Table 17 derives from recent research into the value road users place on avoiding premature death in a range of trip choice situations (see Austroads (2015) and Volume 2 of NGTSM). Those values might not be readily transferrable to active travellers. The value of statistical life that is included in the health benefit estimates has a broader base, representing the willingness of individuals to pay to avoid a small increase in the risk of premature death.

5.4 Effectiveness of interventions

The safety effectiveness of an initiative is measured by the per cent reduction in risk that it delivers. Table 18 to Table 21 report the effectiveness of various types of initiatives found in studies.

Table 18 Effectiveness of active travel safety interventions - cycling

Intervention	Reduction in bicycle crash risk	Reduction (increase) in overall crash risk, all vehicles	Source
Cycle lanes (lane between kerb and parked cars)	10%		cited in Schramm and Rakotonirainy (2008) Europe
Cycle lanes (lane between kerb and parked cars)	28%		Lusk et al (2013) Montreal
Cycle lanes (lane between kerb and parked cars)	30%-62%		Lusk et al (2013) New York City
Mid-block cycle lanes	10%	30%	Elvik and Vaa (2004) cited in Turner et al (2011)
Advanced limit lines (storage boxes)	27%	40%	Elvik and Vaa (2004) cited in Turner et al (2011)
Adding cycle lanes through an intersection	12%	(14%)	Elvik and Vaa (2004) cited in Turner et al (2011)
Traffic calming	36%	40%	Davies et al (1997) cited in Turner et al (2011)
Cycle lanes marked on-road, mid-blocks	29%		UK, Coates (1999) cited in Turner et al (2009)
Cycle lanes marked on-road, intersections	35%		UK, Coates (1999) cited in Turner et al (2009)
On-roadway cycle lanes	57%		York UK: Transport for London (2004) cited in Turner et al (2009)
Shared use footpath	28%		York UK: Transport for London (2004) cited in Turner et al (2009)
Signalled intersections	83%		York UK: Transport for London (2004) cited in Turner et al (2009)
Cycle track + ^	100%		York UK: Transport for London (2004) cited in Turner et al (2009)
Cycle lane	70%		York UK: Transport for London (2004) cited in Turner et al (2009)
Advanced stop line at signals** ^	100%		York UK: Transport for London (2004) cited in Turner et al (2009)

(…) signifies an increase in crash risk.

(+) the definition of cycle track is unclear. See Turner et al (2009).

***Advanced stop line at signals includes storage box.*

^ Turner et al (2009) indicates that reductions of this magnitude are unrealistic.

Table 19 Effectiveness of signalisation countermeasures – walking (US)

Countermeasure (s)	% Crash reduction factor		
	Crash severity	Left-turn crashes	Pedestrian
Add exclusive pedestrian phasing	All		34
Improve signal timing (to intervals specified by the ITE Determining Vehicle Change Intervals: A Proposed Recommended Practice (1985))	Fatal/injury		37
Replace existing WALK / DON'T WALK signals with pedestrian countdown signal heads	All		25
Modify signal phasing (implement a leading pedestrian interval)	All		5
Remove unwarranted signals (one-way street)	All		17
Convert permissive or permissive/protected to protected only left-turn phasing	All	99	
Convert permissive to permissive/protected left-turn phasing	All	16	

Note: US terminology, dimensions and spelling in original

Source: FHWA (2008)

Table 20 Effectiveness of geometric countermeasures – walking (US)

Countermeasure (s)	% Crash reduction factor		
	Crash severity	All crashes	Pedestrian
Convert unsignalized intersection to roundabout	Fatal/injury		27 (12)
Install pedestrian overpass/underpass	Fatal/injury		90
	All		86
Install pedestrian overpass/underpass (unsignalized intersection)	All		13
Install raised median	All		25
Install raised median (marked crosswalk) at unsignalized intersection	All		46
Install raised median (unmarked crosswalk) at unsignalized intersection	All		39
Install raised pedestrian crossing	All	30 (67)	
	Fatal/injury	36 (54)	
Install refuge islands	All		56
Install sidewalk (to avoid walking along roadway)			88*
Provide paved shoulder (of at least 4 feet)			71*
Narrow roadway cross section from four lanes to three lanes (two through lanes with centre turn lane)	All	29	

**Only applies to 'walking along the roadway' type crashes*

Note: US terminology, dimensions and spelling in original

(...) signifies standard error.

Source: FHWA (2008)

Table 21 Effectiveness of operational countermeasures – walking (US)

Countermeasure (s)	% Crash reduction factor		
	Crash severity	All crashes	Pedestrian
Add intersection lighting	Injury	27*	
	All	21*	
Add segment lighting	Injury	23*	
	All	20*	
Improve pavement friction (skid treatment with overlay)	Fatal/injury		3
Increase enforcement **	All		23
Prohibit right-turn-on-red	All	3	
Prohibit left-turns	All		10
Restrict parking near intersections (to off-street)	All		30

**Applies to night time crashes only*

***Applies to crash reductions on corridors where sustained enforcement is used related to motorist yielding in marked crosswalks combined with a public education program*

Note: US terminology, dimensions and spelling in original. Turn directions should be reversed for Australian application.

Source: FHWA (2008)

5.5 International comparisons

There is value in comparing crash statistics for active travel between countries and cities. If for no other reason, such comparisons can provide a benchmarking function, to assist cities and countries seeking to achieve best practice outcomes in road safety. Stevenson et al (2016) have compared a range of cities, including Melbourne (see). While the data is 6 – 10 years old, it is interesting to note some of the surprising comparative risks this table illustrates. The problems with comparing different regions and cities are discussed below, but for now it is worth pointing out as an example that the cycling injury rates in Boston and Copenhagen shown in Table 22 are almost identical, despite Copenhagen having one of the most comprehensive, high quality separated bicycle infrastructure networks. In instances such as this, it is more likely that there is an under-reporting of cycling injuries in Boston, and/or an over-estimate for the amount of cycling. As highlighted below, walking and cycling injury rates are subject to a high degree of uncertainty, due to the poor quality of data regarding both the total number of kilometres walked and cycled, as well as widespread under reporting of crashes, especially those of a minor nature. The difficulties of comparing crash risk in the manner presented in Table 22 are described below.

Table 22 Risk of road death and injury per 100 million km travelled by transport mode

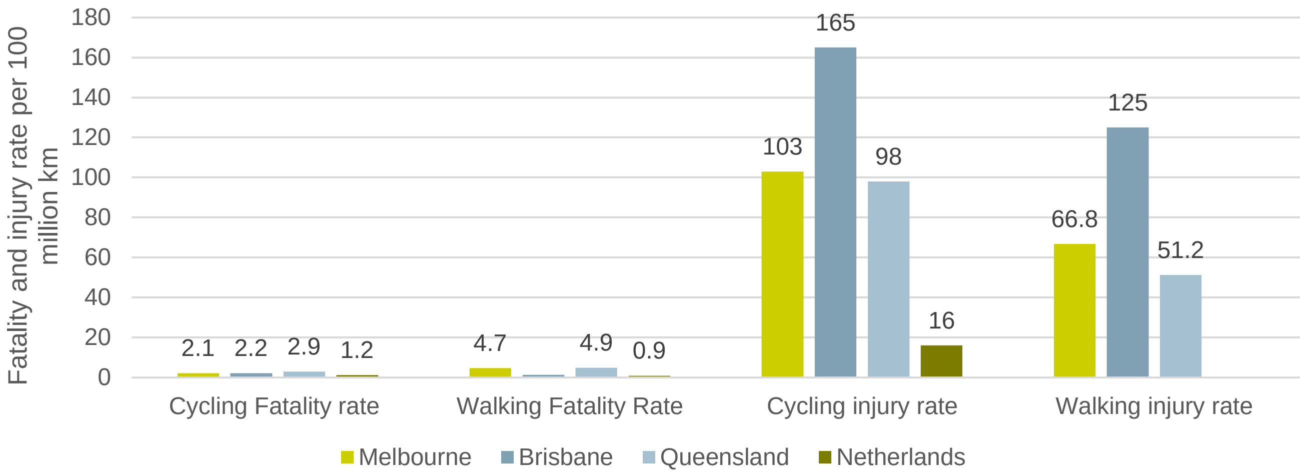
	Melbourne		Sao Paulo		Delhi		London		Boston		Copenhagen	
	Deaths	Injuries	Deaths	Injuries	Deaths	Injuries	Deaths	Injuries	Deaths	Injuries	Deaths	Injuries
Vehicle driver	0.2	7.3	1.7	38.1	0.4	2.5	0.2	3.5	0.9	2.2	0.3	3.7
Vehicle passenger	0.2	7.1	1.9	106.7	0.4	2.5	0.2	3.5	0.5	1.7	0.3	3.5
Train, tram or subway passenger	0.1	0.2	0.0	0.1	1.5	8.7	0.0	0.2	0.0	0.1	0.1	0.6
Bus passenger	0.1	0.7	0.0	7.1	0.2	1.4	0.1	2.5	0.0	0.2	0.3	0.7
Walking	7.6	108.6	16.6	216.6	20.9	125.3	5.9	64.8	2.7	12.0	3.2	50.0
Cycling	1.4	79.8	25.8	472.7	4.3	25.8	4.4	140.8	2.5	23.0	0.6	26.6
Other (incl. motorcycle)	16.5	485.1	23.6	826.5	9.1	54.3	13.1	229.0	0.1	3.5	3.4	171.0

Source: Stevenson et al (2016)

According to the results shown in Table 22, walking in Melbourne is around 5.5 times as risky (from a fatality perspective) as cycling the same distance. In terms of injury rate, walking in Melbourne is about 1.3 times as likely to result in injury, compared to cycling, on a per distance basis (Stevenson et al., 2016). Melbourne walkers are at around twice the risk level for injuries and death compared to those in Copenhagen, and cyclists are twice as likely to be killed and three times as likely to be seriously injured in Melbourne, compared to Copenhagen, per km travelled. While there are likely to be a multitude of factors contributing to this difference, it does underline the importance of widespread protected bicycle infrastructure and lower speed limits, both features of the Danish transport system (Chataway et al., 2014).

Figure 29 provides in indication of the fatality and injury rate (per 100 million kilometres travelled) for various modes, in two Australian cities, and the Netherlands. The Melbourne data was compiled differently to Brisbane, and was calculated using a number of data sources, as part of the development of this report. Using a combination of police recorded crash statistics and estimated annual kilometres travelled for different transport modes in Melbourne, using the VISTA travel survey data (see Table 1). This was done by taking Melbourne's estimated population (5 million) and using the VISTA mode share to get the approximate daily travellers for each mode. Their average number of trips and average distance was then multiplied to get an average daily kilometres travelled, then scaled to annual figures. Police reported crashes for the last five years were broken into travel mode and severity, then divided by 5 to get an average year's crash figures for each mode. The annual crash type (fatality or serious injury) was then divided by the annual kilometres travelled then multiplied by 100,000,000 to get a crash rate per 100 million kilometres. Figure 29 shows the results of that exercise.

Figure 29 Fatality and injury rate, different countries and modes



Source: Melbourne based on data provided by Australian Bureau of Statistics (2017), Transport for Victoria (2017) and VicRoads (2020), Brisbane (Zapata-Diomedi and Veerman, 2017) and Netherlands (SWOV, 2020). Dutch cycling injury rate based on figures in Pucher and Buehler (2012).

NB: Dutch injury figures are those that meet at least a MAIS2 (i.e.at least a moderate injury).[7]

Again, the data shown in Figure 29 highlights some surprising results. These data suggest cycling in the Netherlands is *only* twice as safe as riding in Melbourne, in terms of fatalities per distance cycled. Given the vast differences in the key determinants of cycling safety (bicycle infrastructure, vehicle speed, driver behaviour), this is difficult to reconcile, other than to conclude that the data is not reflective of actual risk levels. While it is unlikely that the fatality rate is reported incorrectly, it may be that the number of kilometres cycled in Melbourne has been overestimated, resulting in Melbourne appearing to be safer than it might actually be, from a fatalities per 100 million kilometres perspective. In any case, the data shown in Table 22 and Figure 29 are offered to highlight the issues associated with active travel risk reporting, rather than to use as a source of reliable information. Finally, it is important to recognise that data for the Netherlands is for the entire country, whereas the Australian data is focused only on Brisbane and Melbourne.

Another way to look at injury exposure is not by distance but by *time.* A New Zealand study (see Tin Tin et al., 2010) took this approach and found that cycling injury rates are 15 times higher for cycling, compared with drivers. They found 30 cycling injuries can be expected for every million hours cycled. See section 5.8 below for further discussion on time-based numbers.

5.6 Safety in numbers

The *Safety in Numbers* effect may occur, that is, the average risk may decrease as cycling level increases (rather than a proportional relationship). The effect is well discussed in the research literature (Elvik and Bjørnskau (2017) provide an extensive discussion), and has been integrated into some practitioner tools (e.g. HEAT and ITHIM). The effect may reflect various factors: as walking and bicycling increase, drivers probably become more cautious, and pedestrians and bicyclists impose minimal risk to motorists, which increases safety to all road users.

The concept of safety in numbers emerges from a seminal paper by Jacobsen (2003) which shows that:

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[7] https://www.swov.nl/en/facts-figures/factsheet/serious-road-injuries-netherlands

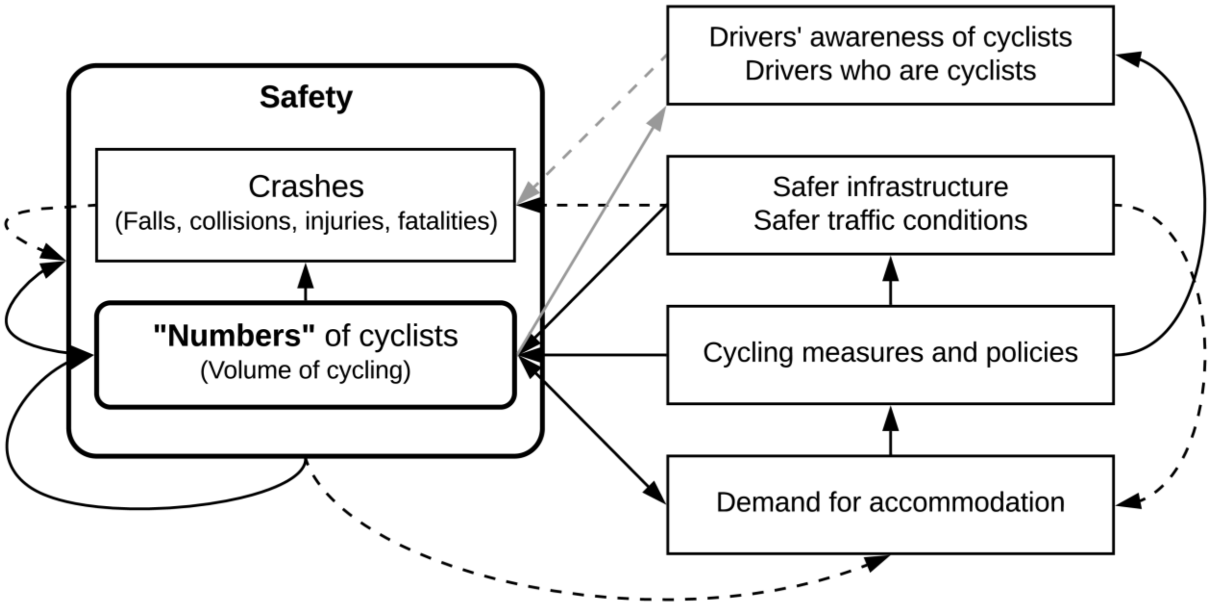
'for pedestrians and cyclists, the fatality rate is inversely related to the amount of travel by that mode. The data is demonstrated with fatalities associated with walking and cycling data in Californian cities, injuries associated with cycling in Denmark and walking and cycling fatalities across European countries. All the data sets show diminishing rates of fatal and serious injury with increasing levels of walking or cycling.' (Austroads, (2010) p.31)

In other words, the *Safety in numbers* theory posits that there is a non-linear relationship between growth in cycling and cycling injuries. Put simply, what Jacobsen found was that there is an inverse relationship between the probability of being involved in a cycling collision and the overall levels of cycling. Jacobsen found that this relationship held true across multiple cities, of varying population. The theory has attracted a great deal of attention and a number of other researchers have investigated the relationship, not always with the same findings as Jacobsen.

Jacobsen found that the likelihood that a 'motorist will strike an individual person walking or bicycling declines with the roughly -0.6 power of the number of persons walking or bicycling' (Jacobsen, 2003, p. 208). There are a number of pathways through which a *safety in numbers* effect is plausible. Firstly, in communities in which more cycling takes place, it is likely drivers are more likely to *'see'* cyclists as they are a more common feature of the road traffic environment. Secondly, in these communities, drivers are more likely to also cycle themselves, which further increases their chance of driving in a more aware/considerate manner. Finally, a city with high levels of cycling is likely to have street designs that support safe cycling, such as protected bike lanes and lower speed (Buehler and Pucher, 2021). In addition, as Elvik and Sundfør (2017) note (see discussion below), when increases in cycling occurs at the same time that motor vehicle travel decreases, the risk of cycle injury is lowered more powerfully than when motor vehicle travel remains constant.

