Designing for the 'Interested but Concerned': A literature review on cycling infrastructure design

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1. Introduction

This literature review is the first stage of a two-year research project for Transport for NSW titled *Interactively visualising street design scenarios for communicating bike infrastructure options to communities and policymakers.* The research project investigates how to integrate cycling facilities into urban environments in ways that address the concerns of the 48% of NSW residents who are “interested” in cycling, but “concerned” about safety (Transport for NSW, 2013a, 2020a). The study will gather new data on what design features influence or change this cohort’s perception of safe bikeability by utilising immersive virtual reality technology to test design improvements on study participants’ sense of safety. This approach aims to mitigate the known weaknesses of stated preference surveys, which has been the predominant approach for examining cyclists’ preferences for routes and riding environments. The findings will inform coordination and decision-making processes for the NSW Government’s cycling infrastructure planning and investment strategy.

Targeting these potential riders means focusing design techniques on the aspects that these customers value. Identifying and investigating these aspects is the key focus of the research project. This literature review aims to understand current and emerging cycling facility design practice within Australia and internationally, and to consider these trends alongside Transport for NSW’s *Cycleway Design Toolbox: Designing for Cycling and Micromobility* (2020a).

Over the last three decades, there has been a significant increase in the number of people cycling in cities around the world, accompanied by a matching shift in government policy and urban planning (Buehler & Pucher, 2021). There is widespread agreement among policymakers and researchers that increased cycling as a mode of transport can help address many of the persistent and difficult transport, economic, environmental and health issues facing cities today (De Hartog et al., 2010; Garrard, Rissel, et al., 2012; Kingham & Tranter, 2015; Krizek, 2007). In Australia, as in the rest of the English-speaking world, cycling rates are moving up from a very low baseline in comparison with cities in Asia and northern Europe (Buehler & Pucher, 2021). As a result, this shift in public attitudes and policy includes a recognition that cycling must appeal to a broader audience than the sport-oriented riders that have characterised the past fifty years of Australian ridership (Fitzpatrick, 2015).

A framework for identifying and addressing this broader audience was theorised in 2006 by Roger Geller from the City of Portland, Oregon (Geller, 2009). Geller categorised people as falling into one of four categories based on their attitudes and practices around cycling – the “Strong and Fearless,” the “Enthused and Confident,” the “Interested but Concerned,” and the “No way, No how” (Figure 1). The “Interested but Concerned” cohort is typically about half of the adult population of a city.[1] The importance of improved safety and comfort to this cohort has spurred a generation of bicycle plans that have gone beyond painted bicycle lanes toward networks of diverse facilities, ranging from quiet, traffic controlled local streets to off-street paths. These facilities all aim to provide greater separation between bicycles and other road users or otherwise reduce the “level of traffic stress” (LTS) for cyclists (Furth et al., 2016).

Bicycle plans are often explicit in their aim to provide low LTS environments to appeal to the large percentage of the population that indicate they would cycle or cycle more if their concerns about danger from motor vehicle traffic were alleviated. For example, the *Cycleway Design Toolbox,* published by Transport for NSW in December 2020, responds to prior research that suggested 48%

[1] The “four types of cyclists” is explored further in section 3 of this report.

of the NSW population could be classified as “Interested but Concerned,” and recommended an increased focus on meeting the needs of this cohort, with LTS used as a measure of infrastructure types (Transport for NSW, 2013a).

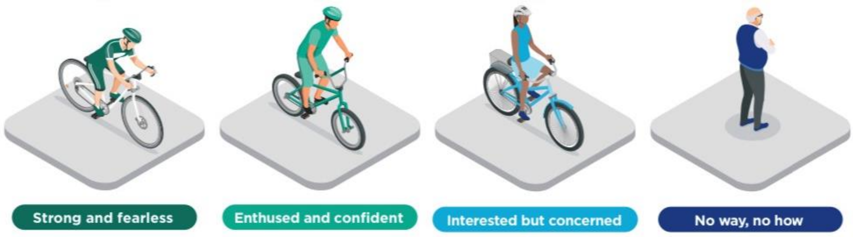

Figure 1. The four types of cyclists as illustrated by Transport for NSW (2020a).

An increasingly common element of bicycle plans is the recognition that bicycle technologies are also changing. This is helping to broaden the appeal of cycling, but also creating new challenges. While the basic diamond frame bicycle has not changed dramatically in the last century, cargo bicycles and electric-assist bicycles (e-bikes) have enabled utility cycling to appeal to more users and more use cases. Cargo bicycles allow for easy transport of children, pets, shopping, and other cargo. E-bikes include an electric motor that augments the rider’s pedal force, which can reduce physical exertion, extend the range of cyclists, and enable comfortable cycling in hilly or hot environments. Some research has recognised the potential of e-bikes to broaden demographic markets by appealing to older or less able people (Dill & Rose, 2012). However, an active transport survey commissioned by the City of Sydney found that the age bracket that most often cited ‘changed to an e-bike’ as a reason for riding regularly was 18-24 year-olds. For those above 55 years of age, wanting to get healthy, the COVID-19 pandemic, more infrastructure and frustration with public transport were more often cited as reasons that they cycled more (Taverner Research, 2021).

Cargo bicycles and e-bikes have also created new challenges for bicycle planning and policy. Cargo bicycles are generally larger and heavier than conventional bicycles, which can make it difficult to use infrastructure and end of trip facilities designed for conventional bicycles (Thomas, 2021). Safe storage for cargo bicycles is a particular challenge (Critchell, 2021). There have been concerns about the safety of e-bikes due to their higher weights and potential for higher speed, and many jurisdictions have established regulations on motor power, maximum assist speed, and where e-bikes can be operated. Research has shown that crash rates for e-bikes and conventional bicycles are generally similar, although slightly higher for women (Fishman & Cherry, 2016; Fyhri et al., 2019; Petzoldt et al., 2017). Some research suggests that injury severity for e-bike riders may be higher, especially for older riders (Hu et al., 2014; Weber et al., 2014), although this finding is contradicted in other studies (Elvik, 2021).

Bicycle planners have taken note of this recent increase in use of e-bikes and cargo bicycles, and some recent plans frame infrastructure needs around the diverse sizes and weights of contemporary bicycles (Ministry of Transportation and Infrastructure, 2019; Transport for NSW, 2020a; Transport Scotland, 2021). Concerns over safety and traffic remain significant barriers to increasing the number of people who cycle regularly (Horton, 2007). Despite evidence the health benefits of cycling outweigh the risks of injury (Rissel, 2015) and that safety of all road users increases when more people cycle (Aldred et al., 2019), fear of dangerous interactions with other road users (predominantly motor vehicles) remains a major disincentive to riding, especially for inexperienced cyclists (Aldred & Crosweller, 2015). While improvements to objective safety remain a vital need, addressing perceptions of safety is also a critical task to increase the appeal for the “Interested but Concerned” cyclist.

2. Methodology

This paper begins by framing the literature review in the context of the conception and development of Roger Geller's "four types of cyclists" framework and its relationship to bicycle planning in Sydney, NSW. Firstly, the wider adoption of this framework as a planning approach for cycling infrastructure design and network planning is considered, particularly in relation to research undertaken by Transport for NSW and the City of Sydney. Secondly, a more detailed analysis is undertaken of the design process that followed the first proposal in NSW for separated infrastructure and for the foundation of a cycling network. These early efforts have resulted in the current suite of separated cycling facilities in Sydney. This analysis provides a spatial and legislative design context from the perspective of a jurisdiction that has traditionally not considered cycling as an integral component of streets and the transport system.

To understand the common practices and themes of current bicycle planning for the international design literature review, thirty-nine bicycle plans from twenty-two jurisdictions were reviewed (at city, state, and national levels – see Table 1). The focus of the review was on plans that include specific infrastructure types and designs, rather than purely strategic or network plans. The plans were reviewed for their general rationale and strategy; for the included (or excluded) mid-block and intersection infrastructure strategies; for general network strategies; and for other supporting programs or policies. The plans were also reviewed for their evolution over time – where feasible, current plans were compared with their previous versions.

A thematic content analysis was undertaken to determine the most common facility design themes in relation to the aim of growing cycling mode share. A conventional and summative approach was undertaken of subjective interpretation of content through systematic identification patterns in which themes were progressively grouped and reduced (Hsieh & Shannon, 2005). Based on this analysis three dominant themes emerged that were subsequently expanded and framed in reference to the literature related to each theme. These are:

1. A general move to establish protected cycleways as standard practice, rather than an exceptional condition;
2. The formalisation of quietways and low-traffic neighbourhoods as a core element of local bicycle networks; and
3. A growing emphasis on the need for protected intersection design.

A final emerging trend in these plans was noteworthy, although it is outside the scope of this current study – many of the reviewed plans included a "movement and place" strategy (also referred to as "link and place") that explicitly establishes the importance of city streets as spaces of social and economic interaction, or the "place" or "living" functions of a street (Pharaoh & Russell, 1991). This place function is in addition to – and intimately linked with – the role of streets as travel or movement spaces (see for instance Transport for NSW & Government Architect NSW, 2020).

This recognition is important for two reasons: First, it aligns transportation planning and policy with the longstanding research on the critical public space role of city streets, following in the footsteps of researchers such as Jane Jacobs (1961), Donald Appleyard (1981), William H. Whyte (1980) and Jan Gehl (1987), who all argued that designing streets solely as motor vehicle spaces is a major detriment to city vitality. Second, it opens up the possibilities of integrating cyclists (and other active transport modes) more fully into that city life, rather than treating cycling solely as transportation (Roberts, 2019).

Government Level	Country	Jurisdiction	Organisation	Plan(s)
National	Australia		Austroads	Cycling Aspects of Austroads Guides, 2017 Guide to Traffic Management Part 4, 2020 Guide to Traffic Management Part 8, 2020
State		New South Wales	Transport for NSW	Cycleway Design Toolbox: Designing for Cycling and Micromobility, 2020 Practitioner's Guide to Movement and Place, 2020
State		Queensland	Department of Transport and Main Roads	Selection and Design of Cycle Tracks, 2019 Advisory Bicycle Lanes and Cycle Streets Technical Note, 2018
City		Adelaide	Adelaide City Council	Adelaide Design Manual - Street design, 2015 Smart Move Transport and Movement Strategy 2012-22
State		Victoria	Transport for Victoria	Victorian Cycling Strategy 2018-28
City		Melbourne	City of Melbourne	Bike Lane Design Guidelines, 2019 Bicycle User Confidence Study, 2017
State		Western Australia	WA Department of Transport	Western Australia Bicycle Network Plan, 2017 Update
City	Belgium	Gent	City of Gent	Gent: Making Cycling the New Normal Principles of the Circulation Plan
State	Canada	British Columbia	Ministry of Transportation and Infrastructure City of Vancouver	British Columbia Active Transportation Design Guide, 2019 Protected Bike Lane Catalogue, 2019
National	Denmark		Denmark Road Directorate	Collection of Cycle Concepts, 2012
City	England	Birmingham	Birmingham City Council	Birmingham Transport Plan, 2021 Birmingham Cycle Revolution: Our Journey, 2020
City		London	Transport for London	Cycling Action Plan, 2018 London Cycling Design Standards Ch. 4, 2014
National	France		Ministry of Ecology, Sustainable Development and Energy	Promoting Sustainable Mobility: Cycling - French Expertise, 2014
City		Paris	Mairie de Paris	Capitale du Velo, 2020
National	Germany		Federal Ministry of Transport	German Cycling Plan, 2020
City		Freiburg	City of Freiburg	Freiburg Cycling Concept, 2020
National	Netherlands		CROW-Fietberaad Tour de Force SWOV Institute for Road Safety Research	Urban Design and Traffic: A selection from Bach's Toolbox, 2006 Design Manual for Bicycle Traffic, 2016 Netherlands Bicycle Agenda 2017-2020 Advancing Sustainable Safety: National Road Safety Outlook for 2005-2020
City	New Zealand	Auckland	Auckland Transport	Urban Street and Road Design Guide v1 Cycling Infrastructure v1
National	Scotland		Transport Scotland	Cycling by Design, 2021
National	United States		National Association of City Transportation Officials Federal Highway Authority	Bicycle Design Guide 2nd Edition Don't Give Up at the Intersection: Designing All Ages and Abilities Bicycle Crossings, 2019 Separated Bike Lane Planning and Design Guide, 2015
City		New York City	New York City Department of Transportation	Green Wave: A Plan for Cycling in New York City, 2019 Street Design Manual, 2020
City		Portland	Portland Bureau of Transportation	Portland Bicycle Plan - 2019 Progress Report Portland Protected Bicycle Lane Planning and Design Guide, 2018