Figure 30 offers a schematic depiction of the relationship between *safety* and *numbers.* The solid arrows reflect positive associations (i.e. increases) and the dashed arrows reflect negative associations (i.e. decreases).

Figure 30 Schematic depiction of the relationship between safety and numbers

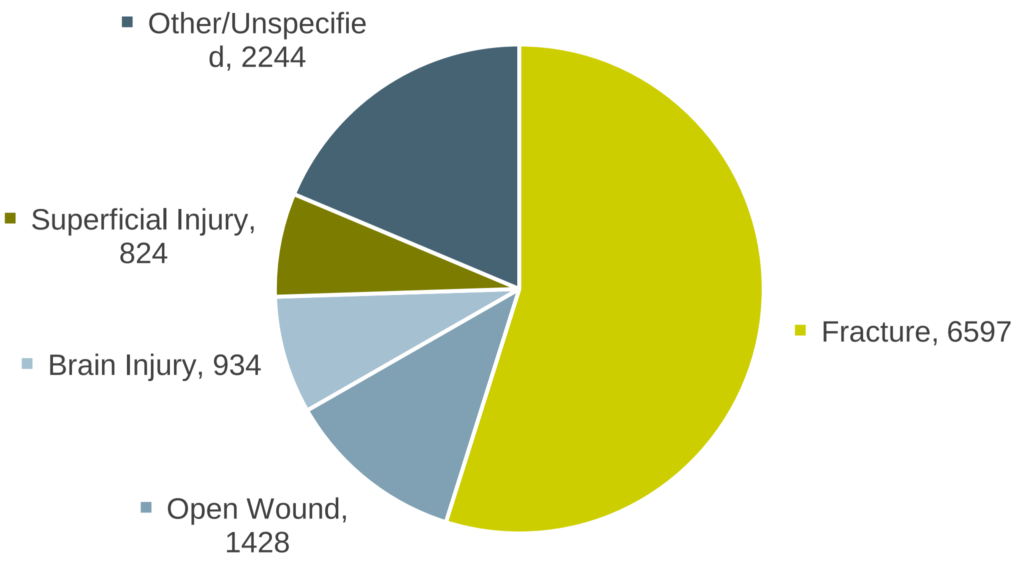


Source: Götschi et al. (2015)

A contentious issue within the field of economic assessment of active transport relates to the approach for integrating road trauma impacts. On the one hand, the development of new bicycle infrastructure is likely to provide a protective function, reducing the likelihood of collision and injury (Schepers et al., 2017). On the other hand, when compared to car occupants, people cycling are at greater risk of collision and injury, on a per kilometre travelled basis, even in cities with very good bicycle infrastructure (Stevenson et al., 2016).

Recent data shows that some one in five people injured on Australian roads are cycling. The Australian Institute for Health and Welfare found that in the year 2015-16, some 12,027 people attended a hospital due to a cycling injury. The breakdown of injury types is shown in Figure 31.

Figure 31 Australian hospital treatments due to cycling injuries, 2015-16



Norweign researchers Elvik and Sundfør (2017) examined how cycling injuries can be included within health impact economic assessment. They note that one of the main barriers for being able to properly include cycling related trauma within these assessments is the fact that many cycling crashes are under reported, especially for those that are less severe. Providing an indication of the magnitude of this gap, the authors note that in one study, only 7.5% of crashes reported from a study were actually reported to police. The two key research problems Elvik and Sundfør (2017) set out to address were:

- What is known about the health impacts of injuries sustained by cyclists? Can health impacts be summarised by means of a generic indicator such as DALYs?
- What is known about the risk of injury per cyclist or per kilometre cycled? Is non-linearity of risk (i.e. Safety in Numbers) sufficiently known to account for it in health impact assessment?

A review of the literature undertaken by Elvik and Sundfør (2017) found mixed results in terms of the impact on injuries from increased cycling, with some studies modelling an increase in injuries, while others found a decrease. This was found to be partially dependent on whether the researchers included *safety in numbers* within their assumption.

In addressing the first question, the researchers provide a table of cyclist injuries from a Swedish database (the STRADA system). While the transport and land use system in Sweden might be quite different from Australia, where cyclist injuries occur of the same type, it is reasonable to assume that the impact on health will be comparable.

Elvik and Sundfør (2017), citing data collected by Nilsson et al. (2017) provide a list of cyclist injury types, including the *duration of disability* and the *Years Lived with a Disability* (YLD), as shown in Table 23. This table also incorporates *disability weights,* which apply a value between 0 and 1, where 0 is no disability and 1 is death. For instance, a spinal cord injury has a disability weight of 0.725 and a sprain has a disability weight of 0.064. This is based on the Eurocost system and provides disability weights for 39 different injuries. The study found that only 1.2% of cyclists' injuries involve lifelong disability. Less than 0.1% of cyclist injuries were fatal, however it is quite plausible that this might be different in Australia, which typically have high average speed limits in built up areas than is common in both Norway and Sweden.

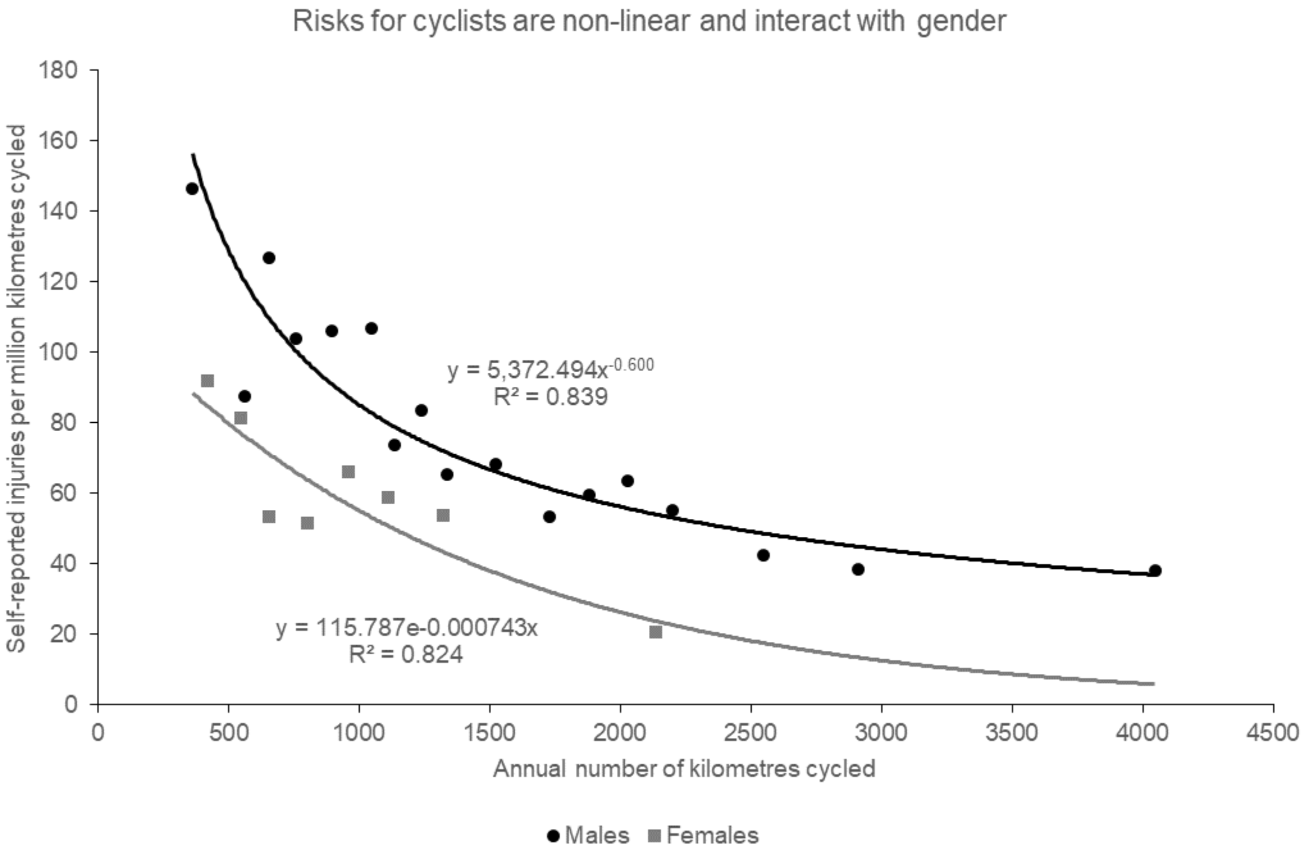
Table 23 Cyclist injuries recorded in STRADA

Injury	Number temporary	Number lifelong	Disability weight	Duration of disability (years)	Total weight	YLD temporary	YLD lifelong
Contusion or sprain (no further details)	643		0.064	0.038	0.0024	1.564	
Open wound (no further details)	1564		0.108	0.024	0.0026	4.054	
Fracture of foot/toes	94		0.077	0.073	0.0056	0.528	
Concussion	602		0.359	0.067	0.0241	14.480	
Fracture of hand/fingers	433		0.100	0.070	0.0070	3.031	
Fracture of facial bones	296		0.223	0.118	0.0263	7.789	
Dislocation/sprain of foot/ankle	16		0.074	0.019	0.0014	0.022	
Dislocation/sprain of hand/fingers	16		0.074	0.019	0.0014	0.022	
Fracture of knee/lower leg	170		0.271	0.090	0.0244	4.146	
Fracture of clavicula	376		0.143	0.112	0.0160	6.022	
Fracture of wrist	746		0.180	0.112	0.0202	15.039	
Fracture of rib	196		0.199	0.115	0.0229	4.485	
Dislocation/sprain of shoulder/elbow	132		0.074	0.034	0.0025	0.332	
Dislocation/sprain of knee	15		0.074	0.019	0.0014	0.021	
Fracture of upper arm	151		0.143	0.112	0.0160	2.418	
Fracture/sprain of vertebrae/spine	85		0.226	0.140	0.0316	2.689	
Fracture of hip/pelvis	44		0.247	0.126	0.0311	1.369	
Fracture of ankle	69		0.196	0.096	0.0188	1.298	
Fracture of femur	64		0.372	0.140	0.0521	3.333	
Fracture of skull/intracranial injury	22		0.431	0.107	0.0461	1.015	
Internal-organ injury	24		0.208	0.042	0.0087	0.210	
Eye injury	2		0.108	0.019	0.0021	0.004	
Fracture of femur		3	0.272	32.8	8.9216		26.765
Fracture of skull/intracranial injury		65	0.361	32.8	11.8408		769.652
Nerve injury		2	0.064	32.8	2.0992		4.198
Spinal-cord injury		7	0.725	32.8	23.7800		166.460
Total or mean	5760	77				73.874	967.075

Source: Nilsson et al. (2017)

There is a strong relationship between the annual distance cycled and the number of (self-reported) injuries, over million kilometres cycled, as shown in Figure 32. What this shows is that those who cycle more, have a lower risk of injury, on a per kilometre basis. This still allows for the possibility that they sustain more injuries in total, but they are at a lower risk of injury for each kilometre that they cycle. Those cycling a low number of kilometres per year have the highest risk of injury (about three times that of those cycling a large number of kilometres). However, this shows that whether people cycle 4,000km or 2,000km, they sustain about the same rate of injury on a distance travelled basis (meaning someone cycling 4,000 km per year will, on average, sustain twice the total number of injuries as someone cycling 2,000km). Australian research has also found that the chance of injury decreases with cycling frequency, with the exception of competitive cyclists (see Heesch et al., 2010).

Figure 32 Self-reported injury rates of Norwegian cyclists by gender and annual distance cycled



Source: Reproduced from Elvik and Sundfør (2017)

Elvik and Sundfør (2017) found that when the amount of cycling increases from 1 to 10, the number of cyclist injuries are expected to increase from 1 to 3.518. The models used in the development of this risk elasticity do not include any changes in the volume of motor vehicles and cannot be used for assessing the effects of modal shifts. When increases in cycling occurs at the same time that motor vehicle travel decreases, the risk of cycle injury is lowered more powerfully than when motor vehicle travel remains constant (Elvik and Sundfør, 2017).

Van Wee and Ettema (2016), summarising the findings by Elvik (2009) on safety in numbers write *'Elvik (2009) concludes that the decrease in risks per kilometre far outweigh the increase in cycling levels, resulting in a decrease in the total number of fatalities, but it is important to realise that this can only apply after a certain threshold value: if no one cycled, there would be zero fatalities. So for very low levels of cycling this decrease cannot apply'.*

A review of the literature by Austroads (ref needed) concluded that empirically demonstrated 'safety in numbers' relationships may provide evidence of correlation rather than causation, in that researchers do not control for improvements in infrastructure and other initiatives (safety awareness campaigns) that might encourage cycling at the same time as making cycling safer. Austroads comments that while safety in numbers might have a behavioural basis in that more cyclists on the road encourages motorists to look out for them, the research does not definitively prove causation.

Garrard (undated) reviewed the evidence and concluded that:

- There is a safety in numbers association in some but not all situations.
- The safety in numbers relationship is strongest and most consistent in European countries with high rates of cycling.
- No studies have controlled for cycling infrastructure or driver/cyclist safety measures.
- There is no evidence that increased cycling precedes injury rate reductions.
- Limited Australian evidence, from Melbourne, is mixed.

In terms of the monetary value of preventing injuries, Elvik and Sundfør (2017) report that, using the Eurocost estimated, a typical cyclist injury is associated with a health loss corresponding to 0.15 years lived with a disability. Thus, preventing such an injury is 0.15 times the value of a life year. The current value of statistical life year (VSLY) is $213,000, in 2019 dollars (Office of Best Practice Regulation, 2019). The Norwegian researchers estimate that the mean injury cost per kilometre cycled was 1.36 Norwegian Krona (around 20 Australian cents). This would appear to align reasonably well with the cost of cycling injuries reported earlier in the Queensland study (see CDM Research, 2016), of around 30 cents, given that it can be expected that cycling risk is higher in Queensland than in Norway, due to lower traffic speeds and more wide spread bicycle infrastructure.

The previously cited Brisbane study by Zapata-Diomedi et al. (2017) estimated the change in health caused by Brisbane meeting its mode share targets (which involves large increases in the number of people walking and cycling). While the study found overall net health benefit, the results suggest an increase in road trauma, even when accounting for the lower risk level associated with the *safety in numbers* effect.

5.7 Challenges when comparing crash rates

Comparing the safety of walking or cycling, even when using an exposure adjusted crash risk (i.e. crashes per X million km walked or cycled) in different cities/regions/countries can be problematic for the following reasons:

- Unreliable data on the amount of walking or cycling that takes place. Australian data is very limited, in that it is only the *journey to work* that is captured by the Census, and that is only for one day in August every five years. Various states have their own household travel surveys (see Table 1), though the sample size and data collection techniques vary widely. Without a firm understanding of the amount of walking and cycling that occurs, expressed in a unit of distance (as opposed to trips frequency for example), it is not possible to calculate a reliable exposure adjusted crash risk.
- Unreliable data on the number and severity of crashes. While there may be reliable data on fatalities, it is widely recognised that many of the minor incidents that occur on foot or bicycle are not captured in official statistics. Without reliable recording of crashes, it is not possible to calculate a robust exposure adjusted crash risk.
- Variations in users. Most crash statistics aggregate all pedestrians and bicyclists, including some high-risk groups (children, drinkers, etc.). As a result, a skilled, sober bicyclist probably has much less risk than the statistics imply.

- Scope of risks. Most data compare the risk borne by a mode user, but not the risk they impose on others. Motor vehicle travel is much more dangerous to other road users, so shifts from automobile to active modes can reduce total crashes.
- Exposure. People who shift from driving to relying on active modes often reduce their total travel and therefore risk exposure. For example, a typical suburban motorist drives about 20,000 annual kms, while a car-free urban neighbourhood resident may walk and bicycle about 5,000 annual kms (van Wee, 2021, Götschi et al., 2015).[8]

When attempting to express crash risk on a per 100,000 people, other problems can arise that can distort the understanding of crash risk. For instance, as pointed out in Götschi et al. (2015, p. 9), the following passage, while accurate, is misleading; *'0.2 in 100,000 people older than 65 years die cycling in the UK every year, while in the Netherlands this rate is 3.5/100,000'.* This does not of course mean that cycling is safer in the UK, as there is far more cycling participation among older people in the Netherlands. Finally, in addition to the myriad of complications of using a cycle crash rate, one must also consider that if the cycle network is going to undergo substantial expansion, historic crash rates may not be suitable for estimating future crash risk. When bicycle infrastructure networks improve, the crash rate drops considerably, and this must be factored into any analysis of future crash likelihood.

SKM & PwC (2011) developed estimated values for road trauma associated with walking and cycling. The cycling injury cost was estimated at $0.37/km and $0.24/km for walking (in 2010 dollars). The injury cost for motor vehicle travel is $0.06/km, thus when a cycle trip replaces a vehicle trip, the increase in cycling injury cost is $0.31/km. As identified elsewhere, these costs are highly dependent on the type of infrastructure in which the walking or riding takes place. This is likely to be especially true for cycling, where there are greater opportunities for collisions in instances without bicycle infrastructure. It can be expected that as bicycle infrastructure networks become more developed and the level of separation between motor vehicles and bicycles increases, the injury cost of cycling, per kilometre, may decrease (Fishman, 2016, Teschke et al., 2012).

5.8 Time-based crash costs

Table 17 gives unit crash costs on a per distance travelled basis, which is not quite the same as the way people experience the network. People will generally judge travel based on time, not distance, and the various modes have very different speed profiles, meaning the crash cost per vehicle minute or hour is very different. Table 24 shows the crash cost per vehicle hour, using average speeds from VISTA data. This demonstrates that when accounting for difference in speed, the difference between cost is much narrower than first appears. While the cyclist bears more cost per hour, this should also be seen as a reflection of the unsafe road environment, and potential for savings through infrastructure improvement. As the cycling network becomes safer, this figure should reduce, as such, regular adjustments would be beneficial.

Table 24 Crash cost per vehicle hour

Mode	Crash cost per veh hour	
	Hybrid human capital approach	Inclusive willingness to pay approach
Car/ motorcycle	$3.54	$6.76
Bicyclist	$5.64	$10.93
Pedestrian	$2.88	$6.19
Total active travel	$3.19	$6.48

[8] While this may be true with respect to safety, switching from longer car trips to shorter active travel trips will have associated with it an opportunity cost as the longer car trips open up a broader range of choices to meet a given trip purpose.

6. Travel time

6.1 Speed

A range of active travel speeds from various studies are shown in Table 25.

Table 25 Average speeds for active travel modes

Source	Comment	Speed description	Speed (km/hr)
Walking			
Parise et al (2004)	Older adult males	'Normal brisk walking speed'	5.8
Parise et al (2004)	Older adult females	'Normal brisk walking speed'	5.5
British Heart Foundation (2014)	Person with excellent fitness	'Moderate' walking pace	6.4
British Heart Foundation (2014)		'Fast' walking pace	7.5
Forde and Daniel, 2020	Teen (aged 13 - 18)	Walk	5.2
Forde and Daniel, 2020	Young adult (aged 19 - 30)	Walk	5.6
Forde and Daniel, 2020	Middle age (aged 31 - 60)	Walk	5.2
Forde and Daniel, 2020	Older (more than 60)	Walk	4.5
Forde and Daniel, 2020	Elderly or physically disabled	Walk	3.7
Cycling			
City of Copenhagen (undated)		Average cycling speed in 2012	15.5
Haworth (2011)	Context suggests the data cited is cruising speed rather than average journey speed	Median cycling speed	24
Aecom (2010, p.51)		Cycle	23
Aecom (2010 p.3)	Dedicated cycleway	Cycle	25
Thompson et al., 1997	Young children		14.3
Vlakveld et al., 2015	Adult- commuter		17.7
	Adult - elderly		14.9
Indicative	Adult - competitive/training		25+

Walking

Walking speeds are generally more consistent than cycling, though this varies, depending on age and ability. Estimates of walking speeds in the literature vary according to age and, it would appear, the purposefulness of particular trips, so that someone walking with the intent of exercising walks faster than if they are walking for non-exercise purposes. A 6 km/h average speed (based on Table 25) would be appropriate for CBAs. It is unlikely that analysts will have information about walker age, trip purpose and whether their purpose is mixed with exercise that would allow finer-grained speed estimates to be used. If such information is available the analysis can be suitably adjusted.

A 6 km/h average speed is in the middle of the estimates shown in Table 25 and would be appropriate for CBAs.

Cycling

Cycling speeds vary considerably, but average at around 17km/h for general transport oriented cycling in an inner city environment (Bernardi and Rupi, 2015). As one might expect, the speed of cyclists can rise considerably higher than 17km/h for competitive/fitness cyclists.

The data sources for cycling speeds are often ambiguous as to whether they are cruising speeds, trip start to trip end speeds[9] or door to door speeds. The higher estimates in Table 25 appear to relate to cruising speeds on a dedicated cycleway, whereas the Copenhagen estimate reflects more of a door to door speed. The door to door estimates would be suitable for estimating the travel time effects of a dedicated cycleway replacing a section of street riding. The door to door speed would be used to calculate travel time effects for users who convert to cycling and whose trip involves a mixture of on- and off-street riding.

Modal comparison

Active travel speeds are generally lower than motorised travel, and thus, when transferring a car trip to bicycle or foot for the same origin and destination, it is likely to involve greater trip time. However, for cycling in particular, at peak times in dense cities, cycling can offer faster door-to-door travel time (DIT 2013). [10]

Methods for estimating speeds of other modes are also set out elsewhere in the other mode-specific (M parts) of the Guidelines.

E-bikes

Somewhat surprisingly, the speed of electric assist bicycles are said to only be 1 – 3km/h faster than conventional bikes (Schepers et al., 2014a). This is expected to be closely related to the fact that European and Australian regulation compliant e-bikes have a maximum speed of 25km/h before the motor no longer provides assistance.

6.2 Value of time savings

M4 guidance distinguishes between two values of time: behavioural values and the equity value. Behavioural values are the willingness-to-pay values observed in surveys, vary across transport, and are used in demand modelling. The equity value is an average value, used consistently in appraisal of all modes. In that context, this section covers some key points made in the literature.

Studies have found that the unit value of time savings can vary with a range of factors: trip purpose, trip segment, traveller preferences, travel conditions such as congestion, crowding, noise, and the quality of the facilities, comfort, productivity and security.

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[9] Trip start to trip end speed would exclude the walk trip to/from the bicycle storage point or shower/change facility.

[10] There is evidence from Europe that for a trip length under 5 km, cycling can be quicker door to door than the private car and for trips under 9 km can be quicker than the train. Walking on the other hand has no time advantage over other modes (see EC, (1999), p.11).

Recent economic analysis of cycling projects in the Netherlands has recommended the value of time for cyclists be the same as for car drivers, based on stated-preference survey data (van Wee, 2021). It is assumed that this relates to travel for work, and it is generally accepted that the value of time for non-work related cycling is zero. The approach recommended in M4 (section 6.8.2) is consistent with this approach.

Travel time reliability

One fundamental difference between the assessment of travel time between motorised and active modes is that active modes, while sometimes slower, do generally hold better travel time *reliability*. This is important because active travellers do not have to include a time buffer for unexpected delays in the manner that a motorised traveller might. For instance, driving to work might usually take 30 minutes, but if once every now and then it takes 45 minutes, that may require the traveller to include a 'buffer' and leave an extra 15 minutes early when making a trip for which they cannot be late. The cycling time for the same journey may be 40 minutes, but, delays are so rare that a buffer is not required. As a result, travel time reliability is better for active travel. Travel time reliability is a valued attribute for travellers (Carrion and Levinson, 2012).

6.3 Influences on the value of time

Within the context of equity and behavioural values of time savings flagged in section 6.2 above, this sub-section and the next provides an extended summary of some the discussion in the literature around value of time generally, and for active travel as background.

Personal travel time is usually estimated at 25% to 50% of prevailing wages, but varies by factors such as type of trip, traveller preferences and conditions. Some travel time has low costs, or even positive value, because people enjoy the experience or value health benefits, particularly for walking and cycling (Mokhtarian, 2005). One survey found that ideal travel times are longer for active travel (walking and bicycling) trips, leisure trips, weekend trips, and when the user conducted activities during trips (e.g., talking, using the phone, looking at the landscape) and travelled with companions (Le et al., 2020).

Under pleasant conditions walking, cycling and waiting can have low or positive value (Björklund and Carlén, 2012), but under unpleasant conditions (walking along a busy highway or waiting for a bus in a dirty and frightening area), costs are two or three times higher than in-vehicle time (Goodman, 2001, Litman, 2008, Liu and Huiying, 2016). Travellers who shift from faster to slower modes, such as from driving to walking or bicycling, in response to improved conditions, must be better off overall, reflecting differences in their travel time values or other aspects of generalised cost (Standen, 2018).

Active travel improvements can provide travel time savings by reducing the need for motorists to chauffeur non-drivers. For example, in car-dependent locations parents must drive children to school and sports events, and non-driving relatives and friends to shopping and medical appointments, trips that are avoided if better active travel options are available.

The research cited above indicates that travel time unit costs are quite sensitive to qualitative factors such as comfort, convenience, productivity, and security. Under optimal conditions, walking, cycling, and public transport costs typically average 25-35% of prevailing wages, less than the 35-50% of average wages for drivers, reflecting the reduced stress and increased enjoyment these modes can offer. However, under unpleasant conditions (crowding, noise and dirt) travel time costs for these modes exceeds that of driving (Litman, 2020).

Similarly, studies indicate that time spent walking to and waiting for transit vehicles generally has unit costs averaging two to five times higher than in-vehicle time, or 70% to 175% of prevailing wages. Improved walking, cycling and waiting conditions can reduce these relatively high unit costs, particularly if people are able to choose their mode based on their preferences. Transfers are estimated to impose penalties equivalent to 5-15 minutes of in-vehicle time, plus waiting time costs. Real-time transit vehicle arrival signs are found to reduce perceived wait times by at least 20% (Litman, 2008).

Table 26 summarises travel time values across modes, relative to prevailing wages, incorporating traveller convenience and comfort factors. It uses a level of service (LOS) index as a generic measure of the influencing convenience, comfort and quality factors. Litman (2019a) reports that on the various systems that exist to measure LOS, summarising the influencing factors for non-motorised LOS as being: network connectivity, network quality, safety and speed of road crossings, protection from motorised traffic, facility congestion and conflicts, topography, sense of security, wayfinding, weather protection, cleanliness and attractiveness.

Wait time unit costs are reduced another 20-30% where real-time vehicle arrival information is provided. Importantly, the time values for ‘personal vehicle drivers’ and ‘pedestrians and cyclists’ are the same, reflecting that for general transport, time is valued to the same extent between these three user groups.

Table 26 Travel time values relative to prevailing wages

Category	LOS A-C	LOS D	LOS E	LOS F	Waiting conditions		
					Good	Average	Poor
Commercial vehicle driver	120%	137%	154%	170%		170%	
Comm. vehicle passenger	120%	132%	144%	155%		155%	
City bus driver	156%	156%	156%	156%		156%	
Personal vehicle driver	50%	67%	84%	100%		100%	
Adult car passenger	35%	47%	58%	70%		100%	
Adult transit passenger – seated	35%	47%	58%	70%	35%	50%	125%
Adult transit passenger – standing	50%	67%	83%	100%	50%	70%	175%
Child (<16 years) – seated	25%	33%	42%	50%	25%	50%	125%
Child (<16 years) – standing	35%	46%	60%	66%	50%	70%	175%
Pedestrians and cyclists	50%	67%	84%	100%	50%	100%	200%
Transit Transfer Premium					5-min	10-min	15-min

Source: Litman, 2008

An Australian study by Mulley (2013) in Sydney undertook a stated preference survey regarding mode choice and route choice involving active travel options. Table 27 shows the relative disutility across a number of cycling facility choices found by the survey. An approach sometimes used is to apply value of time weights across facility types to reflect the implied differences in value to the user of one facility versus another.

Table 27 Relative disutility of cycling facilities

	PwC /SKM (2010)	Wardman et al (2007)	Tilahun et al (2007)	Hunt and Abraham (2007)
Location	**Sydney**	**UK**	**US**	**Canada**
On-road	1.00	1.00	1.00	1.00
On-road with lanes or quiet street	0.43	0.48	0.55	0.24
Off-road	0.34	0.29	0.80	0.36

Source: Mulley (2013)

As discussed in 6.8.2 of M4, there are risks of doubling counting with this approach. M4 recommends not weighting value of time across facilities until future research is able to untangle the various benefit elements involved.

Conventional planning has often applied a single value to all travel time, such as 50% of average wages (see Table 26). The critics of this approach suggest it is not a sufficiently accurate reflection of the value that travellers actually place on their time, failing to account for factors that affect travel time costs (Börjesson and Eliasson, 2019). In particular, the cost that travellers place on their time tends to increase with stress factors; for drivers this includes traffic congestion; for public transport passengers this includes crowding, dirt and odours, excessive heat or cold in vehicles or waiting areas; for pedestrians and bicyclists it includes proximity to traffic risk, noise and air pollution, unpleasant weather and inclines; and for all travellers it increase with arrival time uncertainty (Organisation of Economic Cooperation and Development, 2019).

Conversely, under favourable conditions, time devoted to active travel can have low or negative cost, that is, travellers may place a positive value on this time because they enjoy the activity or value the health benefits it provides (Standen, 2018). This explains, for example, why travellers will sometimes choose to walk or bicycle despite being slower and taking longer than motorised modes. Although those trips take more minutes, their cost per minute is lower, so the trip is cheaper overall (Le et al., 2020), excluding walking during employers business hours. Similarly, many people, and their pet dogs, choose to walk and cycle for purely recreational and health purposes.

As Standen concludes in his thesis on travel time and its relationship to cycling, '*Time spent travelling should not be considered purely a cost to be minimised*, *rather something that can be enriched'* (Standen, 2018).

So travel time costs are just once factor in active travel decisions, with other co-benefits also being considered by users. The same is also true for other modes. For instance, Kent (2014), in her study of drivers who all had a commute in which public transport would have been faster than car, found there were many important attributes to car travel (e.g. privacy, independence) that led to their decision to use the car over public transport, despite it being slower. So all travellers who are faced with multiple mode choices are likely can have co-benefits, or non-time related factors, affecting mode choice.

The concept of effective speed is another approach used sometimes to think about trip decision making. When measured using effective speed (travel distance divided by time spent travelling and earning money to pay expenses), active travel is often faster than motorised travel (Tranter, 2004), particularly for lower-income workers. For example, a typical automobile commuter spends 52 minutes driving to work, plus about 96 minutes (20% of their workday) earning money to pay for their vehicles and residential parking. For a 10-kilometre one-way commute this averages just 4.8 kilometres per hour; a fast walk but only a third the speed of a bike rider. Of course, most motorists also use their vehicles for non-commute trips, but this illustrates the point that travellers often face trade-offs between travel time and money costs, and many travellers might be better off overall choosing slower but more affordable modes over faster but more expensive modes, provided the transport network is able to support this choice. Similarly, public transport users are faced with the same cost impost that must be accounted for

Note that active modes are not always slower than motorised travel. Cycling in particular, at peak times in dense cities, can be equal to or faster than automobile or public transport, measured door-to-door including time required to access motor vehicles (DIT 2013). Active transport improvements, such as mid-block crossings, shortcut paths, and improved bicycling facilities, can provide walking and bicycling travel time savings. Additionally, by reducing the stress of walking and bicycling, these improvements provide direct user benefits that offset user travel time unit costs (Department of Transport, 2020).

Thus, travel time costs are context dependent: unit costs vary significantly depending on conditions and user preferences, particularly for pedestrians and bicyclists, who are more vulnerable to physical discomforts and risks. Under unpleasant conditions, such as walking and bicycling close to high-speed traffic on a busy roadway, travel time unit costs are high. Those travellers might be willing to pay more than their wage rates to avoid that time, but for many people, under favourable conditions, walking and bicycling has low or negative cost.

The discussion above stresses that comfort, safety and other quality factors are important in the assessment of active travel. Section 6.11 of M4 provides methodologies for valuing the amenity of the walk environment. Further research will allow similar valuing of the cycling environment (with the last part of section 6.3 above, and the related discussion in section 6.8.2 of M4 summarising what is currently known for cycling). Chapter 5 above, and section 6.7 in M4, outline how the value of safety improvements can be incorporated in active travel assessments.

7. Physical activity health benefits

As a form of physical activity, active travel produces a range of health benefits. Physical activity results in two types of health benefits:

- Reduced morbidity (illness) and mortality (death) costs — people who are active get sick less often and have a longer life expectancy than people who are inactive. In M4 they are referred to as 'health private costs' (HPC), and are assumed to be perceived and therefore influence travel choices.
- Associated reduction in health system costs — active people are less likely to need medical and hospital care, so less health system resources are required. In M4 they referred to as 'health system costs' (HSC), and considered an externality.

Sections 6.10.2 and 6.10.3 of M4 outline the recommended methodology for estimating these two benefits for active travel initiatives, using unit benefit ($ per km) parameter values in M4 section 6.10.4. This M4-BR chapter provides supporting discussion on these health benefits and the unit benefit values reported in M4 section 6.10.4.