Table 1: Bicycle Plan jurisdictions and titles

3. The ‘four types of cyclists’

In 2006 Roger Geller, the Bicycle Coordinator for the City of Portland, Oregon, released a paper on a hypothesis for categorising the adult population according to their sentiments towards cycling (Geller, 2009). Geller initially inferred percentages for each cohort from his professional experience and interpretation of the literature, and over the following years refined this hypothesis based on US transport data. Categorisation of cyclists into three or four types had been used for some time however the uniqueness of this approach was to apply the categorisation to all adults regardless of whether they cycled or not and attempt to quantify this with attribution of percentages (Dill & McNeil, 2013). This hypothesis was initially developed to inform the Portland Bike Plan but has since found broad appeal in cities around the world where governments are trying to increase cycling mode share (Koorey, 2019) for two primary reasons. Firstly, the framework and category percentages have been tested in several locations and have been found to be consistent enough as a model for population-wide understanding. Secondly, it provides clear direction on interventions necessary to increase cycling mode share.

The four categories as outlined by Geller (2009) are as follows:

- The “Strong and Fearless” comprising 1-2% of the population who are willing to ride regardless of road conditions.
- The “Enthused and Confident” comprising approximately 7% of the population who are willing to share the road with motor traffic if some on-road facilities are provided such as shoulder bicycle lanes, advanced stop boxes, slower local street environments and end of trip facilities.
- The “Interested but Concerned” comprising 50-60% of the population who would be willing to ride if cycling facilities were provided that were physically separated from motor traffic or on street environments with very low motor vehicle speeds and volumes.
- The final “No way, No how” category accounts for approximately one third of the population, 33%, who are not able or not interested in riding regardless of facilities.

This categorisation was first verified by Dill & McNeil (2013) in a phone survey of 900 residents in the Portland region. The percentage for the “Enthused and Confident” was 9% compared to Geller’s seven percent; the “Interested but Concerned” was 56% compared to Geller’s 50-60%; the “No way, No how” was 31% compared to Geller’s 33%. The “Strong and Fearless” deviated the most at 4% compared to Geller’s 1-%. They found that women and older adults were more likely to be in the “No way, No how” and “Interested but Concerned” cohorts, and noted that this was a common in pattern in cities in the United States (Garrard, Handy, et al., 2012). This is also a common pattern in many countries with low bicycle mode share and empirical evidence highlights that this is due to safety concerns. This underlines the importance of separation from motor traffic to attract these under-represented groups (Garrard et al., 2008; Lusk et al., 2011).

Dill & McNeil (2016) further verified the categorisation at the national level in the United States in a phone and internet survey of 3,000 residents in the 50 largest metropolitan areas. Despite some qualifications,[2] the findings still align relatively closely with the original hypothesis. The percentage for the “Enthused and Confident” was 5% compared to Geller’s seven percent; the “Interested but Concerned” was 51% compared to Geller’s 50-60%; the “No way, No how” was 37% compared to Geller’s 33%. The “Strong and Fearless” again deviated the most and by more at 7% compared to

[2] The authors note limitations which may have impacted on the findings. The questions about cyclist types were included as part of a broader survey developed with the National Association of Realtors to understand community and transportation preferences, and the categorisation of respondents required a different judgement process since the questions differed from previous studies.

Geller's 1-2%. Importantly, this study confirmed that traffic safety fears were a key barrier for the Interested but Concerned cohort, suggesting separated cycling facilities would be required for those in this cohort to feel comfortable cycling. This confirmation has helped drive the continued acceptance of the hypothesis and the use of framework to inform policy.

Dill & McNeil's research has informed the 'bicyclist design user profiles' used by the American Association of State Highway and Transportation Officials (AASHTO, 2019) and the US Federal Highway Administration (Federal Highway Administration, 2019). These profiles relate to Geller's four types and are provided as a range between Dill & McNeil's 2013 and 2016 survey findings. The "Interested but Concerned" is 51-56 percent, followed by the 5-9% "Somewhat confident" cohort which aligns with Geller's "Enthused and Confident", and the 4-7% "Highly confident" that aligns with Geller's "Strong and Fearless". This leaves a fourth undetermined 28-40% cohort that presumably accounts for Geller's "No way, No how".

		Strong and Fearless	Enthused and Confident	Interested but Concerned	No way, No how
Geller (2006)		1-2%	7%	50-60%	33%
Dill & McNeil (2013)		4%	9%	56%	31%
Dill & McNeil (2016)		7%	5%	51%	37%
AASHTO (2019) FHWA (2019)		4-7%	5-9%	51-56%	Not stated
City of Sydney (2007)		2%	3-19%	54-61%	25%
Transport for NSW, (2013)	NSW	3.5%	21.5%	45%	30%
	Greater Sydney	3%	19%	48%	30%

Table 2: Comparison of how the four types of cyclists have been measured (the City of Sydney have not used this categorisation explicitly. These figures have been estimated based on alignment with terminology in their market research).

3.1. City of Sydney

Dill & McNeil (2013) list 14 bicycle plans that reference Geller's categorisations, including two in Australia being the City of Melbourne's *Bicycle Plan 2012–2016* and the *Sunshine Coast Active Transport Plan 2011–2031*. They found that none of the 14 plans "attempted to estimate the share of the broader population that fit into each category" (Dill & McNeil, 2013, p. 130). However in the same year Geller released his paper, the City of Sydney commissioned market research to identify target groups and what would increase the likelihood of cycling for each group (Environmetrics, 2006, 2007). Similarly to Geller in Portland, this research was initiated to inform the City of Sydney's *Cycle Strategy and Action Plan 2007-2017*. This plan stated a target to increase the number of bicycle trips as a percentage of total trips, from 2% in 2006 to 5% in 2011 to 10% by 2016 (City of Sydney, 2007). The intention was to identify the potential market for everyday cycling by quantifying segments of the population according to their propensity to cycle. To understand this a typical market research approach was taken (McCabe, 2020). An internet survey was undertaken of 1,150 residents aged 18 to 50 years within a 10-kilometre catchment of the city centre. The survey aimed to establish the types and sizes of the population based on cycling frequency, current riding behaviour, barriers to riding and likely initiatives to encourage more cycling. Respondents were categorised in the following four segments.

- "Cyclists" comprised 21% of respondents and were categorised as those that owned a bicycle and cycled at least once a month.

- "Infrequent cyclists" comprised 16% of respondents and were categorised as those that owned a bicycle but used it less than once a month.
- "Potential cyclists" comprised 38% of respondents and were categorised as those that didn't own a bicycle but were interested in cycling.
- "Non-cyclists" comprised 25% of respondents and were categorised as those that didn't own a bicycle and didn't cycle.

The "Cyclists" category is most difficult to align with Geller's categorisation. Considering cyclists made up 2% of mode share in Sydney based on census data this seems like a more realistic alignment with Geller's "Strong and Fearless". These are people that were already cycling in Sydney despite virtually no separated infrastructure. The City of Sydney's "Cyclists" would likely include the Geller's "Strong and Fearless" and "Enthused and Confident". This would place this cohort closer to the 16% upper range if combining the categorisations proposed by AASHTO and FHWA.

It is plausible that the City of Sydney's "Infrequent cyclists" and "Potential cyclists", making a combined 54%, align with Geller's "Interested but Concerned". These people cycle once a month or less and are interested in cycling or cycling more but do not do so due to safety concerns related to traffic. Both cohorts stated that separated bicycle paths and off-road routes would be the most important initiative to get them cycling more.

The City of Sydney's "Non-cyclists" comprise 25% of respondents in comparison to Geller's 33% "No way, No how" and share very similar definitions. "Non-cyclists" were the most averse to cycling. They did not own a bicycle and exhibited concern for safety but general disinterest in cycling was the key reason why they didn't cycle. No proposed initiatives increased their enthusiasm for cycling. The research concludes that there is little point in allocating resources to attempt to persuade this group to try cycling. Based on these ranges combined with follow-up surveys outlined below the Enthused and Confident could be between 3-19% and the Interested but Concerned 54-61%.

3.2. Identifying the Interested but Concerned and what would make them cycle or cycle more

In the City of Sydney's research, potential cyclists, infrequent cyclists and non-cyclists were grouped together as "non-regular cyclists" for the purposes of articulating potential initiatives that would encourage them to cycle or cycle more. Separation from motor traffic was the highest scoring factor for the question "What would make you cycle more regularly?" 59% of non-regular cyclists stated that availability of bicycle lanes/routes separated from traffic would "definitely" make them cycle more regularly and 25% stated "maybe" more likely. 16% stated it would make no difference. 73% of potential cyclists stated having separated bicycle paths and off-road routes would make them cycle more regularly.

Since the first research in 2006-2007, the City of Sydney has commissioned four follow up surveys that have confirmed these trends. In 2009, 50% of non-regular cyclists stated that availability of bicycle lanes/routes separated from traffic would "definitely" make them cycle more regularly and 30% stated "maybe" more likely. 20% stated it would make no difference. 63% of potential cyclists stated they would "definitely" cycle regularly if there were separated bicycle paths. Once again, the danger of cycling on the road with traffic was the most frequently mentioned reason for not cycling (Taverner Research, 2009). In 2012 a key finding was that over 60% of residents surveyed indicated they would commute by bicycle at least once a week if they had access to a separated cycleway for the entirety of their trip (The NTF Group, 2012). In 2018, 61% of respondents said they would consider taking up riding or ride a bicycle more often if there was a safe and convenient bicycle network (Taverner Research, 2018). In 2021, 68% of respondents who identified as potential riders said they would be more likely to ride if separated bicycle paths were available and 76% of infrequent and potential riders were interested in riding more, however the main barrier was fear of riding with traffic (Taverner Research, 2021).

3.3. Transport for NSW

Transport for NSW released their *Cycleway Design Toolbox* in 2020 to provide design guidance to "justify the planning, design and delivery of high-quality cycling infrastructure by demonstrating the positive impact on level of service for people cycling" (2020a, p. 6) and to support the delivery of the agency's "vision for a safe, connected cycling network across Greater Sydney" (2020a, p. 78). Geller's four types of cyclists are presented with local cohort percentages based on research the agency had undertaken in 2013 (Transport for NSW, 2020a) and developed further in 2020. The "Strong and Fearless" comprised 3%; the "Enthused and Confident" 19%; the "Interested but Concerned" 48%; and the "No way, No how" 30%. 70% of respondents stated they would ride a bicycle if they had access to safe cycling routes. Of the respondents categorised as "rejecters" of cycling, almost half reported that they would not consider riding a bicycle because they do not feel safe sharing the road with drivers – this was tied for first as the most important reason for not cycling. The direction proposed in the *Cycleway Design Toolbox* is to focus on providing high-quality, separated and connected cycling infrastructure that caters to the 48% of potential riders who are "Interested but Concerned".