7.1 Morbidity and mortality

Physical inactivity and activity

The 2007-2008 National Health Survey identified that physical inactivity is related to chronic health conditions including ischaemic heart disease, stroke, Type 2 diabetes, kidney disease, osteoarthritis, osteoporosis, colorectal cancer and depression (AIHW Cat No PHE 157, 2012). These are some of the leading diseases in Australia.[11]

Physical activity reverses the effects of physical inactivity. People who are physically active tend to be healthier than people who are relatively inactive or sedentary, and they suffer less from medical conditions that reduce their life expectancy. Physical activity, can:

- Contribute to reducing risks of cardiovascular disease, Type 2 diabetes, some cancers and osteoporosis
- Assist with managing obesity, high blood pressure and high cholesterol
- Improve mental health (benefits have also been identified but not quantified)
- Improve self-esteem and confidence, and reduce stress, anxiety, fatigue and depression (AIHW Cat. No. PHE 157 2012).

Compared with no physical activity, the following risk reduction in all-cause mortality has been observed (Woodcock et al., 2011):

- 19%, for 2.5 hrs per week of moderate-intensity activity (such as transport cycling or walking)
- 24% for 7 hrs per week of moderate-intensity activity.

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[11] With the exception of kidney disease and osteoporosis, these conditions were amongst the 20 leading causes of burden of disease in 2003 (AIHW 2007, p 39). The AIHW report 'Australia's Health 2010' (Cat. No. AUS 122 2010) identifies these diseases as continuing to be amongst the leading causes of burden of disease in 2010. Of the total burden of disease, cancer was projected to account for 19% while the second leading cause, cardiovascular disease, was estimated to account for 16%. Type 2 diabetes was projected to become the leading cause of disease burden by 2023, partly attributable to the worsening problem of overweight and obesity. In 2010, diabetes accounted for almost 7% of the total disease burden (Type 2 diabetes was estimated to account for 94% of the diabetes burden). Arthritis and musculoskeletal conditions accounted for 4% of the national disease burden in 2010 (Cat. No. AUS 122 2010).

Thus, even a 15-minute, one way walk or cycle to work, five days a week is sufficient for a 19% reduction in all-cause mortality. Other studies have found that if choosing to gain 100% of the 150 minutes of physical activity recommended by the WHO, a 10% in risk reduction in all-cause mortality could be expected (Götschi et al., 2015).

The National Physical Activity Guidelines for Australians for adults recommend at least 30 minutes of moderate-intensity physical activity on most, preferably all, days of the week. Examples of moderate-intensity activity are brisk walking, swimming, doubles tennis and medium-paced cycling.

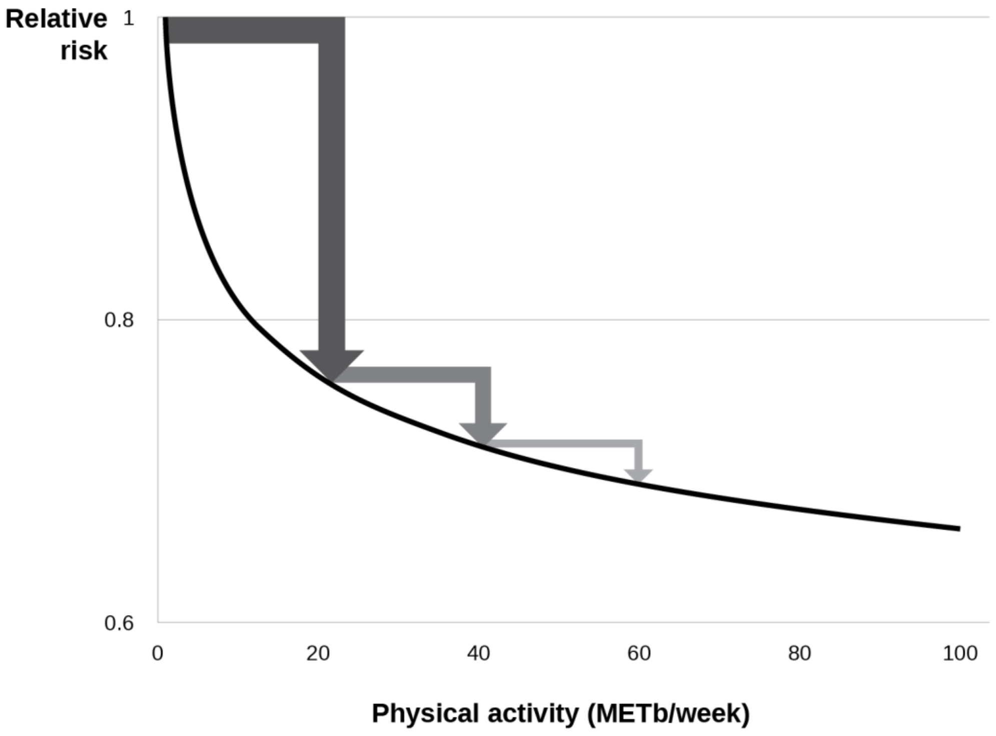
For activity to be sufficient for accruing health benefits, criteria for both time and the number of sessions need to be met. The definition for sufficient time and sessions is 'at least 150 minutes of moderate-intensity physical activity accrued over at least five sessions per week, with vigorous activity counted as double'. Sessions of a minimum of 10 minutes can also be included in the weekly count (AIHW Cat. No. AUS 122 2010, p.93).

The National Heart Foundation advises that its recommended levels of physical activity could be achieved by doing "30 – 40 minutes of moderate-intensity physical activity (like brisk walking) most days of the week. You can build up activity in shorter bursts, like in three ten minute walks". See www.heartfoundation.org.au/active-living/get-active .

Dose response relationship and minimum thresholds for health benefit

The level of existing physical activity is an important consideration when evaluating the health benefit of active travel. Inducing extra physical activity to those already participating in sufficient levels of activity provides less benefit compared to inducing the same amount of physical activity to someone who is currently sedentary. The reduction in risk to health (all-cause mortality) from physical activity varies by about 30% between those that are the most physically active compared to the least (Götschi et al., 2015). The relationship between health impact and physical activity level is captured in Figure 33. This concept is well established in population health research and is discussed more comprehensively in Götschi et al. (2015).

Figure 33 Non-linear dose-response relationship



Source: Reproduced from Götschi et al (2015)

While very high levels of walking or cycling have diminishing levels of health benefit, it is also possible that very small amounts of active travel can have little health benefit. In a review of the literature examining health and cycling, it was identified that bouts of less than 10 minutes are unlikely to offer health gains (World Health Organisation, 2010). Interestingly, the evidence also suggests that it is more beneficial for health to have more frequent episodes of moderate duration exercise than one large bout once a week (Götschi et al., 2015). This is important from an active travel perspective, as *transport* orientated active travel is more likely to involve more frequent episodes.

7.2 Benefit estimation methodology

These Guidelines adopt the methodology used by Genter et al (2008) in valuing the physical activity health benefits of active travel. The Genter et al study was originally undertaken in New Zealand. In Australia, it has been applied by the QLD Government (SKM and PwC 2011) and for the 2016 ATAP version of M4. It is continuing to be applied in this updated version of M4, with outputs updated.

The methodology consists of two stages:

- Estimating the national annual per capita cost of inactivity (section 7.3)
- Converting those estimates into unit benefits (per km) for walking and cycling (section 7.4 for application in the assessment of active travel initiatives.

7.3 Annual per capita benefits of physical activity

7.3.1 Reduced morbidity and mortality

The morbidity and mortality effects of physical inactivity are measured using the concept of disability adjusted life year (DALY), the standard measure used in assessing the impact of disease and injury. One DALY is one year of healthy life lost due to disease or injury (AIHW, Australia's Health 2010, Cat. No. AUS 122 2010). Reducing DALYs is analogous to increasing life expectancy.

DALYs are then monetised using the Value of a Statistical Life (VSL). VSL is a monetary value of a human life measured in surveys based on the willingness to pay concept. VSL is an estimate of the economic value society places on reducing the average number of deaths by one. A related concept is the value of statistical life year (VSLY), which estimates the value society places on reducing the risk of premature death, expressed in terms of saving a statistical life year. The Australian estimate of the value of statistical life in 2007 dollars is $3.5 m (OBPR 2008). Updating the value using the Consumer Price Index yields a 2019 VSL estimate of $ 4.58 m.

The steps used to calculate the annual per person benefit of physical activity are as follows, with Table 28 shows the calculations:[12]

- a) Estimate total DALYs for years of life lost to both morbidity and mortality for Australia

[12] This approach has also previously been used in Queensland (Department of Transport and Main Roads, 2011). The steps shown here are for the original calculation reported in ATAP M4 2016 (using 2010 data expressed in 2013 dollars), and indexed here to 2021 dollars.

- b) Estimate the proportion of (a) attributable to physical inactivity — the Population Attributable Risk Fraction (PAF) for inactivity. This has been estimated by Begg et al (2008, p.38) in their Burden of Disease and Injury in Australia 2003 study (Begg et al, 2007, AIHW Cat. No. PHE 82) to be 6.6% of total DALYs.
- c) Multiplying (a) and (b) gives the DALYs attributable to physical inactivity
- d) Estimate the adult inactive population in 2010. This has been derived from Australian Health Survey 2007-8 and 2011-12 results (ABS 2012, 43640DO001_20112012 Australian Health Survey: First Results, 2011–12 — Australia.)
- e) Determine the annual ratio of DALY per inactive adult by dividing (c) by (d)
- f) Estimate the undiscounted 2013 annual value of a DALY. The annual value of a DALY was calculated by subtracting the average age (37 years) from the average life expectancy in 2010 (82.1 years) to get 45.1 years. The VSL was then divided by 45.1. (Life expectancy and average life data sourced from ABS 2013
- g) Multiply (e) and (f) to produce the annual per capita benefit of physical activity.

Table 28 Per capita annual value morbidity and mortality attributable to inactivity

Item	Value	Code
Estimated total DALYs 2010	2 849 000	a
Population attributable risk fraction for inactivity	6.6%	b
DALYs attributable to inactivity	188 034	c=a x b
Adult inactive population	11 483 475	d
Ratio of DALYs attributable to inactivity per inactive adult	0.0164	e = c / d
Willingness To Pay for a DALY 2013	$104 969	f
Per capita annual value	$1 719	g = f x e

Source: Economic Associates 2013 analysis based on Genter 2008, p.48. Dollar values updated to 2021 dollars.

7.3.2 Reduced health system costs

The cost estimation process is similar to that used above for morbidity and mortality costs: costs are estimated by calculating the proportion of total costs due to inactivity, and then dividing by the number of inactive adults to determine the per capita costs. Table 29 shows the calculations.

Table 29 Per capita annual health system (sector) costs attributable to inactivity

Item	Value	Code
Total health system costs 2010 (1)	$130 266 000 000	a
Population attributable risk fraction for inactivity	6.6%	b
Health system costs due to inactivity 2010	$8 597 556 000	c = a x b
Adult inactive population 2010	11 483 475	d
Per capita health system inactivity costs 2010	$749	e = c / d
Per capita health system inactivity costs 2013 (indexed)	$921	

Source: Economic Associates 2013 analysis based on Genter 2008, p.48. Values updated to 2021 dollars.

(1) See AIHW 2012, Health Expenditure Australia 2010-11, Health and Welfare Expenditure Series No. 47, Cat. No. HWE 56.

Productivity costs are excluded because Genter et al (2008, p. 49) found inadequate evidence supporting the association between active transport and reduced sick days (Genter et al, 2008, p.49) (which aligns with the conclusion in M4 section 6.15.2).

7.4 Unit benefits for walking and cycling

The second stage of the Genter et al process is to convert the annual per person values from section 7.3 into unit benefits per km of active travel. It does this by:

- Accounting for the dose-response relationship
- Dividing the annual benefits by the number of kilometres of active travel required to attain the annual benefit, as per the recommended guidelines outlined above. The more active a person is, the less additional activity needed to achieve a desirable state of health and the lower the benefit from that additional activity. Walkers generally need more physical activity than cyclists because walking is less vigorous than cycling.

Genter et al (2008, p.50) cite research on the does-response relationship, indicating that more health benefits accrue when additional activity is initially taken up, with benefits accruing at a lesser rate for those who are currently active.

Since inactive adults have most to gain by participating in physical activity, full benefits are allocated to those who were previously inactive, with only marginal benefits allocated to existing active adults (Genter, 2008, p.40).

To account for this, Genter et al consider three physical activity levels (see definitions in M4 appendix A): inactive; insufficiently active; sufficiently active. The dose response relationship is applied by assigning suitable weights to the three physical activity levels. The weightings used and the rationale adopted by Genter et al (2008, pp.50-51) are:

- Weighting 1 - Inactive – Shifting the inactive group into some moderate physical activity has most benefits in terms of reduced morbidity and mortality. This group can receive full annual benefits by walking at 5 km per hour for 30 minutes, five days per week. This is an annual walking distance of 625 km.
- Weighting 0.85 – Insufficiently active – The insufficiently active group can receive most of the health benefits of increased activity, even though they already engage in some moderate activity. An additional 20 minutes' physical activity per day for five days per week requires an annual distance of 450 km.
- Weighting 0.15 – Sufficiently active – The sufficiently active group may receive ongoing health benefits and encouragement to maintain physical activity. An additional 14 minutes' physical activity per day for five days per week requires an annual distance of 312 km.

Note Genter et al's (2008, p.51) assumptions cycling relative to walking:

- Average cycling speed of 20 km/h, i.e. 4 times faster than walking, and therefore carries ¼ of the benefit on a per-km basis
- Physical intensity double that of walking, i.e. people only need to be active for half the amount of time to receive the same benefits.

Therefore, cycling has half the benefit per km of walking (¼ x 2 = ½). In other words, twice the cycling distance is required to obtain the same benefit.

Data on the extent of physical activity in the Australian adult population (aged 18 years and older) derive from the 2007-8 National Health Survey, and the 2011-12 and 2014-15 Australian Health Survey. Table 30 summarises the proportion of the population in the three activity levels from these surveys. The values for 2014-15 are used here for calculating per kilometre health benefits.

Table 30 Physical activity levels in the Australian adult population

Physical activity level	Prevalence 2007-2008 (1)	Prevalence 2011-2012 (2)	Prevalence 2014-15 (3)
Inactive	8%	20.5%	29%
Insufficiently active	55%	36.0%	52%
Sufficiently active	37%	43.5%	19%

(1) See AIHW Cat. No. AUS 122, 2010, p 93

(2) ABS, 4364.0.55.004 - Australian Health Survey: Physical Activity, 2011-12, Download Data cube Table 4 Sufficient physical activity measure by selected population characteristics, Persons aged 18 years and over (estimate) (43640DO004_20112012 Australian Health Survey: Physical Activity, 2011-12-Australia), 2013

(3) Australian Institute of Health and Welfare 2018. Australia's health 2018. Australia's health series no. 16. AUS 221. Canberra: AIHW.

Per km unit benefits for walking and are then calculated by combining the annual per person estimates in Table 28 and Table 29 with the above weights and the physical activity level proportions in Table 30. The calculations are presented for morbidity/mortality in Table 31, and for health system benefits in Table 32. The resulting unit benefit values are summarised in M4 Table 6 (in 2021 dollars) for use by practitioners. Note that these values are higher than those reported in the 2016 M4, due to the increased level of inactivity between 2011-12 and 2014-15 as shown in Table 30.

Table 31 Mortality and morbidity benefits of active travel per km according to physical activity status 2013

	Inactive	Insufficiently active	Sufficiently active	
Dose response weighting	1.0	0.85	0.15	a
Walking				
Annual per person benefits of additional activity	$1,719	$1,461	$258	b
Km over which activity benefits are received	625	450	312	c
Proportion of population	29%	52%	19%	d
Contribution to weighted unit benefit per km	$0.80	$1.69	$0.16	e = (b/c)*d
Weighted unit benefit across activity levels	**$2.64**			sum of e
Cycling				
Annual per person benefits of additional activity	$1,719	$1,461	$258	b
Km over which activity benefits are received	1250	900	624	c
Proportion of population	29%	52%	19%	d
Contribution to weighted unit benefit per km	$0.40	$0.84	$0.08	e = (b/c)*d
Weighted unit benefit across activity levels	**$1.32**			sum of e

Source: Table 28 to Table 30.

Table 32 Health system benefits of active travel per km according to physical activity status 2013

	Inactive	Insufficiently active	Sufficiently active	
Dose response weighting	1.0	0.85	0.15	a
Walking				
Annual per person benefits of additional activity	$921	$783	$138	b
Km over which activity benefits are received	625	450	312	c
Proportion of population	29%	52%	19%	d
Contribution to weighted unit benefit per km	$0.43	$0.90	$0.08	e = (b/c)*d
Weighted unit benefit across activity levels		**$1.42**		sum of e
Cycling				
Annual per person Benefits of additional activity	$921	$783	$138	b
Km over which activity benefits are received	1250	900	624	c
Proportion of population	29%	52%	19%	d
Contribution to weighted unit benefit per km	$0.21	$0.45	$0.04	e = (b/c)*d
Weighted unit benefit across activity levels		**$0.71**		sum of e

Source: Table 28 to Table 30.

By way of comparison to the values shown in Table 31 and Table 32, in the recently released New Zealand *Monetised benefits and costs manual* (NZTA 2020) a $4.40/km is ascribed for a pedestrian using a new facility (in 2018 NZ dollars), for physical and mental health benefits. A maximum benefit per new user is set at $1,250 per year (in 2018 NZ dollars). For cycling, the value is half that of walking ($2.20/km), dropping to $1/km for e-bike use. The maximum yearly benefit per new user for conventional cycling is $2,500, and $2,000 for e-bike use. The e-bike figure might be an under-estimate given that section 10.5 reports that e-bike riders obtain around 60 – 70% of the physical activity benefit of regular cycling. All values from NZ are in NZ dollars.

7.5 Updating unit benefit parameter values

Morbidity/mortality reduction benefits

Morbidity/mortality costs estimated in these Guidelines are a product of research into links between inactivity and disease, the effects of inactivity on life expectancy and the quality of life, the potential for physical activity to reduce disease risk and the value of statistical life. Some of the supporting research, such as the 2003 burden of disease and injury study (Begg et al, 2007) and estimates of the value of life, is fundamental.

Because health benefits are complex to assess requiring considerable effort, and are central to active travel policy and to health policy generally, updating should be a joint venture between BITRE, Austroads and health agencies such as AIHW. Commonwealth and state regulatory agencies also have an interest because of the importance of health benefits in the broad suite of health and safety regulation including occupational health and safety, product safety, building safety and the like. With the extent of research involved, updating would be impracticable in anything less than a five- or even a ten-year interval.

Health system reduction benefits

Health system benefits are based on the proportion of health costs attributable to inactivity. Updating that proportion would be a role for the related task of updating morbidity/morbidity costs. Total health care costs in Australia are regularly updated and reported by AIHW.

7.6 Indexing health benefit parameter values

Between undertaking updates of the unit benefit estimates as discussed in section 7.5, users should apply indexation adjustments to the figures presented here.

Morbidity/mortality reduction benefits

The morbidity/mortality unit benefits in Table 31 should be indexed by the ABS Average Weekly Earnings series for Australia.

Morbidity/mortality benefits are based on the value of statistical life (VSL) and should in theory be indexed by reference to the ABS Average Weekly Earnings series, with adjustment for income elasticity – that is, for the tendency for VSL to increase with increases in income and possibly to changes in wealth as well. The Office of Best Practice Regulation (OBPR, 2008) recommends that VSL be indexed to the Consumer Price Index (CPI). Implicit in the OBPR guidance is an income elasticity of one and, combined with the link to the CPI, the long-term value of VSL would be maintained over the long term. Abelson (2008) — in a paper prepared for the OBPR — notes studies recommending an income elasticity closer to 0.5, but notes also that some studies link VSL to wealth, which will be affected by movements in asset prices as well as income. Hammitt and Robinson (2011, p.6) also note the prevalence of income elasticity estimates around 0.4 to 0.6. Their research suggests that this value might not be consistent across a wide income range as might be relevant when projecting incomes across the 30-year life of an infrastructure initiative.

In light of the controversies surrounding the valuation base for VSL and for changes in VSL over time, and the difficulties associated with income and wealth forecasting, the OBPR guidance that VLS be indexed to CPI with an (implicit) income elasticity of one is a conservative middle position. Adoption of that position has the advantage of consistency with Commonwealth regulatory assessments and, in particular, those that relate to health and safety.

Health system cost reduction benefits

The health system unit benefits in Table 32 should be indexed by the Australian Institute of Health and Welfare (AIHW).

The AIHW produces an annual national composite health cost index incorporating a range of health cost elements or areas of expenditure that include for example public hospitals, private hospitals, medical services, dental services, pharmaceuticals and capital expenditure. Sixteen expenditure areas are included in the index. According to AIHW (2013, p.108):

'The national THPI [total health price index] provides the most useful available measure of overall health inflation in Australia. As such, it has been integrated into the indexation formula for payments in support of the National Healthcare Agreement under the Intergovernmental Agreement on Federal Financial Relations.'

7.6.1 Application recommendations

The unit benefit estimates provided above allow practitioners to include physical health benefits in appraisals. Their use is subject to certain qualifications:

- Where local data is available on the levels of physical activity are available, they should be used instead in Table 31 and Table 32 to amend the unit benefits estimates.
- For the benefit to be counted, the trip duration must exceed 10 mins. If benefits involving trips of less than 10 mins are reported, the underlying assumptions and supporting evidence should be provided, and the benefits presented as a sensitivity test.
- If information is available on the per person level of activity, an upper limit should be applied to benefits. The upper limit should be the annual values given in Table 31 and Table 32 by activity category (or the values in Table 28 and Table 29 if activity levels information is not available). Upper limits are adopted in NZ (as discussed above). If any benefits above the annual per person maximum are to be reported, they should be presented as a sensitivity test only.
- If information is available on trip frequency in the catchment, that can be used to moderate the benefits. As discussed earlier, the research suggests that more frequent activity sessions may be more beneficial than only one or two sessions. There is no specific guidance on how to moderate benefits for reduced frequency. A sensitivity test could be undertaken scaling benefits in proportion to say 10 trips per week.
- Purely recreational trips of less than moderate intensity are likely to have more limited health benefits, and this should be considered when estimating benefits of an initiative.

Physical activity substitution

Any assessment of the benefits associated with active travel must be cognisant of the possibility that new active travel comes at the expense of other physical activity. While it is indeed possible that someone that used to attend the gym now foregoes this activity because they now ride to work, there is little evidence to suggest new active travel replaces other forms of exercise (Foley et al., 2015, Laeremans et al., 2017). Some studies have, however, assumed that for short cycle trips (up to 3.7km), 75% of the health benefits are additional, dropping to 25% for trips over 15km (van Wee, 2021).

8. Air pollution exposure impacts

While it is common for the assessment of active travel impacts to include the *negative* health impact of air pollution exposure, there are some inherent difficulties in doing so. Air pollution levels vary by country, city, suburb, and by the route taken by the cyclist, and quiet backroads will have less air pollutants than busy arterials. A number of studies discuss considerations for the impact of air pollution on the health of people cycling, and this usually includes adjustments for the higher respiratory rate of people cycling, compared to those in vehicles.

The exposure of people cycling to air pollution is a common consideration in research assessing the overall health impact of cycling (e.g. see de Nazelle et al., 2015). Motor vehicles are one of the largest sources of air pollution (Götschi et al., 2015), especially in cities, where the majority of the Australian population reside. While there is a general, though not universal consensus that active travel exposes the walker or rider to higher levels of pollution than if they were undertaking the same trip by car, there are a number of complexities. The complexities of determining the precise impacts to active travellers from air pollution relate to local differences in air pollution rates (i.e. some cities and towns are more/less polluted than others), spatial differences (peak hour more polluted their inter-peak period) and weather conditions.

Air pollution has been found to be a greater mortality risk than road trauma resulting in death (Mueller et al., 2018). There are a few reasons for this. Firstly, a commute of a certain distance by bicycle will usually be temporally longer than the same commute by car, leaving a longer time for the rider to inhale pollutants. Secondly, the respiratory rate of the rider is higher than that of a car driver (Merritt et al., 2019), with cyclists estimated to increase their inhaled dose of air pollution up to five fold compared to resting (de Nazelle et al., 2009) Thirdly, as pointed out by Götschi et al (2015), people walking and cycling lack the protection from air pollution afforded by the shell of a vehicle. The research by Merritt et al. (2019), which examined the exposure of those using different modes of transport in Stockholm, highlights the complexity of this area of study. While average concentrations of air pollution were lowest while walking, the actual travel-related exposure dose was in fact *highest* for walking, due to lower speed (and thus higher exposure time), and high respiratory rate (than sedentary modes). The same research also found that quiet roads consistently have significantly lower levels of pollution than busy streets. It is important to recognise however that cyclists have a preference for quieter routes, and this is expected to lower both their exposure to air pollution *and* their risk of road trauma.

Commuting (across all modes), exposes the traveller to disproportionately high levels of pollutants. A Dutch study found that compared to driving, there was an increased risk of mortality of between 0.5 – 5% when cycling, due to air pollution (de Hartog et al., 2010). The same study found that people riding would lose between 0.8 and 40 days in life expectancy due to air pollution but would gain 90 – 168 days as a consequence of the increased physical activity. Indeed, Karanasiou et al. (2014) found that the commute exposes the traveller to up to 30% of the black carbon and 12% of the $PM_{2.5}$ intake they would be expected to inhale over the course of a day, even though the commute only represents around 7% of the day.

Implications for active travel network design

This section has shown that exposure to air pollution impacts those walking and cycling negatively. Even though these negative impacts are far outweighed by the beneficial impact of physical activity (see chapter 7), there is still a public health need to minimise the harm that may be caused by exposing active travel users to air pollution. Based on the evidence reviewed in this section, this is best achieved by designing infrastructure that maximises the separation between motor vehicles and walkers and cyclists. In addition to substantially reducing their exposure to harmful emissions, pedestrians and cyclists will also be less exposed to the risk of road trauma. Previous research has shown that bike paths, separated from the roadway have 33% lower levels of black carbon and nitrogen dioxide compared to on road bike lanes (MacNaughton et al., 2014). A final benefit of this approach is that these paths and protected lanes are more likely to have stronger usage levels, due to the stated preference towards these types of facilities (CDM Research & ASDF Research, 2017), which is discussed more directly in Section 3.2).

9. Net health impacts of active travel

While the study of health impacts of active travel may be in its infancy, it is a highly active sub-topic within the broader active travel field. The interest in this topic appears to be more actively taken up by population health researchers as opposed to those working in the transport field, with the bulk of publications being authored by those in health. Yet it is the transport profession that is largely responsible for the implementation of measures designed to increase population levels of active travel, as they have ultimate responsibility for the development of the transport network.

The health impacts of active travel can be either positive (physical activity) or negative (air pollution exposure and road trauma). While these are the main impact pathways through which active travel can influence health, they are not the only areas of interest. Researchers have identified that other benefits to health may come in the form of enhanced quality of life, improved cognitive function, reduced risk of depression and when used as a replacement for motor vehicle travel, reductions in air and noise pollution (Götschi et al., 2015).

A large number of studies have examined the overall health costs and benefits of active travel, with the consistent finding that the benefits far exceed the costs (Elvik and Sundfør, 2017, Götschi et al., 2015, Mueller et al., 2015, Mueller et al., 2018). Some of the findings the studies are:

- Health costs consist primarily of road trauma and exposure to air pollution, which have been found to have a small negative health impact, including in Australian cities (e.g. see Zapata-Diomedi et al., 2017).
- There is a consistent finding that while a small reduction in health can be expected for those engaging in active travel due to air pollution, this is considerably outweighed by the benefits of physical activity (de Hartog et al., 2010).
- Götschi et al. (2015) find that physical activity is the dominant health benefit arising from active travel, concluding from their review of the literature *'increases in cycling lead to disproportionately smaller increases in crashes, and that negative impacts of crashes do not outweigh benefits from physical activity'.*
- Ker et al (2011, p.16) report that that the health and fitness benefits of active travel more than offset the net road trauma increase.
- A recent, multi-city study applied a health impact assessment (HIA) model to the expansion of cycling networks (Mueller et al., 2018). Mortality impacts were quantified for changes to physical activity, air pollution and road trauma (fatal incidents only). As with previous studies, the beneficial impact of physical activity associated with cycling was found to outweigh the negative effects of air pollution and road trauma due to increased cycling (Mueller et al., 2018).
- A recent study by Zapata-Diomedi et al. (2017) sought to estimate the potential health gains in Brisbane from achieving the mode share targets it has set for active travel. This includes lifting the share of trips done by foot and bicycle to 15% and 5% respectively. The categories of impact included physical activity, air pollution and road trauma. The results showed that the benefits to health caused by increased physical activity significantly outweighed a slight deterioration in respiratory health due to the exposure to air pollution associated with increased active travel. Road trauma, associated with greater levels of walking and cycling, was found to increase by 30% for mortality and 7% for years lived with a disability. This road trauma calculation accounted for a *safety in numbers* effect that results from higher levels of cycling. Overall, the researchers calculated savings of $183 million, in 2013 values, in health care costs.

The mode share targets used in the Zapata-Diomedi et al. study (2017) are shown in Table 33. This is interesting because it shows the outcomes of achieving the government established mode share targets, in terms of the change in the number of trips by different modes. This also include the estimated decrease in car kilometres travelled.

Table 33 Mode share travel targets, Brisbane

Baseline		Travel targets		Change in number of weekday trips (% mode)		
9% walking		15% walking		291,834 (65%)		
1% cycling		5% cycling		196,864 (390%)		
8% public transport		14% public transport		291,834 (73%)		
82% car occupants		66% car occupants		-780,531 (-19%)		
Baseline transport mode distribution by age and sex						
	17–49, male	**17–49, female**	**50–74, male**	**50–74, female**	**75 +, male**	**75 +, female**
Walking	26%	41%	14%	15%	1%	2%
Cycling	61%	20%	17%	2%	0%	0%
Public transport	37%	40%	8%	12%	1%	2%
Mean increase in weekday trips from baseline to the travel target scenario, by age and sex[a]						
Persons	475,481	486,670	217,226	226,625	35,807	49,980
Walking	0.8	1.24	0.95	0.99	0.56	0.49
Cycling	1.27	0.4	0.77	0.10	0	0
Public transport	1.15	1.19	0.53	0.76	0.46	0.63
Baseline car trip length for each distance category, by age and sex						
<2km	1.27	1.27	1.17	1.18	1.19	1.19
2–5 km	3.37	3.32	3.34	3.31	3.18	3.04
5–16 km	9.47	8.91	9.57	9.44	8.74	7.31
Baseline mean minutes of walking to get to/from public transport, by age and sex						
	13.39	13.15	12.58	12.77	10.03	13.31
Decrease in car occupant km driven per year from baseline to the travel target scenario, by age and sex[b]						
Walking	24,880,419	39,893,226	12,584,681	13,781,943	1,240,537	1,531,142
Cycling	105,524,358	33,231,580	29,150,158	3,732,041	-	-
Public transport	269,397,592	267,323,368	57,491,462	84,207,133	7,424,688	11,975,262

[a] Equals: Change in number of weekday trips*Baseline mode distribution by age and sex/Persons in age and sex group*5 (weekdays).

[b] Equals: Travel target scenario mean increase in daily trips by age and sex * Baseline car trip length by distance category by age and sex*Persons in age and sex group*260 (weekdays in a calendar year).

Source: Taken from Zapata-Diomedi et al. (2017)

The modelling by Zapata-Diomedi et al. (2017) accounted for the fact that physical activity is dose dependent, that is those that are more active in the population will derive less health benefit from each additional minute of physical activity. It is well established that the benefit offered by physical activity is dose dependent (Fishman et al., 2011, Ker et al., 2011), and it is important that the dose-response relationship is included in any assessment of the benefits of active transport.

Figure 34 provides an overview of the health adjusted life years associated with the modelled increase in active transport in the Zapata-Diomedi et al. (2017) study. This indicates that the negative health impact associated with greater air pollution exposure and road trauma are outweighed by the increase in health associated with the increase in physical activity. It should be noted however that in order for Brisbane to plausibly increase cycling levels by a factor of five (which is essentially what the model involved), there would in reality need to be a substantial increase in the quantity of safe bicycle infrastructure. This is likely to result in a lower risk, which does not appear to have been included in the model.

The Zapata-Diomedi et al. (2017) study integrated a measure of the impact of increasing levels of active transport on respiratory health (specifically $PM_{2.5}$). The researchers included $PM_{2.5}$ exposure in two ways. Firstly, they looked at the health effects for the population in general from a reduction in car use. Secondly, they estimated the increased exposure to air pollution associated with increasing levels of people walking and cycling. On balance, the overall impact on health from $PM_{2.5}$ exposure was a slight negative impact.