A common position in both Transport for NSW and City of Sydney research is that by satisfying the needs of the Interested but Concerned, conditions for the other cohorts more comfortable with cycling, are also improved. Based on the above percentages this means that provision is being made for 60-72% of the population, a figure that approaches Transport for NSW and the City of Sydney's findings that 70-75% of the population have indicated interest to cycle should safe facilities be provided.

In general, these "Interested but Concerned" survey findings tend to be verified by increases in cycling once infrastructure is built. This has subsequently emboldened planners to advocate a "build it and they will come" mantra (Geller, 2011, p. 1). Many cities across Europe and North America that have built separated networks have witnessed significant increases in cycling mode share. In Europe these include London (Greater London Authority, 2013), Paris (Bowers, 2020), and Seville (Marqués et al., 2015). In North America these include New York (City of New York, 2019), Austin, Chicago, Portland, San Francisco (San Francisco Municipal Transportation Agency, 2020), Seattle (Seattle Department of Transportation, 2020), Washington, D.C (Monsere, Dill, McNeil, et al., 2014) and Vancouver (City of Vancouver, 2018).

It has been noted that a range of measures is required alongside physical infrastructure to enact mode change toward cycling (Doğru et al., 2021; Winters et al., 2011). However, the dominant theme in the literature is the need to address the concern for safety present from motor traffic. Geller explicitly discussed and described these categories though 'fear' for one's safety while cycling in an urban environment. This is more commonly discussed as 'comfort level' (Dill & McNeil, 2013) however fear remains an instructive term. When people make decisions on how to travel, fear for one's safety is likely more relevant than a softer discussion of 'comfort level' that might be more useful for fine-tuning bicycle infrastructure design. Until cities create "fearless" urban cycling environments, the likelihood of attracting significant numbers of new riders remains small (Geller, 2009).

The categorisation of the four types of cyclists has always intended to be general. As Geller – and Dill & McNeil after him – pointed out, the intent is not to get too fixated on precise cohort percentages and instead use the ranges to assist planning objectives. It has proven to be generally consistent with study results in a range of locations and has become accepted as providing a reasonable and practical framework. The categorisation has been utilised by governments as a useful approach to understanding potential latent demand and has been referenced directly in policy and planning directions. The large Interested but Concerned cohort offers promise to planners hoping to enact a mode share shift towards cycling as it suggests a majority, or near majority, of the population would take up cycling for some of their trips should safe environments be provided. It puts forward a compelling case that investment will be worthwhile. As Geller points out if cycling is to be a widely adopted form of everyday transport the concerns of the majority must be addressed, and that majority is the Interested but Concerned. The high cycling mode share in cities where safe and convenient cycling infrastructure is widespread supports Geller's hypothesis.

3.4. Broad support for bicycle networks

Proposals to build a cycleway network have enjoyed broad community support in Sydney. The City of Sydney has commissioned several research surveys to determine the level of support for building a bicycle network. In 2010, 84% of residents of the City of Sydney and 14 neighbouring council areas considered it important that the Inner Sydney region had a good bicycle network (Galaxy Research 2010). In 2018, 71% of respondents said they "somewhat" or "strongly" supported Sydney's planned bicycle network. This included 73% of City of Sydney residents and 71% of residents of other areas within 10 kms of the city centre (Taverner Research, 2018).

These findings are further supported by research showing positive perceptions after separated infrastructure has been introduced. In Sydney a study by Crane et al. (2016) found local communities where separated cycleways were built are generally supportive after implementation, perceiving it to have positive impacts on their neighbourhood and quality of life. A 2021 survey of residents and businesses along Sydney's Bourke Street cycleway found that 84% believed the cycleway makes a positive contribution to the street with 8% being indifferent (Harris, 2022).

These positive perceptions of separated infrastructure are shared elsewhere in NSW and around the world. 81% of Wollongong respondents in the 2020 National Cycling Participation Survey believed that more off-road paths and cycleways would encourage more bicycle riding (CDM Research, 2020). In a US study of five cities,[3] Monsere et al. (2014, p. 13) found that "nearly three times as many residents felt that the protected bike lanes had led to an increase in the desirability of living in their neighbourhood". These findings suggest opposition to new cycling infrastructure represents a small minority, is highly localised and can be reconciled with detailed design considerations during community consultation (Harris, 2022).

4. Development of cycling infrastructure in Sydney

In NSW separated cycleways were first proposed as a standard street network treatment in the City of Sydney's Cycle Strategy and Action Plan 2007-2017. The following discussion outlines the design process that followed in which the current suite of treatments used in Sydney were conceived and developed in relation to the local spatial and legislative context. It draws on research undertaken in 2020-2021 on the development of the separated cycleway model in Sydney, community perceptions on streets with cycleways, and the governance and delivery shifts occurring in response to COVID-19 (Harris, 2022; Harris & McCue, 2022). This research included interviews with project participants from the City of Sydney, NSW Government and design consultants. Interviewees are listed in the reference list. Views expressed in these interviews were personal opinions, given without prejudice and may not necessarily reflect government policy.

The separated network proposal was informed by the City's research that found separated facilities were required to overcome safety concerns and encourage more people to cycle (Environmetrics, 2006, 2007). The immediate challenge was how to find space for new infrastructure in the constrained rights of way on Sydney's streets. A highly standardised street network meant that solving one cross section would allow network scale application. Most streets in Sydney conform to the British imperial width of 'one chain' stipulated in the NSW Width of Streets and Lanes Act of 1881. This equates to 20-metre-wide street corridors comprising 3.6 metre verges and 12.8 metre carriageways between

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[3] The five cities were Austin, TX; Chicago, IL; Portland, OR; San Francisco, CA; and Washington, D.C.

kerbs. Today, these streets tend to operate in one of two ways. They are either configured as local streets with permanent parallel parking on both sides and one motor vehicle lane in each direction; or as higher vehicle capacity roads with 'clearways' to allow two car lanes in each direction and no parking during peak periods.[4]

A kerbside separated bidirectional cycleway was devised that could be implemented in typical streets with parallel parking on both sides and no clearway restrictions without displacing current uses such as car parking, two-way vehicle movement or pedestrian space on footpaths. The proposed concept was originally intended as a relatively low-cost reallocation of space defined by installing medians or bollards. Road lanes could be reduced to minimums to find space for a 2.4 metre separated kerbside cycleway and a 0.4 metre median to parked cars. This design would not be possible on streets with clearways and the City of Sydney was advised to avoid bus routes as bus operating widths were seen as problematic within the narrowed lanes.

These dimensions were below the current desirable Austroads requirements of a bidirectional cycleway adjacent to a carriageway which stipulated a 3 metre cycle path and a 1 metre wide median where adjacent car parking is present (Austroads, 1999). The bidirectional cycleway is generally considered inferior to the one-way pair common in Europe due to more complex integration with intersections, established patterns of traffic and visibility (Adriazola-Steil et al., 2021). However, bidirectional cycleways can be appropriate in situations where destinations are concentrated on one side of the street, or where flows of cyclists tend to be "tidal" and predominantly flow in single directions at different times of day (Transport for London, 2014, pp. 15-16). Bidirectional cycleways can also be installed in narrower streets or with a lesser impact on on-street parking. A bidirectional cycleway can occupy less overall space than a one-way pair, and the width of the median separating the cycleway from car parking or travel lanes can be narrower (Figure 2).

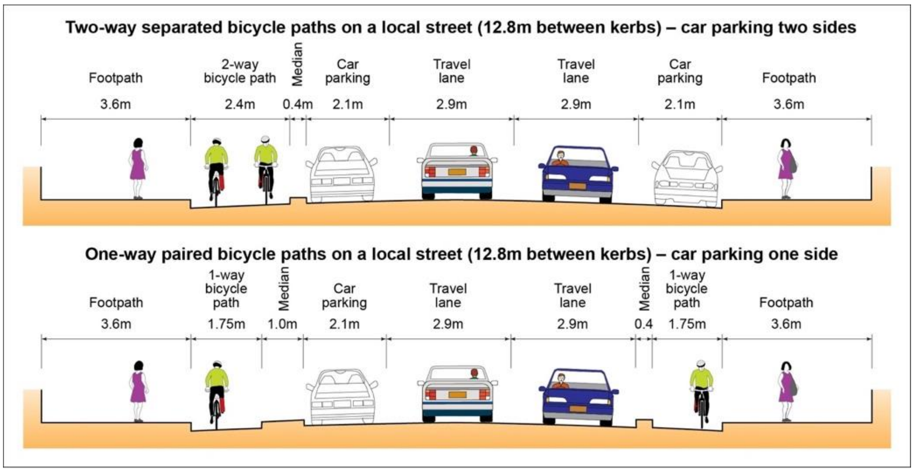

Figure 2: Comparison of bidirectional cycleway and one-way pair. Image credit: Warren Salomon.

The City of Sydney (2008a) acknowledged a preference for one-way pairs, however this was not seen as feasible due to the necessity for significant loss of car parking or converting streets to single lane one-way movement for motor traffic. The City of Sydney (2008a) also noted that bidirectional cycleways had been implemented in other cities as a transition phase between no separation and one-way pairs. Nevertheless, this model satisfied the key condition identified by the City of Sydney's

[4] The first clearway in NSW was introduced along a 19-kilometre stretch of Parramatta Road in June 1967. The following year this measure was extended to several major roads in Sydney (NSW Roads and Maritime Services, 2006).

research – to make cycling more attractive to the general population through physical separation from motor traffic.

The Bourke Street cycleway was not the first delivered but it was the first on a residential street, the longest and most significant in terms of resolving the suite of design techniques that would be required for most routes of the proposed network (Table 3). The City of Sydney was responsible for design and delivery and the then responsible NSW Government agency Roads and Traffic Authority (RTA) was tasked with approvals of the new design under NSW Road Rules.

Opening date	Cycleway	Length (km)	Street width (m)	Cycleway & median width (m)	Modifications
May 2009	King Street	0.22	17.8	2.4/0.6	One way motor traffic before and after. North side parking replaced with cycleway. South side parking converted to permanent clearway. Kerb and gutter modifications on cycleway side.
March 2010	Bourke Road, Bowden Street, Mandible Street	3.1	20	2.4/0.4	Parking removed one side for truck movements in industrial area. No kerb and gutter modifications.
September 2010	Union Street	0.35	20	2.4/0.4	Parallel parking retained. Two-way motor traffic retained.
December 2010	College Street	0.64	22-24	2.4/0.4	West side parking replaced with cycleway. No kerb and gutter modifications.
December 2010	Kent Street	1.2	17.8-24	2.4/0.4	East side car lane replaced with cycleway.
May 2011	Bourke Street	3.4	20	2.4/0.4	Parallel parking retained. Two-way motor traffic retained.

Table 3. The first tranche of separated cycleways in the City of Sydney.

The Bourke Street cycleway design and construction tender was awarded in February 2008, construction began in February 2010 and the cycleway opened in May 2011. This was a longer and more costly process than anticipated due to three factors. Firstly, to comply with NSW Road Rules significant and novel intersection modifications were required. This process is discussed in the following section. Secondly, as an unprecedented intervention in an inner-city residential street the cycleway needed to be accepted by the local community. This was essentially a cycleway project however it was delivered as a street upgrade with pedestrians considered the priority in the hierarchy of street users (Merchant, 2020). A range of additional streetscape measures were undertaken (City of Sydney, 2008a; Salomon, 2020; van den Dool, 2020) including installation of bio-filtration gardens for stormwater harvesting, eight pedestrian priority crossings across Bourke Street, kerb extensions to reduce parking set back and lower light poles under the tree canopy. The speed limit was reduced from 50 to 40 kilometres per hour and road centrelines were removed. 90% of the western footpath and 40% of the eastern footpath were upgraded. Three variations on the cycleway cross section were developed that responded to varying grade and pedestrian access conditions with two requiring stormwater modifications (Figure 3). Tree and shrub planting was increased. Original sandstone kerbs and gutters were reused and cycleway deviations were created around large leaning trees. Thirdly, several infrastructure upgrades not originally foreseen were triggered including installation of signalised intersections, upgrading streetlights from halogen lamps to LEDs, and replacement of a trunk stormwater main. The final cost was $24 million, or $7.1 million per kilometre.