Figure 34 Health-adjusted life years (HALYs) by risk factor over the life course of the Brisbane adult population

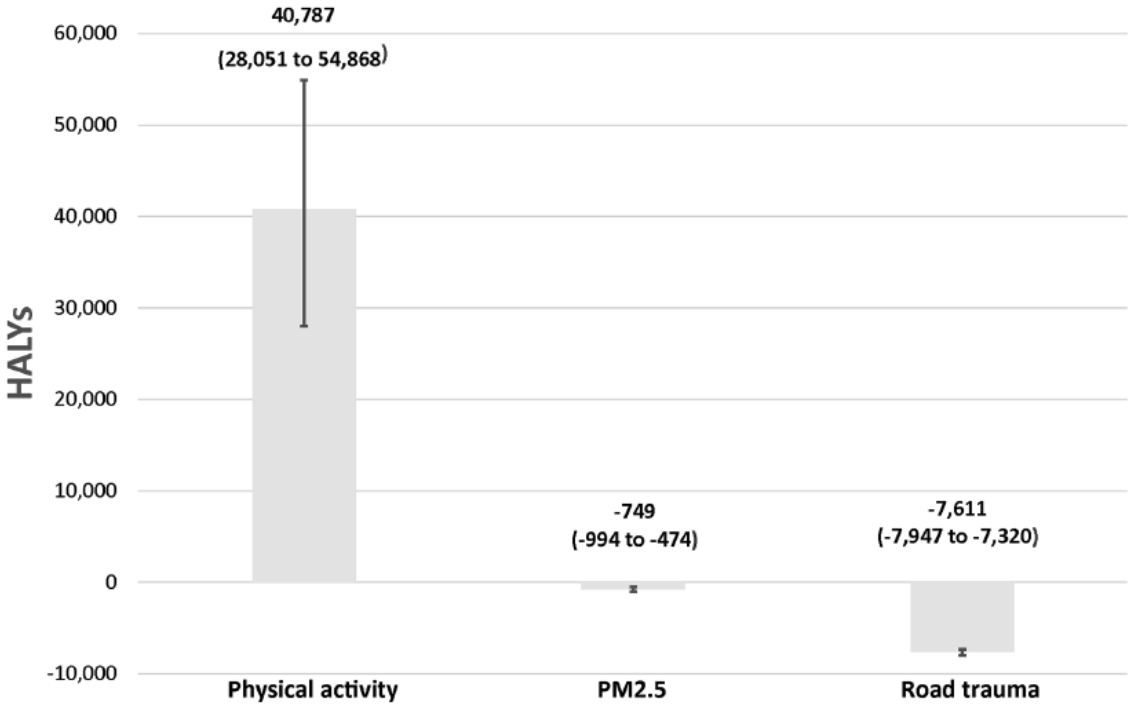


Fig 2. HALYs by risk factor over the life course of the Brisbane adult population (95% uncertainty interval).

https://doi.org/10.1371/journal.pone.0184799.g002

Source: Zapata-Diomedi et al. (2017)

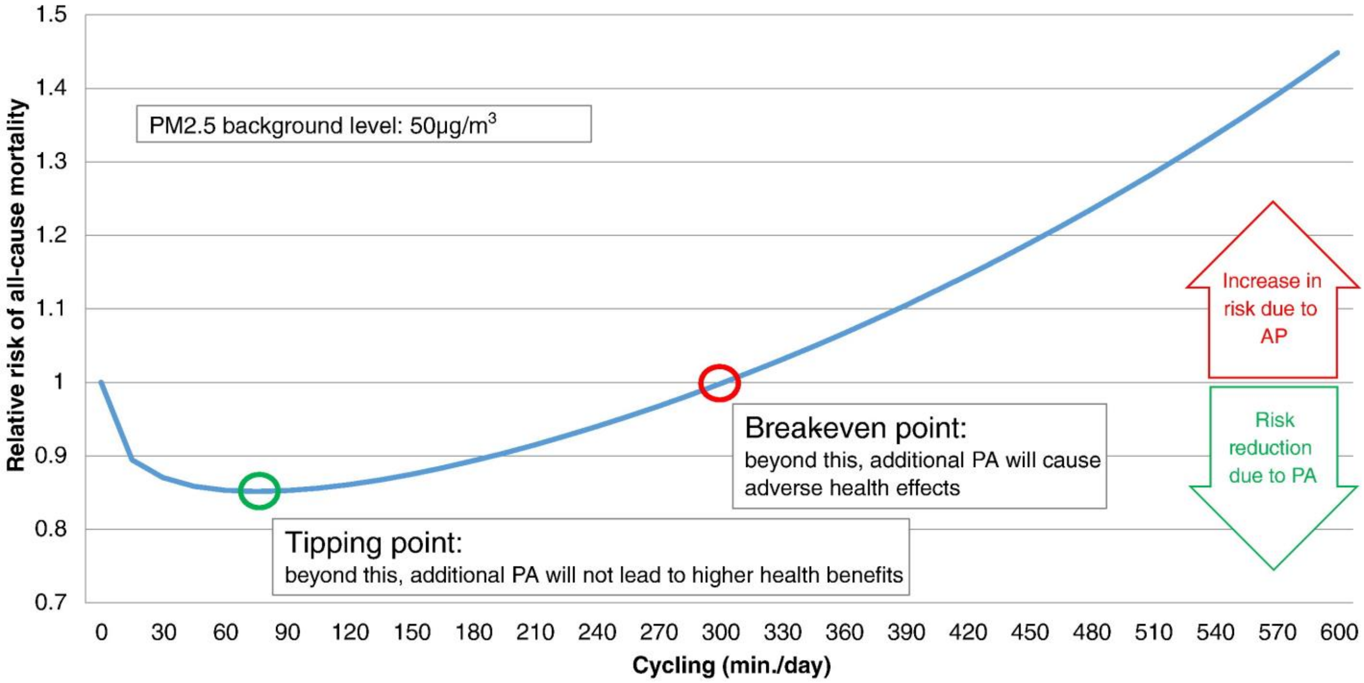
NB: Brackets are 95% uncertainty intervals.

HALYs are summary measures of population health, incorporating both morbidity and mortality, and provide evidence of differences in duration and quality of life that are useful in the evaluation of measures that can impact health.

One study, which compared the health risks of air pollution, with the physical activity benefits associated with cycling, were able to explain this relationship via a tipping point and a breakeven point (Tainio et al., 2016). This relationship is shown in Figure 35 and highlights that cycling around one hour a day provides more health gains through physical activity than health negatives due to exposure to air pollution. The relative risk of all-cause mortality then begins to rise to the point where the risk is the same as if one did not cycle at all (i.e. the benefits of physical activity are equal to the negative impact of air pollution exposure). This occurs when cycling for 300 minutes per day. While it is unusual for many people to cycle regularly for this duration, it does have implications for delivery riders, especially given that they are more likely to be riding in built up areas, and more likely to be riding e-bikes, which the physical activity benefit is some 60 – 70% of that of regular bike riding (Fishman and Cherry, 2015).

Most of the research examining the impact of air pollution on cyclists health also make the important observation that any increase in cycling that substitutes for motor vehicle trips will reduce pollution levels, resulting in general population health benefit (e.g. see Tainio et al., 2016, de Hartog et al., 2010). ATAP PV5 discusses the environmental impacts of motor vehicles.

Figure 35 Relative risk for all-cause mortality of effects of air pollution and physical activity (cycling)



Source: Tainio et al (2016)

Finally, it is important to recognise that the research this section refers to, undertaken primarily by population health, safety and environmental scientists, focuses on the costs and benefits to health from active travel, under *current* conditions. Should the trend towards more sedentary lifestyles, cleaner vehicles and safer infrastructure continue, it can be expected that the health benefits of active travel will *increase* relative to their costs (Götschi et al., 2015).

10. E-bikes

While the overall structure of the bicycle has remained remarkably similar over the last century, the emergence of e-bikes has begun to significantly change the way the bicycle contributes to mobility patterns. Beginning in Japan in the early 1980s (Rose, 2012), e-bike technology has improved substantially over recent decades, becoming more reliable, having greater range (improved batteries) and applied to a wider range of bike styles (Fishman and Cherry, 2015).

Figure 36 provides an image of a modern e-bike. Such bikes are generally capable of travelling ~80km between charges, which typically take between 4 – 6 hours.

Figure 36 Modern e-bike

The global electric bicycle (e-bike) market has grown substantially in the last decade. E-bikes represent the largest, most rapid uptake of alternative fuelled vehicles in the history of motorisation (Fishman and Cherry, 2015). Australia’s harmonisation of e-bike regulation, which broadly equates to European standards, coupled with growing market interest, has resulted in a flourishing local e-bike sector. Bicycle Industries Australia estimate that between 25,000 – 30,000 e-bikes were imported into Australia in 2017, which is approximately twice the number imported in 2016. It is not clear whether this estimate includes sales of conversion kits, and online sales from overseas e-bike merchants and sales data collection is insufficient to have certainty regarding the precise number of e-bikes in Australia. However, the general trend towards higher sales figures is clear.

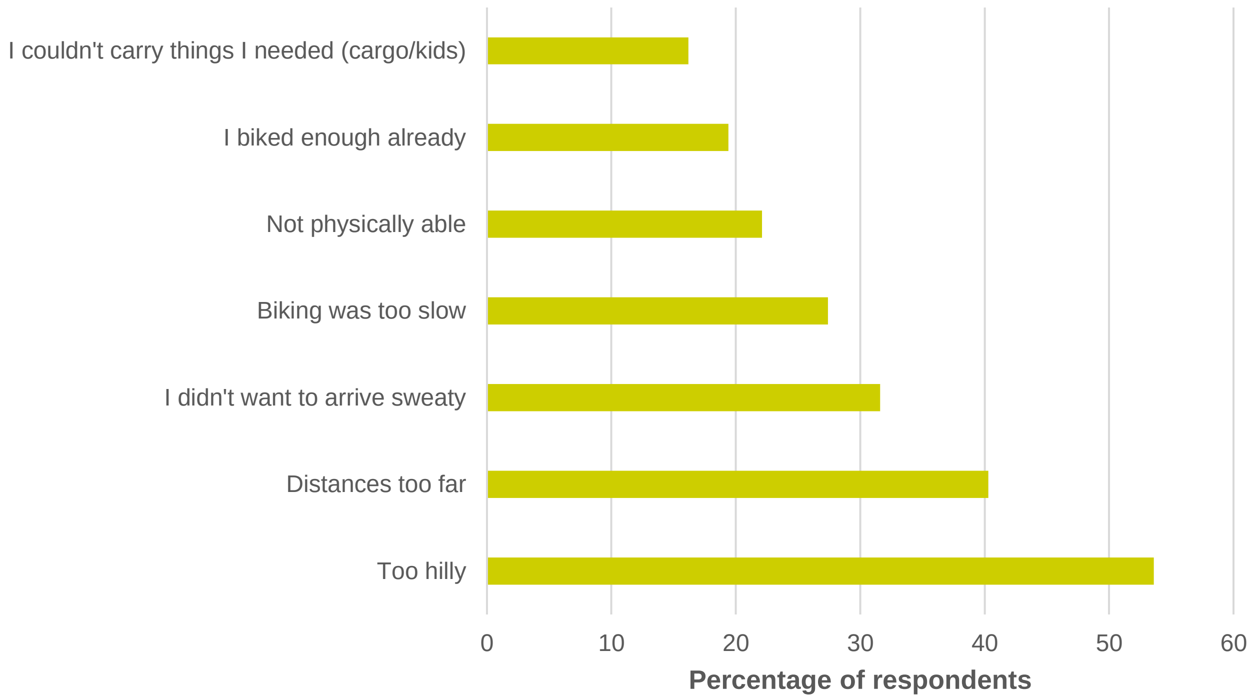
As this section describes, e-bikes have changed bike riding patterns, and it is for this reason that their emergence can have an important impact on how bicycle projects are assessed and on cost benefit analyses. In essence, it is likely the growth of the e-bike sector will gradually enhance the benefits of bicycle initiatives and projects.

10.1 Why people ride e-bikes

E-bikes offer the user quicker travel time, with less effort. E-bikes have been found to lessen some of the common barriers to conventional bikes, including the ability to overcome topographical challenges, physical limitations of the rider and arriving at work without perspiring (Fishman and Cherry, 2015, Fyhri and Fearnley, 2015, Popovich et al., 2014). Moreover, e-bike owners report that being able to ride with greater loads (e.g. children or groceries) opens up greater possibilities for cycling, including replacing some car use.

Figure 37 provides an overview of the barriers limiting the use of conventional bikes, according to a survey of e-bike owners.

Figure 37 Barriers limiting conventional bike use according to e-bike owners



NB: Excludes safety

Source: Macarthur et al. (2018)

As shown in Figure 37 *'Too hilly'* and '*too far'* were the two most common reasons, followed by *'I didn't want to arrive sweaty'*. These are pertinent to Australia, as some of our major cities can be hilly (e.g. Sydney and Brisbane), our cities are low density (relative to many other cities), which can result in longer trip distances than high density cities and are frequently hot. A pertinent finding from North American research found 67% of riders said they often needed a shower after a conventional bike trip but only 26% did after an e-bike trip (MacArthur et al., 2014). For these reasons, e-bikes are likely to represent a compelling value both now, and in the future.

Importantly, research has also shown that in addition to the reasons mentioned above, e-bikes also increase people's perception of both *safety* and the *fun* of riding (Popovich et al., 2014) and this might be why e-bike owners ride more than those owning a conventional bike only.

10.2 Barriers to e-bike use

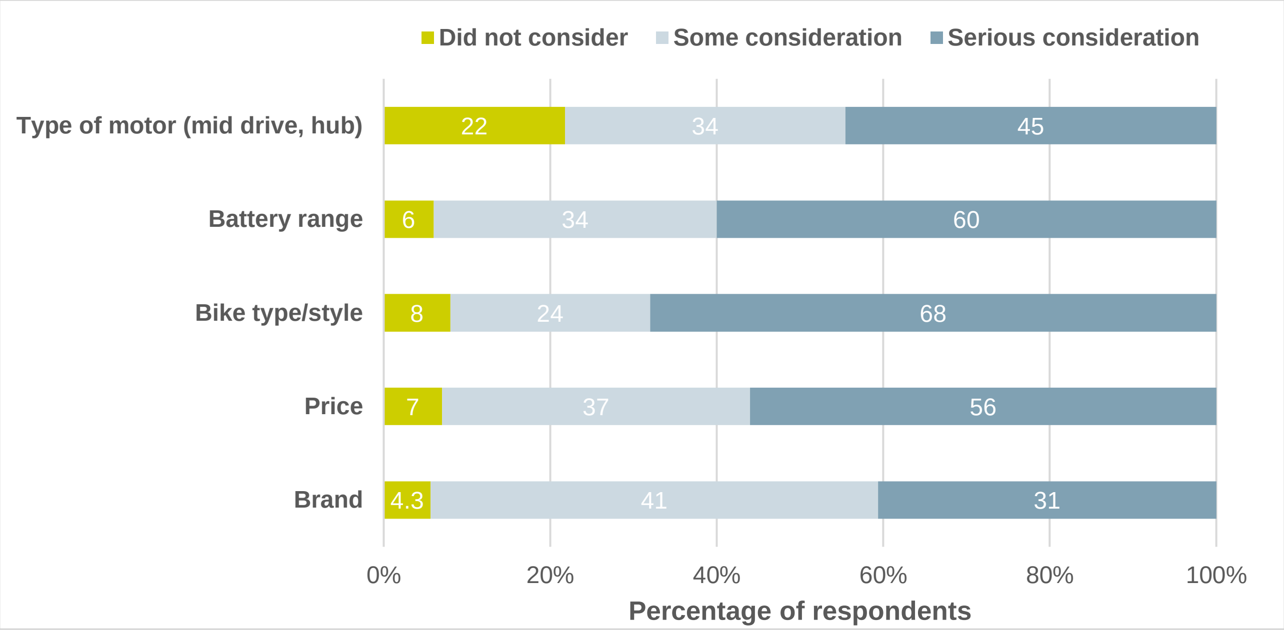
Cost, battery range and the stigma associated with the assistance offered by the motor are three of the main reasons preventing more people from riding an e-bike. The other key barrier, which is the same as for regular bicycles, is the lack of protected bicycle infrastructure. This last barrier was highlighted in recent Near Market study into riding preferences (CDM Research & ASDF Research, 2017).

A North American study asked participants who did not own an e-bike what the key barriers to purchasing one might be. Overwhelmingly, *'expensive to purchase'* was the dominant reason offered, with almost 4 in 5 respondents citing *high purchase cost* as the primary reason (Ling et al., 2017). The younger respondents were more likely to cite high purchase price as the key barrier. E-bikes are generally more expensive than conventional bikes (~$2,000 – 4,000), and this can also act as a barrier to increased adoption (Johnson and Rose, 2013). An interesting finding to emerge from the literature is that once people had *the experience* of riding an e-bike, they were more willing to spend a greater amount of money to purchase an e-bike (see Fyhri and Fearnley, 2015).

A study of e-bike owners in the Netherlands and the UK identified that battery life, the heaviness of the bicycle and a social stigma were limitations or negative aspects of e-bikes. A desire for the battery range to be longer was expressed, and some identified that a social stigma surrounds the use of e-bikes (a perception of 'cheating'), with their social network sometimes making jokes about their use of an e-bike (Jones et al., 2016), especially if the rider is relatively young (e.g. under 60 years of age). It is plausible similar attitudes exist in Australia, given that our cycling culture is broadly similar to the UK, and that a significant proportion of urban cycling is 'lycra' style, in which the physical nature of the activity is more prominent than it is in, for example, northern European cycling. It is therefore possible that e-bikes, especially for younger people, are associated with a laziness, or 'cheating'. Paradoxically, the same attitudes do not extend to very short car trips, despite this activity being widespread and holding no physical activity benefit (unlike e-cycling).