The space requirement for the bidirectional cycleway cross section created no impact on the provision of kerbside parking. However, the introduction of pedestrian crossings, traffic calmed intersections and cycleway deviations to retain large leaning trees, as well as a short section of Bourke Street found to be 11 metres between kerbs as opposed to the standard 12.8 metres, resulted in localised parking loss. Residents in this narrow section, in which 13 spaces were removed, demonstrated “considerable resentment” (City of Sydney, 2008b, p. 5). The City responded by providing compensatory parking, mostly by installing extra kerb extensions at intersections to bring parking closer to the intersection and some angle parking in side streets. This resulted in a net loss of 44 spaces along the 3.4-kilometre corridor.

Parking and travel lane considerations constrain the dimensions of most separated cycleway designs implemented by the City of Sydney. This has led to a lower level of service on busier cycleways where there is insufficient width for safe passing in the cycleway. Intersections where the short signal time for cyclists causes congestion in the cycleway encourages some riders to use footpaths or roadways.

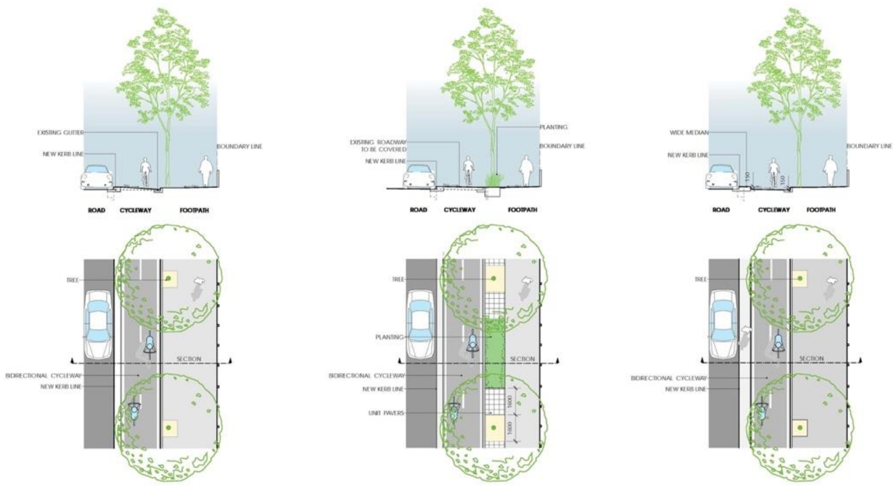

Figure 3. Three cycleway cross sections, from left to right: double stepped, flush with footpath and raised median. Image credit: City of Sydney.

4.1. Intersections

The suite of intersection treatments used in Sydney were developed in response to legislative constraints on bidirectional cycleways, which effectively create two parallel two-way systems, within the NSW Road Rules. Street reserves in NSW are divided into two distinct operational classifications (NSW Government, 2020): The ‘road’ between the kerbs for traffic movement and the ‘road related area’ between the kerbs and property boundaries for footpaths. During the design process for the Bourke Street cycleway the RTA determined the bidirectional cycleway could not be located in the ‘road’ as this would create a situation at intersections (where separation between vehicles and bicycles is limited to painted delineators) in which one flow of the cycleway would be on the wrong side of the centreline of the road and thus violate NSW Road Rules. The separated cycleway was therefore classified as a ‘bicycle path’ located in a widened ‘road related area’ on one side of the street, legislatively coupling it with the footpath (Figure 4).

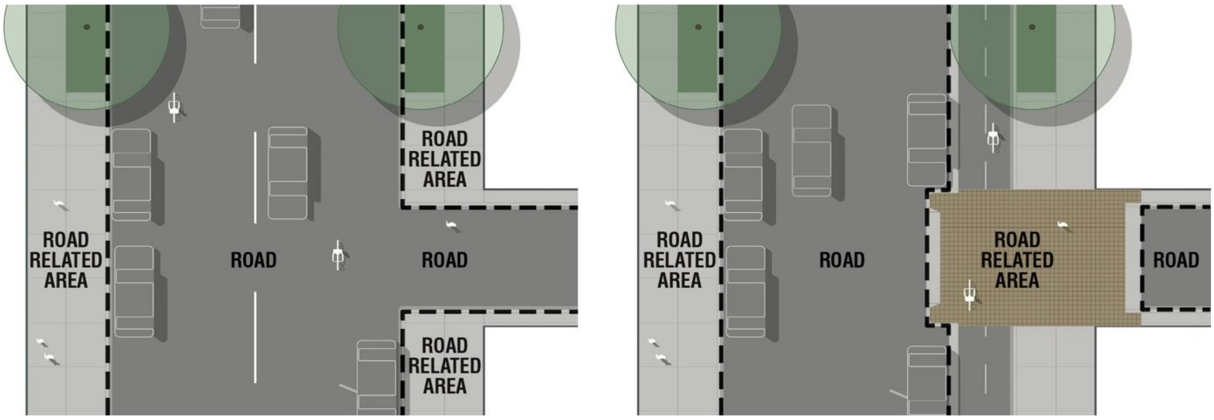

Figure 4. Changes to the 'road' and 'road related area' in the NSW Road Rules under the bidirectional cycleway design. Image credit: Mike Harris.

However, when the cycleway crossed a side street it was leaving the ‘road related area’ and entering the ‘road’. Under NSW Road Rules, this meant that the cycleway terminated at the intersection, and cyclists would be required to stop and give way to vehicles turning into or leaving a side street, including laneways. This is not the case in jurisdictions the cycleway was attempting to learn from such as the Netherlands, Denmark and Germany, where straight-travelling cyclists have right of way. The requirement for cyclists to stop and give way at every side street was seen as placing an impractical burden on cyclists’ movement with likely high levels of non-compliance and dissatisfaction. While NSW Road Rule 71 allows for bicycle path priority at road crossings, this rule is rarely used and thus the operation and safety of this design is poorly understood (Salomon, 2020). In response the consultant team proposed two alternate solutions for non-signalised intersections. Both were based on international precedent and extended the classification of the road related area across the side street with raised thresholds (Figure 5).

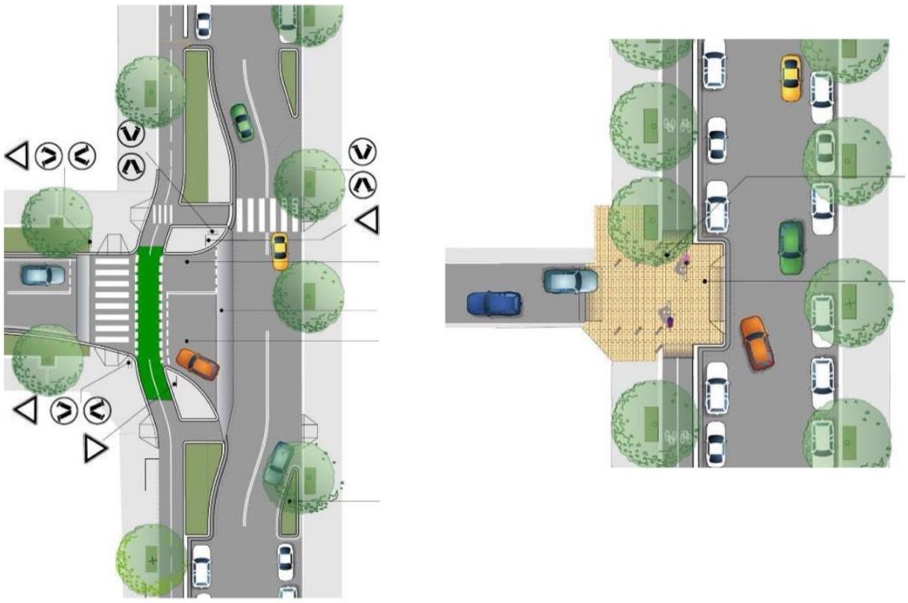

Figure 5. Two solutions for non-signalised intersections: Bent-out and shared environment. Image credit: City of Sydney.

4.1.1. Bent-out cycleway intersections

The 'bent-out' treatment was available in the Austroads 1999 Guide however had very rarely been implemented and only in suburban conditions. In this treatment the bicycle path deviates away from the parallel street at the intersection to create a cyclist priority crossing of the side street. The primary purpose for the deviation is to allow turning vehicles to address the crossing control device after turning into the side street and reduce obstruction of straight travelling vehicles on the parallel street. This intersection treatment includes a raised and narrowed threshold to reduce vehicle speed and a priority crossing for pedestrians (City of Sydney, 2008a).

The bent-out treatment was designed to be used at higher volume un-signalised intersections. However, due to the costs associated with kerb buildouts and associated engineering and drainage modifications, this treatment was only possible at two of the 16 side streets along Bourke Street.[5] While bent-out intersections can be implemented within a standard 20-metre corridor, this intersection design remains rarely used, likely due to the cost implications. As of December 2021, there only are five bent-out intersections within the City of Sydney LGA.

4.1.2. Shared environment intersections

Shared environment intersections were designed primarily for smaller width, lower volume intersections, in which the road related area was extended by reconstructing the intersection on a platform at footpath level. These were based on typical intersection thresholds with 30 km/h speed limits in European countries such as Germany and the Netherlands (Salomon, 2020). The design parameters specified by Austroads allows for a range of ramp slopes (Green et al., 2020b, pp. 73-76). The implemented design at Bourke Street uses a flatter ramp that increases driver comfort but reduces the traffic calming benefit of the facility. Previous technical direction required steeper slopes that are more effective in slowing vehicle movement through the facility (Transport for NSW, 2013b). The international precedent typically includes a priority bicycle lane, however in this case the space operates as a four-way give-way in which all vehicles, including bicycles, are required to give way when entering the intersection and pedestrians have priority. RTA permitted the installation of the shared environment intersections as a trial, and found no unacceptable safety risks (SKM & CDM Research, 2012). As of December 2021, there are 27 shared environment intersections in the City of Sydney.

4.1.3. Signalised intersections

Signalised intersections were relatively straightforward with two types developed. For most, the cycleway continues to the intersection with cyclists provided a green phase linked to the pedestrian crossing phase. As discussed below in Theme 2, providing cycle-specific signal phases can significantly improve the safety and comfort of intersections for cyclists. In some instances where RTA was not willing to relocate space from vehicles at the intersection approach the cycleway terminates prior to the intersection with cyclists required to join the footpath that had been designated a 'shared path' on which cyclists are required to give way to pedestrians.[6]

4.2. Exploring the delivery processes

Bourke Street is considered an exemplar of integrative streetscape design and one of the City's most used routes however the network rollout has been stubbornly slow. On the eve of COVID-19 only 12.5 of the 55 kilometres of separated cycleway proposed over 10 years in the 2007 Cycle Strategy had been implemented. Part of the delay has been due to cost - these projects have all been more costly than originally anticipated, largely due to the inclusion of a range of complementary streetscape

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[5] One bent out intersection on Bourke Street was replaced with a signalised intersection in 2019 as part of the CBD & South East Light Rail project.

[6] In NSW, cyclists over the age of 12 are not legally allowed on footpaths, except when accompanying a child or within a designated shared path.

upgrades. The cost of the Bourke Street cycleway in particular was seen as financially unviable at the network scale. During the delivery of the Bourke Street cycleway and since that time a range of more cost-effective approaches have been explored.

Beginning in 2010 a separate team was established in the City of Sydney's civil engineering arm to deliver 2.5 kilometres of a low-cost cycleway for Bourke Road (an extension of but separate to Bourke Street), Mandible Street and Bowden Street in Green Square, a light industrial area transitioning to a mixed-use neighbourhood. Extruded concrete medians were installed in weeks to provide the mid-block facility and no intersection treatments or additional streetscape works were provided. This achieved a rapid rollout however quality compromises resulted in poor pedestrian and cyclist amenity and significant drainage issues. The City was taken to the Land and Environment Court by local businesses for not undertaking a Review of Environmental Factors, and after car parking was removed on one side for 1.5 kilometres of Bourke Road to maintain truck operations within the light industrial area. The cycleway remained, however the problems that arose from the faster approach reinforced the City's practice of progressing cycleways in a slower, more consultative and integrative way. Nevertheless, the awareness that this approach would not achieve the network rollout in a timely manner remained an underlying concern for the City (Campbell. 2020).

Some cycleways since have adopted hybrid designs that include sections of the more integrative approach and sections of simpler techniques primarily consisting of median installation, resurfacing and intersection treatments (Figure 6). These hybrid designs are the outcome of research and testing by the City of Sydney of alternative median designs to reduce costs and construction time. The outcome of these tests, formalised in the internal Standard Cycleways Treatments Overview guideline in 2015, has influenced current City of Sydney cycleway projects.

Figure 6: A hybrid design was used for the George Street cycleway. The southern section uses an intermittent median design to simplify construction and reduce costs. The medians are located to allow car doors to open between them – this required marking the parking bays. Image credit: Warren Salomon.

4.3. COVID-19 pop-up cycleways

From early 2020 the COVID-19 pandemic radically changed mobility patterns around the world. Quick and inexpensive 'pop-up' cycleways emerged as a common transport response for their unique ability to provide physically-distanced travel and recreational opportunities, while also capitalising on underutilised road space due to widespread work-from-home mandates. In Greater Sydney public transport use fell by 75-80% (Rabe & Singhal, 2020) and traffic volume halved (Rabe & Gladstone, 2020). Dramatic increases in walking and cycling for local trips and recreation resulted in overcrowding of parks and cycleways (O'Sullivan & Singhal, 2020). The Bourke Street cycleway witnessed a 30% increase during the early months of COVID-19 restrictions (City of Sydney, 2020a).

Early implementation of pop-up cycleways occurred in cities with greater 'rapid response' planning powers coupled with political interest in active transport. New Zealand appears to have been the first jurisdiction to fund pop-up cycleways as part of official government policy, followed by Bogota in Columbia, US cities such as New York and Oakland, and European cities such as Milan and Paris (Nikitas et al., 2021; Nurse & Dunning, 2020).

Pop-up cycleways emerged later in NSW than many international counterparts. However, once enacted the design and delivery process demonstrated unprecedented levels of collaboration between City and State Governments that appear to be enduring beyond the immediate COVID-19 crisis (Campbell, 2020; Stace, 2020). On 29 May 2020, after a request from Transport for NSW and under the powers of the Emergency Measures Bill, the Minister for Planning and Public Spaces made the *Environmental Planning and Assessment (COVID-19 Development - Temporary Cycleways) Order 2020.* Six pop-up cycleways totalling 7.6 kilometres were installed within the City of Sydney during July-September 2020. The City and Transport for NSW each delivered three of the collectively agreed routes. Route selection was based on missing links in the network that were seen to be most important for alleviating public transport use. Through August-November an additional 20 kilometres of pop-up cycleways were announced for delivery in five other LGAs in Greater Sydney.

The cross-section design was virtually identical to the low-cost concept originally envisioned by the City in 2007. Four of the cycleways were bidirectional and two were one-way pairs. In line with City of Sydney practice, bidirectional cycleways were wider than the minimum 2.4 metres wherever possible, with one being up to 3.5 metres wide (Figure 7). The cost and time savings were significant. The City (2020b) reported the Henderson Road cycleway costing 20% of anticipated cost for a permanent project on the same route, and an installation period of 6 weeks compared to eight months. The route witnessed a 30% increase in bicycle trips from one week after opening. 17% of cyclists surveyed on this route stated they would have used public transport to travel without the cycleway and 7% stated they would have driven a car.

Figure 7. Left: Henderson Road pop-up cycleway at up to 3.5 metres. Image credit: City of Sydney. Right: Moore Park Road pop-up cycleway at 3 metres. Image credit: Mike Harris.

The three-metre-wide bidirectional pop-up cycleway on Pitt Street in the city centre became the most used cycle route in the city within two months of opening, with an average of 4,430 trips per week (City of Sydney, 2020a). The one-way pair on Bridge Road was the second most used pop-up. The narrow one-way pair on Dunning Avenue, furthest from the city centre, has had the lowest usage at 100 trips per day.

Those responsible for active transport delivery in both City and State Government believe the pop-up cycleway process has been the single most powerful driver of political support, interagency cooperation and delivery of cycling infrastructure in Sydney to date (Campbell, 2020; Stace, 2020). Both levels of Government acknowledge the value of pre-prepared designs providing the basis for pop-up implementation. The City's detailed pre-prepared plans allowed for efficient review and assessment process by Transport for NSW as the critical State Government partner. Following the overall success of the pop-up program, a series of permanent cycleways on major streets were announced, including lane reallocation from motor traffic on Sydney's iconic Oxford Street, and the reinstallation of a well-used city centre cycleway that had been controversially removed five years prior.

Despite cycling increasing across Greater Sydney by 40% compared to pre-pandemic levels (Transport for NSW, 2021), a second round of pop-up cycleways in other LGAs faced challenges that proved too difficult to overcome, with some being cancelled. These appear to have not proceeded due to two primary causes. Firstly, the selected routes did not have the same level of advanced planning and design documentation as the first-round routes. Secondly, other local councils were unable to overcome internal political disagreements and complaints about potential loss of car parking. Both challenges highlight the importance of establishing local level bicycle policies; preparing a bicycle network plan and detailed design work, as well as developing adequate political agreements, to allow councils to take advantage of opportunities to implement infrastructure when they arise.

5. Literature review on cycling infrastructure design

5.1. Theme 1: Separated bicycle paths as standard practice

> *The findings from the study clearly reveal that the extent of separated cycleways has the largest impact on whether residents choose to commute by bike. "The effect of separated cycleways 'dominates' all other potential explanators of commuter choice behaviour"* (The NTF Group, 2012, p. 8).

5.1.1. Background

In general, a separated bicycle path refers to a one-way or two-way bicycle lane physically separated from motor vehicle lanes (Austroads, 2017). This separation can be in the form of kerbs, bollards, parked cars or moveable objects such as planter boxes.[7]

Separated bicycle infrastructure can be traced from the late 19th century in Germany and the early 20th century in the UK, Netherlands and Denmark. The literature for contemporary practise, however, commonly refers to the policy shifts in the Netherlands and Denmark from the mid-1970s. As a response to the energy crisis of 1973 and growing public protest over injuries and deaths on Dutch roads, planners built separated cycleways in The Hague and Tilburg (as well as a range of other projects, including creating car-free city centres). These early designs were protested by retailers who worried their businesses would suffer from a lack of car traffic and parking spaces (Reid, 2017, p. 207). Their concerns turned out to be unfounded, and with the new separated lanes cycling rates increased by 30 to 60% in The Hague, and 75% in Tilburg (Wagenbuur, 2011). This success spurred continued experimentation and the steady expansion of separated path networks. Today, the Netherlands has more than 35,000 kilometres of separated bicycle paths (van Lith, 2019). Emerging cycling cities around the world often refer to Dutch and Danish cycling planning and infrastructure

[7] *Separated bicycle paths* are called by a range of terms around the world, including *separated cycleways*, *protected bike lanes* and *cycle tracks*. This report will use the term separated bicycle paths throughout, except where directly quoting or referencing a plan that uses a different term.

design in an effort to replicate their success in changing behaviours and increasing cycling mode share (Pucher & Buehler, 2008).

Research has consistently shown that separated bicycle paths increase cyclists' perceptions of safety (Hourdos et al., 2021; Koorey, 2015; McNeil et al., 2015). The City of Melbourne Bicycle User Confidence Study of 2017 found that, while only 22% of people felt confident riding on a painted bicycle lane, that number increased to 83% if physical separation of the bicycle lane was provided (City of Melbourne, 2017, pp. 18-19). In a study of five cities from the United States with new bicycle infrastructure, 97% of cyclists on those new routes felt that protection from motor vehicles made cycling safer (Monsere, Dill, Clifton, et al., 2014). Importantly, this study also surveyed neighbours of the new facilities – among these neighbours (which included people in all four of Geller's categories), 80% believed that the infrastructure had made cycling safer. This figure includes 88% of the "Interested but Concerned" category of potential riders (Monsere, Dill, Clifton, et al., 2014, p. 103). This suggests that providing separation for bicycle paths is a critical step in attracting new cyclists.

Other studies have evaluated cyclists' perceptions of safety based on the type of separation – studies from London have found that the height of the separation is important – tall posts were preferred to lower kerb barriers. Taller posts were preferred even when the posts were flexible, and thus provided no real protection from motor vehicle intrusion into the bicycle lane (Monsere, Dill, Clifton, et al., 2014, p. 107).

Where the type of protection does deter motor vehicle intrusion, however, there is ample evidence that separated bicycle paths do provide actual safety benefits to cyclists. Studies in the Netherlands show that separated bicycle paths reduce crashes by 59% on distributor roads (roads with speed limits of 50km/h or 70km/h, and generally higher traffic volumes). A longitudinal study of 12 cities in the United States over a period of 13 years showed that separated bicycle paths significantly reduced injuries and fatalities, and that these safety improvements also benefitted all road users (Marshall & Ferenchak, 2019).

This research joins a common global theme that highlights the safety concerns of mixing cyclists with motor vehicle traffic and the need for physical separation to overcome this concern. Cyclist confidence increases notably on separated facilities, especially for under-represented groups such as women, children and seniors (Boufous et al., 2021; Garrard, 2016; Lusk et al., 2011). A study in New Zealand found safety in relation to motor traffic was the most significant concern for potential cyclists and that the preferred solution for this cohort was a consistent network of dedicated paths with separation from motor vehicles (Kingham et al., 2011). Community consultation reports from the Queensland State Government show that non-cyclists rate physically separated cycleways as the biggest factor in whether they would begin to cycle or not (Queensland Government, 2020).

5.1.2. Methods

Separated bicycle paths can be costly to implement, depending on type. *Full separation* is usually defined as a continuous vertical separation between the bicycle path and motor vehicle lanes, usually in the form of a concrete kerb or raised planter bed, although a range of combinations have been implemented (Figure 8). In the Netherlands and Denmark, fully separated bicycle paths are usually on a stepped kerb – a level halfway between the primary roadway surface and the footpath. The half kerb between the separated bicycle path and the footpath is sometimes sloped to make it mountable by bicycles (either continuously or at specific access points), allowing cyclists to cross into the footpath at their destinations (Figure 9).

Figure 8. A separated one-way pair in Adelaide uses a combination of raised planter beds and trees planted flush with the road surface. Image credit: Mike Harris.

Figure 9: Left: A stepped kerb cycleway with a precast mountable kerb to the footpath in the Netherlands. Image credit: Mark Philpotts. Right: A stepped kerb cycleway with an in-situ mountable kerb to the footpath in Adelaide. Image credit: Mike Harris.