Macarthur et al. (2018) asked e-bike owners how important various factors were when making their e-bike purchase. The results are presented in Figure 38 and reveal that the *type of bike* (e.g. upright style, cargo etc.), *battery range* and *price* were the most important considerations when making an e-bike purchase.

Figure 38 Considerations at time of purchase



Source: Macarthur et al. (2018)

10.3 Differences in riding behaviour

E-bike owners ride more often, and further than other cyclists and are able to better maintain speed with less effort (Macarthur et al., 2018). E-bike ownership reduces car use to an even greater extent than regular bicycles (Jones et al., 2016).

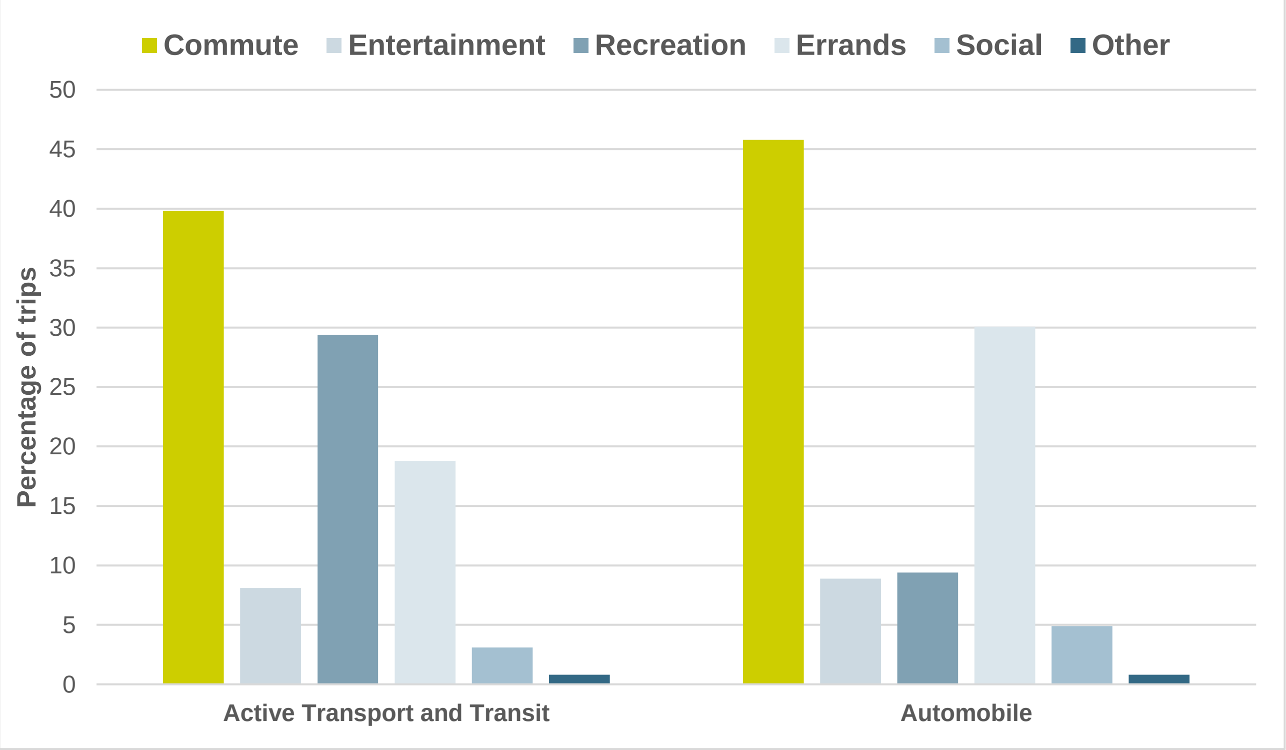
E-bikes are especially useful for making longer (i.e. >10km), more complicated journeys (Jones et al., 2016). Most studies looking into the impact of e-bikes on reducing car use find that between 40% - 50% of e-bike trips replace a journey that would have otherwise been completed by car (Cairns et al., 2017). The degree to which e-bikes replace car trips can increase for the commute trip.

A study on US e-bike owners found replacing car trips was cited by almost 65% of respondents as one of their primary reasons for beginning to use an e-bike (MacArthur et al., 2014). In Australian research, 60% of respondents to an online survey cited replacing some car trips as a main motivation for e-bike purchase, followed by 49% who said they were motivated by being able to ride with less effort (Johnson and Rose, 2013). Neither of those two surveys documents actual car substitution. One study found that when provided with an e-bike, study participants increased the proportion of trips done by bike from 28% to 48% (Fyhri and Fearnley, 2015).

Females are under-represented in cycling participation in Melbourne (Pucher et al., 2010) and e-bikes have been shown to boost female cycling levels (Macarthur et al., 2018), in part because they make it easier to carry shopping and children, both of which fall disproportionately to females (Heinen, 2011). Perhaps unsurprisingly, those living in a hilly environment are more like to express interest in an e-bike (Ling et al., 2017).

Figure 39 shows two mode categories for which e-bikes are acting as replacement modes. *Active Transport and Transit* includes foot, standard bike, bike share, or public transport. *Automobile* includes any form of car use (e.g. private car, Uber, taxi or car share). The results show that e-bikes are most likely to be used as a replacement for a commute trip formerly done by car (46% of respondents), and active/transit (40%).

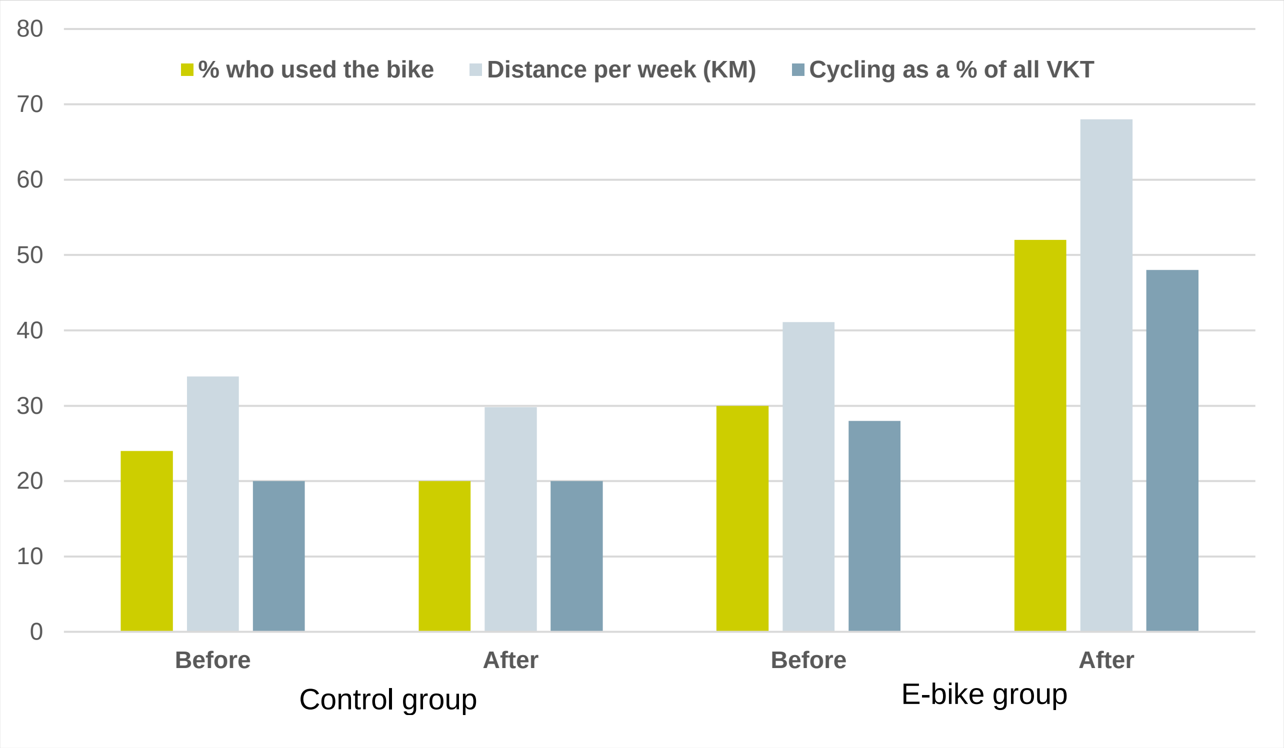
Figure 39 Modes replaced by e-bike



Source: Macarthur et al (2018)

When researchers have provided some participants with an e-bike, and had others act as a control group (no e-bike), the results have shown that the number of cycling trips increases significantly for those with the e-bike (Fyhri and Fearnley, 2015). The researchers found cycling trips increased from 0.9 to 1.4 per day and distances increased from 4.8km to 10.5km following the provision of the e-bike. The control group showed no increase. The increase among the e-bike group was greatest for women. The results are shown in Figure 40.

Figure 40 Bicycle use: E-bike vs control group



NB: VKT refers to Vehicle Kilometres Travelled

Source: Fyhri & Fearnley (2015)

Cherry and Cervero (2007) found travel speed was between 10 - 15% higher for e-bikes than regular bicycles, but mean travel times were similar, supporting literature on constant travel time budgets (Marchetti, 1994).[13]

10.4 E-bikes and safety

E-bikes are beginning to reach sufficient levels of market penetration to observe crash data in some European countries (Schepers et al., 2018). Research shows that of the crashes that do involve an e-bike, they are no more severe than crashes on regular bicycles. Papoutsi et al. (2014) investigated hospitalisation data for e-bike riders in Switzerland. The authors investigated 23 crashes that were reported to the emergency department (ED). Just over one quarter of the reported crashes resulted in head injuries, with upper extremities being the second highest injured region. These results may be somewhat different in Australia, with helmet use mandatory and very high levels of compliance (Haworth et al., 2010). Interestingly, most of the crashes reported were as a result of being caught in a tram rail, not a result of motor vehicle collision. This is pertinent to Melbourne in particular, which is at the centre of the world's largest tram network. The authors found that crashes tend to be less severe in Switzerland than China, in part due to wider use of helmets and the relatively low number of e-bike crashes involving motor vehicles.

[13] The Marchetti Constant is the observation that throughout history, people have maintained a similar duration of travel, even if the speed may have increased. On average, people generally travel for around 35 minutes each way between home and work.

Schepers et al. (2014a) compared the safety outcomes of e-bike and bicycle use in the Netherlands, using data from Emergency Departments, as well as surveys of cyclists without any known crash experience. In total, 294 e-bike and 1,699 bicycle crash victims were included in the study, as well as 791 e-bike users and 517 bicycle riders without any known crash involvement (control group). The age group with the highest likelihood of Emergency Department treatment were those 65 years and older. Overall differences in safety outcomes were not dramatic between e-bike and bicycle riders.

10.4.1 Influence of e-bikes on rider confidence

A number of studies have found that people who ride e-bikes report that they feel safer than when riding a conventional bike (Macarthur et al., 2018). E-bike users note that they are more willing to take longer routes that avoid streets that feel dangerous and are better able to utilise shared paths and other routes that do not involve cycling in mixed traffic. Moreover, the assistance of the motor enables e-bike riders to take off faster from a standing start, helping to achieve a cruising speed that reduces the speed differential with motor vehicles. E-bike owners are eight times *more* likely to report that their e-bike helped them avoid a crash than they were to report that the e-bike contributed to a crash (Macarthur et al., 2018). The authors identified that *'Perceived safety plays an essential role in whether an individual is likely to ride a bicycle for a given trip; thus by enhancing one's sense of safety e-bikes could potentially tap latent demand for bicycling by encouraging those who may not feel safe on a standard bicycle* (Macarthur et al., 2018, p. 6).

Aside from rider confidence per-se, a number of studies have found that e-bike owners report that they feel a sense of *joy* when using their e-bike (Jones et al., 2016, Popovich et al., 2014). This increase in enjoyment may be one of the reasons e-bike owners ride more. This effect on increasing cycling participation may also, cumulatively, work to reduce crash risk via the *Safety in Numbers* phenomenon (e.g. see Jacobsen, 2003) — see discussion in section 5.6 here.

10.4.2 Infrastructure considerations

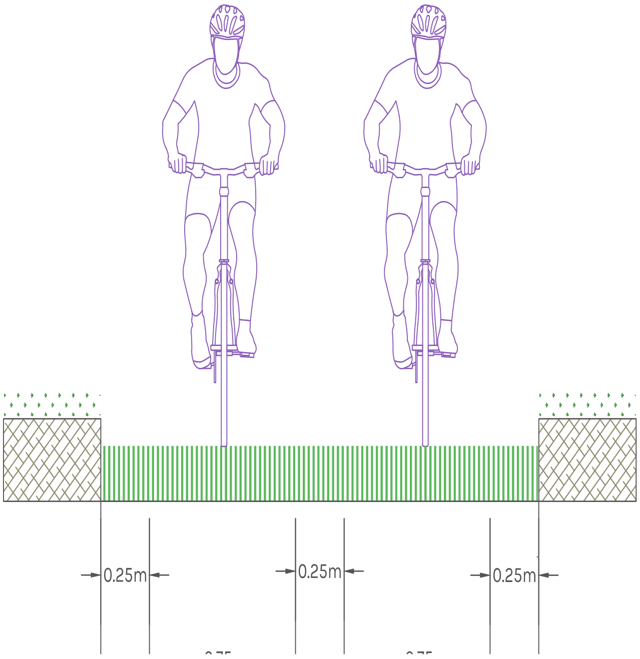
E-bikes may trigger modal shift and this may have wider impacts on transport safety generally, particularly if the shift replaces motor vehicles (Schepers et al., 2015).

A study using in-depth interviews with e-bike owners in the Netherlands and the UK found that when using their e-bike, the speed of participants had to be moderated, in order to feel safe (Jones et al., 2016). For busy Dutch bicycle paths, e-bike users reported that they sometimes need to plan their route to reduce interactions with other users that would slow them down (Jones et al., 2016). Users also reported that they moderate their speed depending on the environment in which they are cycling. On open bike paths users felt comfortable to have maximum assistance (25km/h), while on congested, central city streets, it was necessary to ride at a speed consistent with the prevailing bicycle traffic speed.

Bicycle infrastructure quality has also emerged as an important element of perceptions of safety for e-bike users (Jones et al., 2016). Compared to their Dutch counterparts, participants from the UK reported that having to share the road with motor vehicles and the lack of a cohesive cycling network reduced their level of perceived safety and enjoyment. Interestingly, (and consistent with US findings), the extra speed with which people were able to travel *increased* perceptions of safety, as they reported being able to better keep up with motorised traffic flow; i.e. the speed differential was less (Jones et al., 2016). This finding is relevant to Australian cities, which generally lack a coherent network of protected bicycle infrastructure.

The width of bicycle lanes may need to be widened, in order to better accommodate safer overtaking, as e-bike adoption continues to grow. E-bike riders generally travel between 20km/h and 25km/h, whereas many conventional cyclists will often travel at a slower speed. In order to reduce potential conflict and delay, it will be necessary to provide widths capable of allowing safe overtaking. While this will vary based on context, the minimum future dimensions for high demand bike routes is indicated in Figure 41.

Figure 41 Double width protected bike lane



Source: Created by Institute for Sensible Transport using data contained in CROW Manual (CROW, 2017)

Many e-cargo bicycles/trikes are wider and slower than other bicycles and infrastructure design should allow for safe overtaking possibilities. For protected bicycle infrastructure, it may be necessary to make these semi-permeable, to facilitate over taking.

Bi-directional protected lanes may cause conflict between oncoming bicycle traffic due to the width consumption of some of the larger e-cargo freight bikes. Bi-directional lanes should only be used once all other options have been considered.

10.5 Physical activity impacts of e-bikes

Several studies have emerged over the previous decade seeking to measure the impact of e-bikes on health. For the purposes of this review, the meaning of the term ‘health’ is restricted to improved health from increased *physical activity*.

The overwhelming, consistent theme to emerge from this body of research is that e-bike riding holds many of the physical activity benefits associated with regular cycling. In sum, e-bike riders have a metabolic workload of around 60 – 70% of a regular cyclist (on a per distance basis). As noted in section 10.3, e-bike riders tend to ride longer, and more frequently than regular cyclists, meaning that much of the overall metabolic activity differences between e-bike and regular riding evaporates when considered in aggregate.

Simons et al. (2009) conducted a study in the Netherlands on 12 healthy, physically active subjects, who rode a 4.3 km route three times using an e-bike while measuring physiological performance. Key points of the study:

- First circuit was undertaken without any power assistance
- Second while the e-bike was on ‘eco’ (low power) mode
- Final circuit was completed using the most electrical assistance.