Providing full separation for a bicycle path can require significant reconstruction of a street with added or relocated stormwater drains and underground pipes. While fully separated bicycle paths are cost effective to implement during new road construction or integrated with other substantial roadwork projects, these projects are relatively rare. For most separated bicycle path projects, a retrofit solution is needed, at least as an interim solution. Retrofit solutions are generally considered to be *light separation,* typically defined as a barrier of vertical elements spaced at intervals between the bicycle path and motor vehicle lanes. The vertical elements can take many forms, including concrete kerbs, plastic or rubber traffic separators, posts or bollards or planters – or a combination of these elements (Figure 10). Light separation is relatively fast and inexpensive to install and can be used to retrofit existing roads without requiring extensive reworking of kerbs and stormwater systems (see also section 4.2). As noted above, light separation may not provide significant protection for cyclists from intentional or unintentional intrusion of motor vehicles into the cycleway, but they provide visual and tactile communication to all road users of the cycle-specific areas of the street.


Figure 10: Light separation elements. Image credit: UK Department for Transport.

Many of the reviewed plans include temporary or short-term separated bicycle path designs as an integral component of their toolboxes – these designs have the advantages of speed and cost (City of Melbourne, 2019; Federal Highway Administration, 2015; Ministry of Transportation and Infrastructure, 2019). Temporary protection can be as much as 90% less expensive to implement, and often only require restriping of existing asphalt and installation of the protection elements (Deegan, 2018, p. 8; Portland Bureau of Transportation, 2021). Temporary protection usually requires more frequent maintenance but can easily be reconfigured or replaced as needs change.

These temporary designs have been used in cities around the world during the COVID-19 pandemic as councils and planners have looked for ways to create more outdoor recreation space for residents (see also section 4.3). Pop-up separated bicycle paths, like other tactical urbanism approaches, have enabled quick and flexible responses to the changing conditions of the pandemic (NACTO, 2020). The success of many of these pop-up lanes (and other popup urban spaces) have also been important indicators for city leaders of the latent demand for safe cycling infrastructure (Nikitas et al., 2021). As a result, some high-performing pop-up lanes are being converted into permanent infrastructure, for example in Sydney (City of Sydney, 2021) and Berlin (Kallgren, 2021). Other cities, such as Liverpool and Birmingham in England are considering similar measures (Johnson, 2021).

The majority of reviewed plans (seventeen of the twenty-two jurisdictions) included specific guidance on cycleway widths.[8] The minimum widths of one-way separated bicycle paths ranged from 1.2m (New York City and Austroads) and 2.0m (several locations, including the Netherlands, Scotland, Auckland, and South Australia). For two-way separated paths, minimums ranged between 2.0m (Austroads and London) and 3.0m (Denmark, Portland, and Western Australia). All the reviewed plans recognise that separated bicycle paths must be wider where more bicycle traffic can be expected, and many called for wider lanes to allow passing, riding side-by-side, increased comfort when riding uphill (where weaving movements are more common) or to accommodate different types of bicycles. Some plans specifically recognised that the high cost of rebuilding separated infrastructure makes careful analysis of future demand an important aspect of the design process.

There was a clear preference for one-way bicycle paths in the reviewed plans. One-way paths were found to be easier to integrate into existing signalling and traffic flows, more consistent and

[8] Four of the remaining five jurisdictions do not publish technical guidance documents in English.

predictable (and thus safer), and made for simpler intersection designs. However, two-way bicycle paths were considered acceptable, or even preferable, in certain situations. Two-way separated bicycle lanes require less space than a pair of one-way separated paths – this may be important along narrower streets. Where shops or other destinations are located on just one side of the street, a two-way bicycle path provides better access. Conversely, where side streets or driveways are clustered on one side of a street, a two-way bicycle path on the other side can reduce potential conflicts. Two-way paths also provide space for passing manoeuvres which can be useful where paths are narrow or there are 'tidal' flows of cyclists in particular directions at different times of day.

5.1.3. In practice

The City of Melbourne, Victoria published the Bike Lane Design Guidelines in 2019 with a clear mandate to create a network of separated bicycle paths. The Guidelines state, as part of the Decision Support Tool, that "in all cases, the first preference is to achieve kerbside physically separated bicycle lanes" (City of Melbourne, 2019, p. 4). The intent of this preference is "to attract less confident and inexperienced cyclists," a task that "requires more effective mid-block separation and better protection at intersections" (City of Melbourne, 2019, p. 4). The design guidelines recognise, however, that "the extent of kerbside physically separated bike lane treatments is limited as a proportion of the entire bike network" (City of Melbourne, 2019, p. 10) and that fast-tracking the construction of separated lanes will have significant transport benefits for the city. In order to make efficient use of funds, the Guidelines recommend a standard separated bicycle path design that consists of two-metre sections of bolted down, precast concrete or rubber separator islands with 10 to 15 metre gaps between them. The gaps are to be striped to indicate the edge of the cycleway. These gaps can be reduced in size in locations where motor vehicle intrusions are likely. Melbourne Council estimates that this design approach could reduce cost by 60 to 80% in comparison to more continuous designs (City of Melbourne, 2019, p. 15).

When Portland, Oregon adopted the Portland Bicycle Plan in 2010, "protected bicycle lanes were not widely used in the United States and the recommended bikeway network map did not differentiate between standard, buffered, and protected facilities" (Portland Bureau of Transportation, 2020, p. 10). Within a few years, the city recognised that this lack of differentiation was limiting the likelihood that "Interested but Concerned" riders would be willing to cycle more on city streets. In 2015, the city established a policy that "protected bicycle lanes should be the preferred design for all retrofit and new construction roadway projects" (Portland Bureau of Transportation, 2020, p. 25). By 2019, a progress update on the bicycle plan recognized that "numerous studies from around the world, as well as our experience…have confirmed that providing protected bicycle lanes on busy streets is a key element to addressing people's concerns about cycling on busy roadways" (Portland Bureau of Transportation, 2020, p. 10). Like Melbourne, the 2019 Progress Report identifies a key strategy to driving increased cycling mode share to be "build as much of the bicycle transportation system as possible, as quickly as possible. Fast implementation of a dense, high-quality network is important to give more Portlanders access to destinations they can ride to" (Portland Bureau of Transportation, 2020, p. 24).

The newly-published Portland Protected Bicycle Lane Design Guide specifically focuses on retrofit designs given the limited budget and opportunity for new road construction or significant reconstruction projects (Portland Bureau of Transportation, 2021). Due to this focus, the Design Guide includes a range of temporary elements, from paint (for parking protected lanes) to plastic delineator posts, to planter boxes, that can be used to implement separated lanes quickly and affordably (Figure 11). Including these temporary elements, this design guide identifies 28 possible design configurations for separated cycleways based on existing road configurations. The guide includes cost-per-mile estimates for each of 6 separated bicycle path designs and the 21 road widths in the city (including both one-way and two-way streets). Based on these per-mile estimates, the guide establishes a cost range to implement the entire 137 miles of separated bicycle paths identified in the Portland Bicycle Plan.

Figure 11. Retrofitted separated bicycle path in Portland, Oregon. Image credit: Monsere, Dill, McNeil, et al., (2014).

5.1.4. The *Cycleway Design Toolbox* in reference to international best practice

The *Cycleway Design Toolbox* states clearly that “the preferred facility for a high priority cycling route is a bicycle path, especially where on-road operating speeds exceed 30 km/h” (Transport for NSW, 2020a, p. 18). The *Toolbox* prioritises one-way bicycle paths on either side of the street, since this improves safety, intersection operation, legibility, and local access (Figure 12). However, the *Toolbox* also recognises that one-way bicycle paths require a greater dedication of road space. As a transitional step, a two-way separated bicycle path can be used, with the option for converting it to one-way when it becomes possible to build a second bicycle path (Transport for NSW, 2020a, pp. 30, 33).

The *Cycleway Design Toolbox* is consistent with international best practice around separated facilities – recognising that one-way bicycle paths have safety and coherence benefits but taking a pragmatic approach that fits with the political and economic realities of building safe bicycle infrastructure in cities that lack a strong cycling culture.

Figure 12: One-way separated bicycle path on Campbell Street, Sydney. Image credit: Cycleway Design Toolbox p. 23.

5.2. Theme 2: Quietways and low-traffic neighbourhoods through traffic calming and speed reduction

> *[B]oth absolute injury numbers and injury risk decreased substantially inside the LTNs [low-traffic neighbourhoods]. The estimated improvement in walking and cycling safety (three to four-fold for risk) would bring the UK into line with the best European countries…LTNs should be seen as an intervention that improves road safety as well as improving health through increased physical activity (Laverty et al., 2021, p. 5).*

5.2.1. Background

While separated bicycle paths are a critical component of the cycling network of a city, many urban streets can be made into safe and comfortable cycling environments without needing dedicated bicycle infrastructure. These are streets on which motor vehicle volumes and speeds are low enough that most people (including the "Interested but Concerned" cohort) feel comfortable riding in the street without protection. The benefits of traffic calming for road safety and the social life of city streets have been established to the point that traffic calming is a component of the reviewed plans for all twenty-two jurisdictions. Traffic calming is often framed around calming individual streets (called quietways, quiet streets, active travel streets, bicycle boulevards, neighbourhood greenways, neighbourhood bikeways, home zones, or woonerfs), or larger areas, neighbourhoods, or districts (often called low-traffic neighbourhoods (LTNs), home zones, traffic cells, or liveable neighbourhoods). In the 1960s in the Netherlands, during a period of disillusionment with the modernist concepts of functional separation, the concept of woonerfs and home zones were introduced by the Dutch urban planner Niek De Boer in Emmen under public space principles of meeting and playing (CROW-Fietsberaad, 2006). A team of urban planners and traffic engineers from the City of Delft developed this concept further over the coming decade resulting in the 1976 Dutch Home Zone Decree for "restoring… the original function of public space" in residential streets (CROW-Fietsberaad, 2006, p. 83).

The NACTO Urban Bikeway Guide (2014) lists four key criteria of traffic calmed streets for safe and comfortable cycling: First, speed management that slows vehicles to 30km/h or slower. Second, volume management that limits vehicle through traffic and reduces vehicle volumes to less than 3,000 vehicles per day. Third, traffic calming that extends through intersections, allowing for comfortable travel across major and minor roads. Fourth, wayfinding through signage and pavement markings that direct cycle travel and communicate safe behaviours.

Lowering motor vehicle speed has clear safety benefits. It has been well established that risk of crashes increase with vehicle speed, especially when different road users are moving at different speeds (Transport for NSW, 2014, p. 5; Wegman et al., 2008, p. 326). The risk of crashes increases at higher speed due to increased perception-reaction-stopping time and the increased forces involved when motor vehicles are moving more quickly (Svenson et al., 2012, p. 487; van den Dool et al., 2017, p. 57; Wegman et al., 2008, p. 326). In response, a primary task of traffic calming is to slow motor vehicle movement. There is a growing effort to limit motor vehicles to 30km/h on streets where there is a likely mix of motor vehicles, pedestrians and cyclists, culminating in the UN General Assembly resolution in September 2020 and a World Health Organisation plan in October 2021 (World Health Organization, 2021). Cities around the world have designated 30km/h (or 20mph) zones, and a few cities, including Brussels, Belgium; Munich, Germany; Lyon, France; Graz, Austria and many cities in the United Kingdom have established citywide or extensive 30km/h limits on most streets. Studies have indicated that lower speed limits do not significantly impact motor vehicle travel times, even while slowing speeds and improving safety (van den Dool et al., 2017, p. 59). In Graz, by the end of a two-year test phase of the city-wide 30km/h limit,[9] the city's Department of Transportation reported that 77% of all people in Graz (including two-thirds of car drivers) approved of the program, which was then made permanent (Hoenig, 2000). While Australia has experimented with 30km/h limits in a few urban areas, general speed limits are 50km/h (outside of designated 40km/h high pedestrian and school zones). This is despite evidence that 55% of pedestrians (and up to 90% of young adults) will die in a crash with a motor vehicle moving at 50km/h (NSW Centre for Road Safety, 2020). Extensive research has shown that the risk of death or serious injury increases rapidly as motor vehicle speeds increase (Figure 13). An adult hit by a car traveling at 30km/h has a 25% chance of death or serious injury. At 40km/h, the chance is 58 percent. At 60km/h, the risk of death or serious injury is 95% (Auckland Transport, 2019b, p. 113).

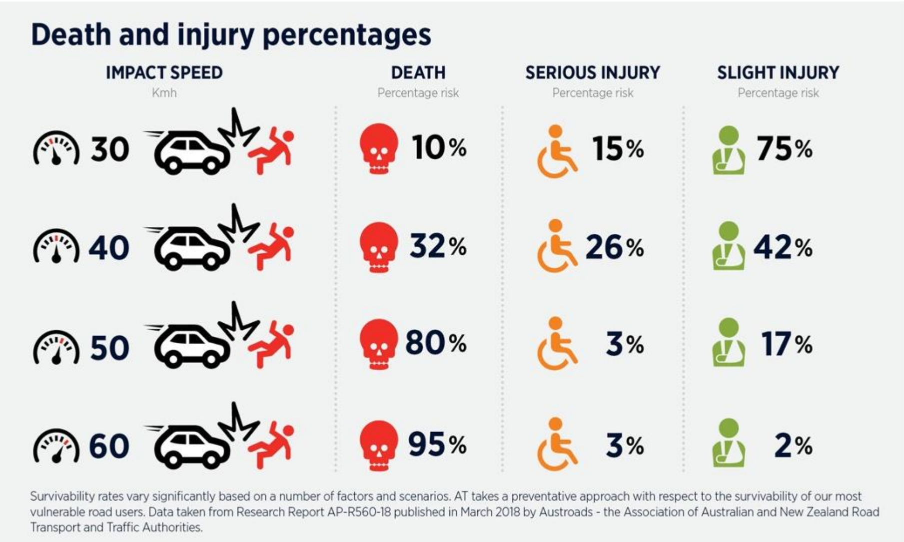

Figure 13: Probability of pedestrian death and injury by motor vehicle speed. Image credit: Auckland Transport (2019a) with data taken from Austroads (2018b).

Lowering vehicle speeds and volumes also benefits the social and economic life of streets. Building on foundational work by Donald Appleyard and his collaborators (1981), lower vehicle speeds and volumes have been shown to be more comfortable for neighbours, pedestrians, and cyclists, thus allowing for more social interaction and more engagement with retail businesses and public space (Demerath & Levinger, 2003). It is for this reason that public spaces and shopping areas are often traffic calmed or made car-free, an effort that can also benefit everyday cycling if designed appropriately.

While traffic calming is implemented on the scale of an individual street and can be effective at creating a safe and pleasant linear cycling route, plans for twelve of the twenty-two jurisdictions also called for traffic calming on a precinct or neighbourhood scale – slowing or rerouting motor vehicle traffic to create a LTN. These plans are usually built upon a hierarchy of road types, where a network of roads that prioritise vehicular movement are differentiated from local access roads that prioritise slower, safer travel for all users.

For example, the Dutch Sustainable Safety system classifies roads into three functions – *through roads* are intended for high speed, high volume vehicle flows (and are thus inappropriate for bicycles); *distributor roads* prioritise flow (and bicycles should be accommodated in separated infrastructure) but where cross-road exchange is important at intersections; and *access roads* where all aspects of the

[9] The 30km/h limit applies to more than 75% of streets in Graz. The remainder, major roads with important public transport lanes, have a 50km/h speed limit.

road are designed for safe mixing of bicycles and cars (and, in some cases, for pedestrian movement and play – a home zone or woonerf) and thus do not require dedicated cycling infrastructure (SWOV, 2018). Within this framework, decisions for how to accommodate different road users are clearly articulated. Access roads, for example, are set for a maximum speed of 30km/h and use traffic control measures to discourage or prevent through traffic for motor vehicles through residential precincts, while allowing more direct pedestrian and bicycle travel. In 2008, 85% of all Dutch roads in urban areas were classified as access roads with a maximum 30km/h limit (Schepers et al., 2017). Even where these access roads carry major cycling routes, they do not have separated cycle facilities.

Movement and Place frameworks, as discussed above, also establish or formalise road classification systems. For example, the Movement and Place approach in NSW identifies four primary street environments – *main roads*, routes where efficient movement of people and freight are high priority; *main streets*, where movement and place values are balanced and including all types of movement is key; *civic spaces*, where high place meanings are served by pedestrian-priority movement routes; and *local streets*, where activity levels are lower but local place meanings can be significant (Transport for NSW & Government Architect NSW, 2020, p. 53). Movement and Place frameworks can be used to designate low traffic neighbourhoods or districts of quietways that create good pedestrian and cycling environments while also creating inviting places.

Low-traffic neighbourhoods enjoy lower crash and injury rates for all modes of travel, but importantly, injury rates on the boundary roads have been shown not to increase as a result of the establishment of the low-traffic area (Laverty et al., 2021). And while route directness for motor vehicles is intentionally impacted, and increased vehicle travel times are a concern for many residents, the benefits of traffic calming in LTNs often outweigh the inconveniences (Reid, 2020).

5.2.2. Methods

Quietways and low-traffic neighbourhoods can be implemented using a range of traffic calming and Local Area Traffic Management (LATM) techniques. A key step in designing quiet street or low-traffic neighbourhood approaches is to analyse the existing road hierarchy and develop an area-wide plan. Implementing traffic calming elements on one street can encourage traffic to move to non-calmed nearby streets, so planning must holistically consider all streets in the local network (Green et al., 2020b, p. 6). This road hierarchy planning can be productively informed by a Movement and Place framework that considers the needs and priorities of the various local and regional users of a street network (Green et al., 2020a).

At a precinct or district scale, a primary task is to determine the degree to which through traffic for motor vehicles will be allowed. This is normally done in concert with public consultation and input from other neighbourhood stakeholders, including police and fire services, neighbourhood retail areas and schools and other institutions (Green et al., 2020a, p. 83). This process leads to the creation of a Network Operating Plan, and appropriate traffic calming and control methods will be chosen based on this plan (Green et al., 2020a, pp. 64-69).

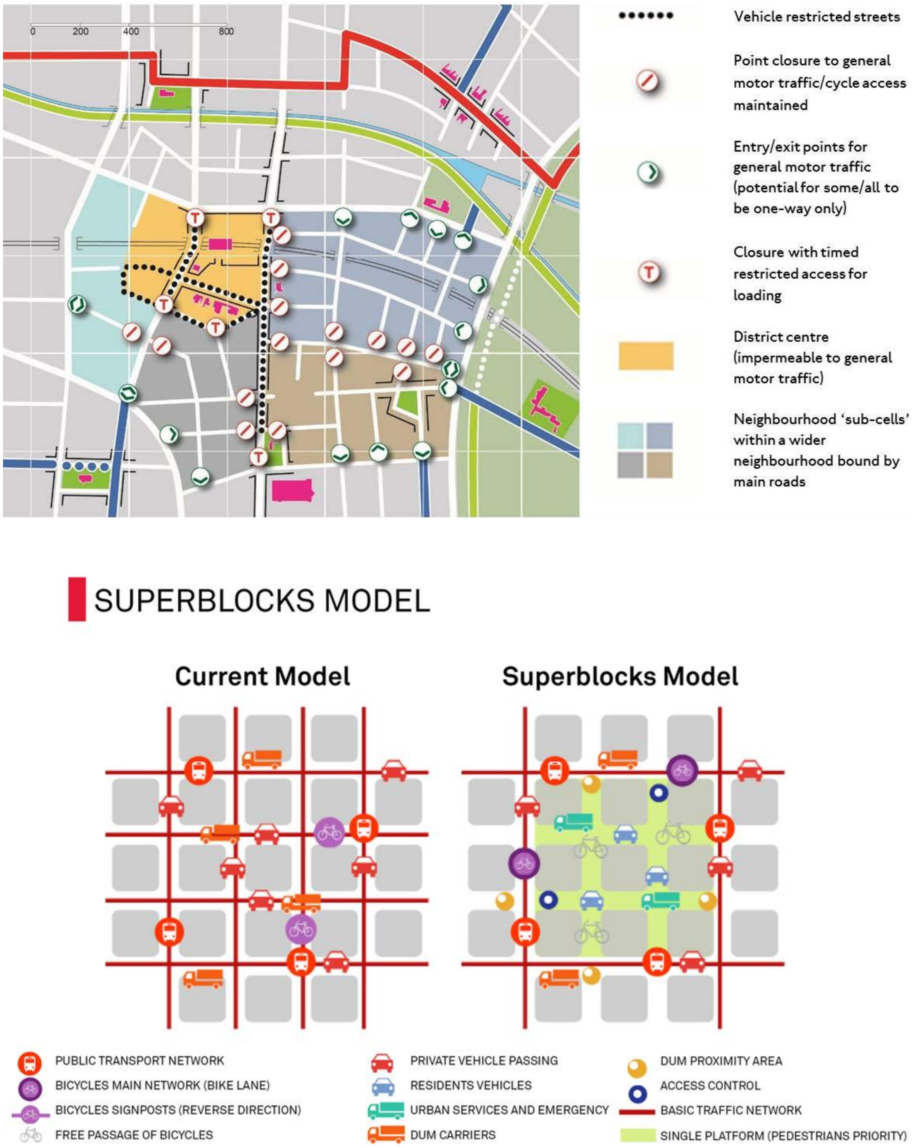

Figure 14: Above: illustrative example of a low-traffic neighbourhood design. Image credit: Transport for London. Below: Barcelona superblock concept. Image credit: Urban Mobility Plan of Barcelona 2013-2018.

The methods of traffic calming and control fall into four main categories, listed here in increasing order of scope of intervention, and illustrated in Table 4: Examples of traffic calming devices. They are: First, speed limits, one-way vehicular movements, stop signs, and movement prohibitions can be implemented largely though signage and require little in the way of road modification, but may be less effective in modifying driver behaviour. Second, vertical deflection devices since as road humps, wombat crossings or raised intersections can be implemented without significant impacts to vehicular movement patterns or property access but can be hazardous to bicyclists and cause noise or discomfort issues. Third, horizontal deflection devices such as kerb extensions, slow points, median treatments or roundabouts often require a reconfiguration of bicycle paths, on-street parking, or intersection designs. Fourth, diversion devices such as filtered permeability, and diagonal, partial, and full road closures are typical methods for creating low-traffic neighbourhoods, but inevitably (and intentionally) have a strong impact on vehicular movement and access.