The researchers measured physiological variables such as heart rate and oxygen consumption as well as power applied through the pedals. Results:

- All three-power settings provided a useful contribution to meeting minimum physical activity requirements.
- Even with electrical assistance, riders achieved the necessary physical activity intensity (between 3 - 6 Metabolic Equivalent of Task, or METs[14]) to help reduce the chance of sedentary lifestyle diseases.

Not surprisingly, riders under the most powerful assistance setting achieved a higher average speed, which had the effect of reducing overall riding time. While this does have the effect of reducing the duration of physical activity, previously cited evidence suggest that those riding e-bikes tend to spend more time on their bikes than if they did not have an e-bike available (MacArthur et al., 2014).

Gojanovic et al. (2011) set out to examine whether e-bikes were able to provide sufficient physical activity for the user to gain health benefits. Conducted in a hilly part of Lausanne, Switzerland, 18 sedentary participants (12 female) performed four set trips at their own pace. The first trip involved a 1.7 km uphill walk, the second a predominately uphill 5.1 km trip on a conventional bicycle, an e-bike with a standard power setting and with a high-power setting. The walking and e-bike (high power setting) resulted in average METs of 6.5 and 6.1, respectively (no significant difference). The e-bike using the standard power setting and the traditional bike resulted in an average MET of 7.3 and 8.2, respectively. These results led the authors to conclude that e-bikes are effective in providing health enhancing physical activity in a topographically challenging environment.

A study conducted by Sperlich et al. (2012) involved eight sedentary females and required them to cycle at their own pace along a 9.5 km route, once on an e-bike and again on a conventional bike (the order was randomised). Measures of physical exertion were lower when using an e-bike compared to a traditional bike, but the level of enjoyment and speed was higher. Despite the lower levels of physical activity recorded by participants on e-bikes, the energy expenditure was found to be within the range necessary for health enhancement. De Geus et al. (2013) found positive physiological changes in 20 people following a 6-week period of e-bike use.

Finally, Langford (2013) investigated the 19 users of a bicycle and electric bike sharing system in Knoxville, Tennessee, USA on a fixed 4.4 km hilly course using laboratory, GPS and onboard power meters to measure physical exertion. This research found that energy expenditure per unit time for e-bike trips is 11% less than that for regular bicycle trips and 8% more than for walking trips. Average cruising speed for the three modes was 5.1 km/h for walking, 14.4 km/h for bicycle, and 16.4 km/h for e-bike. Walking trips, while requiring less energy per unit time, take longer to complete and, in this case, require a greater amount of total energy from the user, consistent with other active transport research (Fishman et al., 2015a). Considering the performance advantages of e-bikes over the course of the trips studied, the total energy demanded for e-bike trips was 21% less than required for regular bicycles trips and 62% less than for walking trips.

10.6 Best practice e-bike case studies

The benefits associated with e-bikes have led to a number of initiatives intended to boost their contribution to the transport and sustainability challenges faced by cities. The most common method for encouraging the use of e-bikes is purchase price subsidy. Sweden and Oslo both have programs designed to incentivise e-bike purchase through direct subsidy and a number of other jurisdictions are planning similar programs,

[14] A physiological measure expressing the energy cost of physical activities and is defined as the ratio of metabolic rate (and therefore the rate of energy consumption) during a specific physical activity to a reference metabolic rate, set by convention to 3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$

including the UK.

Many governments have subsidy programs for the purchase of electric cars. E-bike subsidy programs typically cost less than 8% of the typical dollar value of an electric car subsidy (Haubold, 2016).

10.6.1 Purchase subsidy programs

Subsidies for e-bikes are an effective method of boosting ownership levels, and the literature review found that e-bikes are much more likely to be used frequently and for longer trips than conventional bicycles. Moreover, recent large-scale surveys of e-bike owners showed that price is one of the most important considerations when making an e-bike purchase. In fact, of all the most important considerations when deciding to purchase an e-bike, price is the only one that government have a level of control over.

Sweden’s e-bike subsidy

In 2017, Sweden created a subsidy program in which the purchaser of an e-bike was able to receive a 25% subsidy, up to a value of €250. The program was budgeted for 2018, 2019 and 2020. The take up was strong, with 40% of the annual €35 million depleted within the first 3 months of the program (Business Insider Nordic, 2018). Sweden’s EPA received around 2,000 applications per week. Around 40% of surveyed Swedes reported that they would be interested in purchasing an e-bike (Business Insider Nordic, 2018). The subsidy was scheduled to end in 2020 (Electric Bike Report, 2018), but ended in 2018 once the funds expired.

The 25% subsidy is on the purchase price and includes not just e-bikes but also electric mopeds, motorbikes, and electric powered mobility aids for those with a disability. Applications are only for Swedish residents aged 15 and over and restricted to one bike per person and year (Christofides, 2017). As the program is relatively recent, no data is available on the impact of the scheme, the demographics of applicants or other program outcomes. Evaluation of the scheme continues (CEPR 2022).

Oslo, Norway

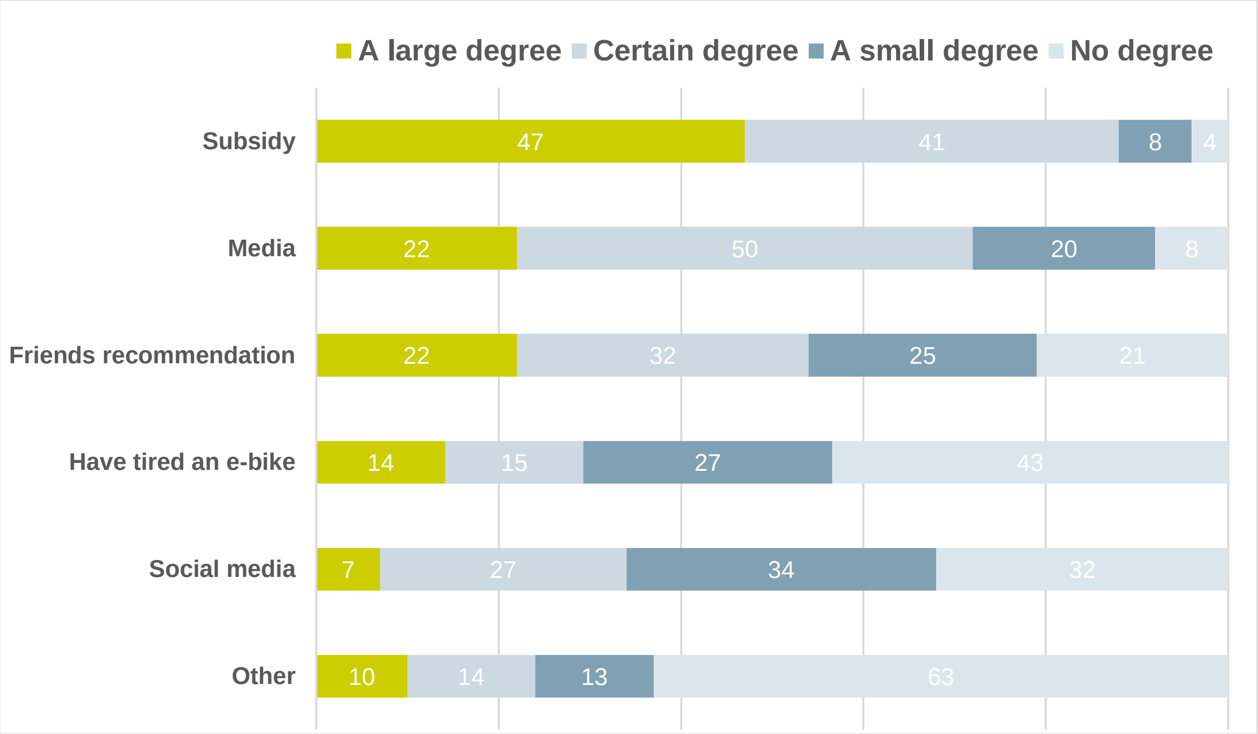
In 2016 City of Oslo announced that it would provide a purchase price subsidy to overcome the price barrier and encourage the uptake of e-bikes. The City now provides a €500 subsidy for residents who purchase an e-bike, as one part of a broader strategy of reducing car use. This subsidy can be doubled for the purchase of a cargo bike (Business Insider Nordic, 2018). The subsidy is only open to residents of Oslo. There is also a requirement for the recipients to respond to a questionnaire prior to their e-bike purchase (Fyhri et al., 2016).

The subsidy program had very strong uptake, with the quota of 1,000 applicants being reached within the first month of the subsidy announcement.

A study into the impact of the subsidy program was undertaken and used both the questionnaire data, and actual travel behaviour data recorded through the use of an App (Sense.DAT). Figure 42 provides an indication of the influence of different factors in the purchasing of an e-bike, using the responses from 830 people who had recently become e-bike owners. It shows that overwhelmingly it was the subsidy from the City of Oslo that influenced the purchasing decision.

Media and peer recommendation was also found to be an important factor – both of which may have been influenced to some degree by the subsidy program itself which attracted a lot of media attention when it was announced.

Figure 42 Factors influencing decision to purchase an e-bike (%)



Source: Fyhri et al (2016)

In terms of the influence that the e-bike purchase had on cycling activity, the study by Fyhri et al (2016) found that for those taking advantage of the e-bike subsidy, their bicycle usage increased by 30% (in terms of trip frequency). This resulted in a reduction in walking, public transport and car use by 4%, 10% and 16% respectively. Prior to the purchase of an e-bike, the share of kilometres cycled among participants was 17% and this increased to 52% after e-bike purchase.

As the City of Oslo has strong emissions reduction targets, an analysis was performed on the impact of the subsidy program on CO_2 emissions (Fyhri et al., 2016). For each e-bike provided as part of the subsidy program, an estimated 87kg – 144kg of CO_2 is avoided annually. This estimate does account for the fact that riding levels reduce considerably in the Norwegian winter. With milder winters, Australia could expect to have relatively smaller reductions in winter cycling, and thereby potentially larger reductions in CO_2 emissions.

United Kingdom

The United Kingdom currently provides a £4,500 subsidy for the purchase of a new electric car, and £8,000 for an electric van, with a budget of £1.5 billion for its *Ultra-Low Emission Vehicles Program* (to 2021). The government has begun to explore possibilities to extend incentives to e-bikes as well (e.g. see Reid, 2018). Scotland has launched an interest free loan program to assist in reducing the barrier of upfront purchase price of e-bikes. The loan can be for as much as £6,000 with a repayment period of 4 years and covers (per household):

- 2 e-bikes, capped at £3,000 each
- 1 family cargo or e-cargo bike capped at £6,000
- 1 adaptive bike or e-bike.

10.7 Freight and other commercial uses for e-bikes

E-bikes also hold great potential to reduce negative impacts associated with last kilometre freight delivery. The density of small parcel freight delivery in central city areas lends itself to e-cargo cycles. This type of delivery has experienced a surge since COVID-19. E-cargo cycles are currently experiencing a surge of activity in European cities. E-cargo cycles offer an important opportunity to reduce the congestion and emissions caused by small parcel delivery in Australia's capital cities.

E-cargo cycles have undergone significant technological development over the last four years and the following provides a snapshot of the key numbers:

- Capacity for up to 300kg of cargo
- Battery range of ~50km
- Uses ~6% of the energy of an electric van
- Purchase price of $4,000 - $12,000
- Around twice as many deliveries can be made per hour in congested, dense inner cities (compared to standard vans)
- Power output can be compliant with existing legislation (250W max.)

Road freight has a major impact on central city transport systems and local amenity. Road freight makes up between 8 – 18% of vehicle movements and reduces road capacity by 30%, due to their frequent stops for pick up and deliveries (Nocerino et al., 2016). Within the City of Melbourne, it is estimated that 15% of all CO_2 emitted by *on road transport* can be attributed to light commercial vehicles (Davies et al., 2018), which is broadly consistent with international averages (e.g. see Nocerino et al., 2016).

Electric assistance is considered especially important for the viability of cargo cycles, as it reduces the physical burden on the rider, which becomes increasingly important as payloads increase (Conway et al., 2011). Electrical-assistance also increases average vehicle speed, helping to boost its travel time competitiveness with conventional delivery vehicles. One Italian study found that for each kilometre in which an electric cargo cycle replaced a traditional delivery vehicle, between 45 – 370 grams of CO_2 were avoided (not emitted). Over the course of a day, this amounts to between 17 and 21kg of $C0_2$ (Nocerino et al., 2016), which, annually, would represent a saving of around 4.5 tonnes of $C0_2$, assuming 240 working days per year. To put this in context, this is roughly the equivalent of taking 1.3 average Australian cars off the road.

Considerable potential exists to transfer a portion of the freight task for small parcel delivery to low impact, electric cargo cycles. It has been estimated that between a fifth and half of all kilometres travelled by logistics firms that are currently done by internal combustion engine vehicles could be substituted with electric cargo cycles (Gruber et al., 2013). For European cities, it is estimated that half of all motorised vehicle trips involving goods transport, could be carried by bike or cargo cycle (Schliwa et al., 2015). It is unlikely this number is comparable to Australian metropolitan areas, due to lower density. For the central city areas of our major capitals however, the congestion, parking difficulties and density factors mean that they are likely to hold some similarities to European cities and therefore offers a more favourable environment for e-cargo cycles.

10.7.1 DHL Cubicycles

DHL began introducing cargo cycles produced by the Swedish firm *Velove* into their European fleet in 2015. The cargo cycle accepts a loaded small container directly from a distribution warehouse or conventional van, reducing handling time. The cargo cycles receive power through the rider's pedalling and a 250W motor. The electric motor uses 6% of the electricity needed by a small electric van and a similar proportion of raw resources for its production (Velove, 2018).

DHL Express has introduced bicycles in more than 80 European cities in 13 European countries to date, including 14 Cubicycles in seven cities. Cubicycle couriers cover 50km per day on average.

Up to 125kg can be carried by the cargo cycle. In terms of operation, a standard van typically travels to a central city area, where the repacked containers are loaded onto the cargo cycles for last kilometre delivery. The containers match the dimensions of a standard shipping pallet and their height has been designed to be low enough for other cyclists to see over it. Figure 43 provides an example of the Velove bikes DHL containers.

Figure 43 DHL couriers using e-cargo cycles, The Netherlands

Source: DHL

While the DHL pilots are yet to be completed, early results suggest that productivity varies from 0% improvement (i.e. same number of parcels delivered per hour as conventional small vans) through to 100% improvement (twice as many parcels delivered per hour). Marijn Slabbekoorn is the operations manager with DHL's *GoGreen* program and was interviewed as part of the current project. During this discussion, it was revealed that DHL's cargo cycles can often deliver their parcels 2 – 3 times as quickly as a van on the same route. Generally, around 15 parcels can be delivered per hour using an e-cargo cycle. An e-cargo cycle could travel up to 60km per route and were capable of carrying two batteries to extend the distance travelled.

Mr Slabbekoorn reported that one of the key reasons e-cargo cycles are competitive with traditional delivery vans in the Netherlands is the quality of the bicycle infrastructure network. There is also a supportive attitude from businesses and consumers towards the delivery of goods via cargo bike.

For DHL, they recognise that as cities in the Netherlands move towards restrictions on polluting vehicles (due for implementation in 2025), clean, low impact delivery will become essential.

CEO of DHL Express Europe, John Pearson reports that '*DHL Express has already replaced up to 60% of inner-city vehicle routes in some European countries with cargo bicycles, and we expect that the City Hub and Cubicycle will both help us to accelerate this approach in other markets over the next 3-5 years'* (Erlandsson, 2017).

The three most important measures government can take to boost the level of cycle freight deliveries are:

- Completing a cohesive network of protected bicycle infrastructure
- Restricting motor vehicle access and delivery for polluting vehicles
- Assisting in creating suitable handover points where goods can be shifted from larger vehicles to last mile e-cargo cycle delivery vehicle.

11. E-scooters

E-scooters are a relatively new form of mobility being used, often in trials, in cities across the world. Although it does not technically involve physical activity, and therefore not active travel, it is discussed here because they share some of the facilities provided for active travel, and because many of the benefits and costs are similar to active travel.

Many cities are undertaking trials and are yet to conclude evaluations. There are many questions that will need to be well researched and reported. Some of the learnings arising from published research to date (Sanders et al. 2020, Bozzi and Aguilera 2021, Wang et al. 2023) are that e-scooters:

- Are seen as a convenient form of travel (particularly in the heat) and fun to use
- May fill an important transport niche
- Are sometimes advertised as “effort-free”, suggesting they probably offer few fitness and health benefits
- Divert most trips from walking, resulting in a potential overall reduction in physical activity (if not substituted with other forms of physical activity)
- Have associated traffic safety concerns, particularly for women.

These points provide a high level early picture of e-scooters as a form of travel. Further research will inform the full effects of e-scooters.

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