Method	Notes	Image
Signage, Wayfinding and Linemarking Methods		
Threshold	Signage or paving that indicates an entry or exit into a traffic calmed street or neighbourhood	 *Image credit:* Andrew Macbeth
Speed limit	30km/h maximum for quietways and low-traffic neighbourhoods	 *Image credit:* Matthew Mclaughlin
School zone	School zones in NSW are generally 40km/h, but this is too fast to be considered bikeable to the “Interested but Concerned” cyclist.	 *Image credit: NSW Government: Tomorrow's Sydney*
Prohibited traffic movement	Can be applied flexibly (part time or to specific user types).	 *Image credit: Austroads Guide to Traffic Management Part 8: Local Street Management*
Bicycle lanes and signage	Can alert road users to expect cyclists to share traffic lane. Requires additional interventions to create safe and comfortable cycle environments.	 *Image credit:* Warren Salomon

Vertical Deflection Devices		
Road hump	Effective at slowing traffic speeds. Can increase traffic noise and can be uncomfortable for cyclists. Can impact on-street parking.	 *Image credit: Bayside Council, NSW*
Road cushion	Inexpensive and fast to install. Increases road noise from passing vehicles and can be a hazard to cyclists.	 *Image credit: Austroads Guide to Traffic Management Part 8: Local Street Management*
Flat-top road hump	Effective at slowing traffic speeds. Can increase traffic noise and can be uncomfortable for cyclists.	 *Image credit: Town of Victoria Park, WA*
Wombat crossing	Provides clear pedestrian crossing point – zebra crossing can be combined with a bicycle crossing. Can cause drainage issues. Can increase traffic noise and be uncomfortable for cyclists.	 *Image credit: WalkSydney*

Raised intersection	Can integrate with pedestrian and bicycle crossing facilities. Can be used as a threshold treatment at the start of a quietway or low traffic neighbourhood. Can cause drainage issues if kerbs are not rebuilt.	 *Image credit: Cara Seiderman*

Horizontal Deflection Devices		
Kerb extension	Can extend protection for pedestrians and cyclists at crossings while also slowing motor vehicles. Can impact on-street parking and create pinch points for bicycles.	 *Image credit: Richard Drdul*
Slow point	Slow points use kerbs or islands to narrow down traffic lanes, sometimes to a single lane. They often include a curved path to further slow vehicles.	 *Image credit: Burnside Council, South Australia*
Centre island	Can be used as a crossing refuge and combined with kerb extensions or wombat crossings to further slow vehicles.	 *Image credit: US Federal Highway Administration*

Median	Can be used to narrow roads without requiring stormwater system or driveway reconstruction. Can be combined with other facilities and used to limit turning movements. Can create pinch points for cyclists.	 *Image credit: Project for Public Spaces*
Roundabout	Can reduce vehicle conflict points and slow vehicle movements. Can require intersection reconfiguration. Can restrict access for larger vehicles. Additional infrastructure is necessary for pedestrian and cyclist safety and comfort.	 *Image credit: NACTO*

Diversion Devices		
Full road closure	Closes street to all large vehicles but allows pedestrians and bicycles to pass. Requires turning area for vehicles. Reclaimed space can be used for other street uses. Must be planned carefully to not impact emergency vehicle access. May reduce on-street parking.	 *Image credit: Mike Harris*
Half road closure	Helps reinforce prohibited vehicle movements. Requires turning area for vehicles. Reclaimed space can be used for other street uses. Must be planned carefully to not impact emergency vehicle access. May reduce on-street parking.	 *Image credit: Austroads Guide to Traffic Management Part 8: Local Street Management*

Diagonal road closure	Restricts through traffic but does not require vehicles to turn around. Can permit pedestrian and bicycle movement through barrier. Can be impassable for large vehicles.	 *Image credit: A Block at a Time (abaat.org)*
Modified T-intersection	Modified T-intersections can be used to restrict turning movements or to change priority of travel direction. Can provide space for additional road uses. Must be designed to allow safe bicycle and pedestrian movements.	 *Image credit: Austroads Guide to Traffic Management Part 8: Local Street Management*

Table 4: Examples of traffic calming devices

5.2.3. In practice

In 2015, Western Australia created a Bike Boulevard pilot project (now called Safe Active Streets) to trial quiet street designs on three streets in suburbs around Perth, as a local complement to the region-wide Principal Shared Path Program, which generally runs along freeways, highways, and rail lines. These were opened between 2016 and 2019, and the success of these projects prompted the inclusion of the Safe Active Streets Program in the 2017 update to the Western Australia Bicycle Network Plan. The Safe Active Streets program includes a suite of possible traffic calming interventions as well as new street trees and landscaping to create “self-enforcing” 30km/h environments and improve the attractiveness and comfort of the routes for active transport. These interventions include single lane slow points; road narrowing using kerb extensions, landscape treatments and on-street parking; clear wayfinding; and signals, signage, and traffic controls to prioritise pedestrian and bicycle movement along the street.

The Safe Active Streets program will be monitored for its performance through a set of before-and-after measurements, including bicycle and motor vehicle traffic volume and speed on the routes and their surrounding streets, crashes, cyclist behaviour and route choices, motor vehicle parking counts, and surveys to evaluate community perceptions and attitudes toward the routes.

In Melbourne, Victoria, the Yarra City Council conducted a test of low-speed streets in a residential neighbourhood. This project involved the creation of 12-month pilot of a 30km/h zone within an 83 hectare portion of this inner-city Melbourne suburb. All streets (except two) had speed limits reduced to 30km/h (Yarra City Council, 2017). Signage was the only intervention – this trial did not include other traffic calming measures. Despite this light intervention, the treatment area saw reductions in vehicle speeds, especially vehicles travelling at higher speeds. Reductions in the number of vehicles travelling more than 40km/h dropped by up to 25% on some roads in the treatment area. The study estimated a small reduction in risk of a severe or fatal injury to pedestrians and cyclists, although this was not tested directly. Support for the 30km/h limit increased over the period of the pilot study – a slim majority of surveyed residents in and around the treatment area supported the slower speed limit.

There was consistent belief among respondents that the slower speed limit would increase safety for walking and cycling (approximately 75%), and small increases in the number of respondents who believed the intervention improved safety for children and the elderly (from approximately 60% to approximately 66% of respondents) and reduced the risk of serious injury in a crash (from approximately 66% to approximately 68%) (Lawrence et al., 2020). The 30km/h zone was made permanent in 2019.

The 2021 Update to Scotland's Cycling by Design strategic plan includes a new LTN element that restricts motor vehicle movement through the centre of neighbourhoods (Transport Scotland, 2021). The plan calls for the development of urban LTNs through five steps: First, classify local streets to identify strategic transport movements and delivery routes through stakeholder engagement. Second, designate the size and structure of the LTN "cell" based on boundary streets, active transport access to trip attractors such as schools and parks, and the goal of discouraging short trips by car. The plan suggests that a suitable size for an LTN cell is 1.0 to 1.5 square kilometres. Third, identify locations of filtering measures such as modal filters, pocket parks, turning restrictions and one-way streets. Fourth, design individual streets for specific functions (for instance, play-focused activities or high cycle volume streets) by using appropriate traffic calming devices or visually distinct markings or surfaces (Transport Scotland, 2021). Fifth, create connections between LTN cells by providing safe walking and cycling connections across boundary roads. As of December 2021, two LTNs are currently being planned in suburbs of Edinburgh (City of Edinburgh Council, 2021).

In the outer London borough of Waltham Forest, two LTNs were created in 2015/2016 as part of the Mini-Holland programme, which seeks to transform three outer London boroughs into cycling hubs by introducing "high specification Dutch-style infrastructure" (Greater London Authority, 2021). The LTN design eliminated through motor vehicle traffic on residential streets in two small sections of the borough through modal filters and other traffic controls (Figure 15). Pre/post comparisons of casualties and fatalities from police records showed an almost two-thirds reduction in all casualties compared with the rest of the borough and Outer London as a whole, with motor vehicle drivers and passengers experiencing the greatest drop in casualties (Laverty et al., 2021). This reduction in casualties, coupled with increases in walking and cycling during the same period, suggests reduced risk to pedestrians and cyclists. This is consistent with a larger study of LTNs throughout Greater London that were implemented in 2020 under COVID-19 legislation (Goodman et al., 2021). These LTNs cover 4% of the population of Greater London. This study found that injury numbers were approximately halved after LTN implementation, and there were no changes in injuries on boundary roads. Laverty et al., found reduced motor vehicle traffic within the low traffic area, and slightly higher traffic along boundary roads, but also found no significant changes in casualty rates along the borders of the LTN. This addresses a common concern regarding LTNs that they will dramatically increase traffic and risk on surrounding streets (Chandler, 2020).

Figure 15. Entry to a low-traffic neighbourhood in Waltham Forest as part of the mini-Hollands program. Image credit: Transport for London.

5.2.4. The *Cycleway Design Toolbox* in reference to international best practice

The Transport for NSW *Cycleway Design Toolbox* describes a quietway as "a high-quality mixed traffic treatment where bicycle riders travel in a mixed traffic environment with motorised traffic…the key design philosophy of a quietway is the safe integration of people cycling as equal road users to motor vehicles…This requires drivers to reduce travelling speeds to 30km/h or lower…" (Transport for NSW, 2020a, p. 40). The *Toolbox* discusses the Movement and Place framework as a tool for classifying streets and street segments and then applying a set of techniques consistent with international best practice examples, including coloured or textured pavement, lane narrowing, filtered permeability, vertical displacement and other traffic calming features to slow motor vehicles and restrict their movements (Transport for NSW, 2020a, pp. 14-15 and Figure 16).

Figure 16: Modal filter. Image credit: Transport for NSW Cycleway Design Toolbox.

While the *Toolbox* does not explicitly promote the use of traffic cells or low-traffic neighbourhoods, it does reference London's Low Traffic Neighbourhoods program as an example of how to plan and design for bicycle-friendly quietways (Transport for NSW, 2020a, p. 40).

5.3. Theme 3: Protected intersections and priority crossings

> *Protected intersections create shorter, simpler crossings, more predictable movements, and better visibility between people on bikes and people driving. As a result, the intersection is more comfortable and safer for people using the bikeway and the crosswalk (NACTO, 2019, p. 9).*

5.3.1. Background

The most dangerous portion of most urban bicycle trips is where bicycles and motor vehicles interact in intersections. A ten-year study of crashes in Victoria found that 60% of all bicycle crashes occurred in intersections (Garratt et al., 2015). A study in Adelaide showed motorists were at fault in more than 75% of reported collisions between motorists and cyclists, with most occurring at intersections (Lindsay, 2013). This is also an issue for pedestrians – just over half of pedestrian-motor vehicle crashes take place at intersections (Transport for NSW, 2014). This risk is a global problem – a majority of crashes in many countries occur at intersections (see, for instance Hunter et al., 1996; Isaksson-Hellman, 2012; Schepers et al., 2017). The complexity of movements, the high number of required perception tasks, and the difficulty of correctly recognising speed and predicting others' behaviours makes safe movement through intersections more difficult (Jannat et al., 2018; van den Dool et al., 2017; Wang & Nihan, 2004).

Bicycle and motor vehicle movements through intersections create potential conflicts when turning movements and straight-through movements overlap. This issue occurs often when straight-through bicycle movements occur at the same time with turning vehicular movements, which is common with typical bicycle lane configurations at intersections (Monsere, Dill, McNeil, et al., 2014). The safest intersections are those where movements of pedestrians, bicycles, and motor vehicles are separated from each other in space or in time (or both).

5.3.2. Methods

The separation of different user types in space can be achieved through vertical or horizontal separation. Vertical separation, via tunnels or bridges, is often prohibitively expensive or space consuming, and can inconvenience pedestrians or cyclists (Pettinga et al., 2009, pp. 104-107). As such these are used only in very particular conditions. Horizontal separation between motor vehicle lanes and bicycle paths where they cross an intersection can be effective – either be extending kerbs into the intersection to protect cyclists and pedestrians (and shorten their crossing distance of motor vehicle lanes), or by "bending out" the bicycle path at the intersection, drivers of turning vehicles have a clearer view of straight-through bicycle movements, have a longer time to react to that bicycle, and the "pocket" of space between the two travel lanes provides a waiting area for a motor vehicle (see section 4.1.1). "Bent-out" paths can be combined with elements that slow vehicle movements (tight radius corners and narrow lanes, for example) to give additional time for different road users to see each other and react (NACTO, 2019).

Movement of different types of users through intersections can also be separated in time, usually through management of signalling. Creating signal phases where motor vehicles cannot turn while bicycle straight-through movements are occurring can eliminate many conflict points, or bicycles can be given a "bicycle scramble" phase where all motor vehicles are stopped. Alternately, a leading bicycle interval (as is common for pedestrians) can allow waiting bicycles time to move through the intersection before car turns are allowed (NACTO, 2019).

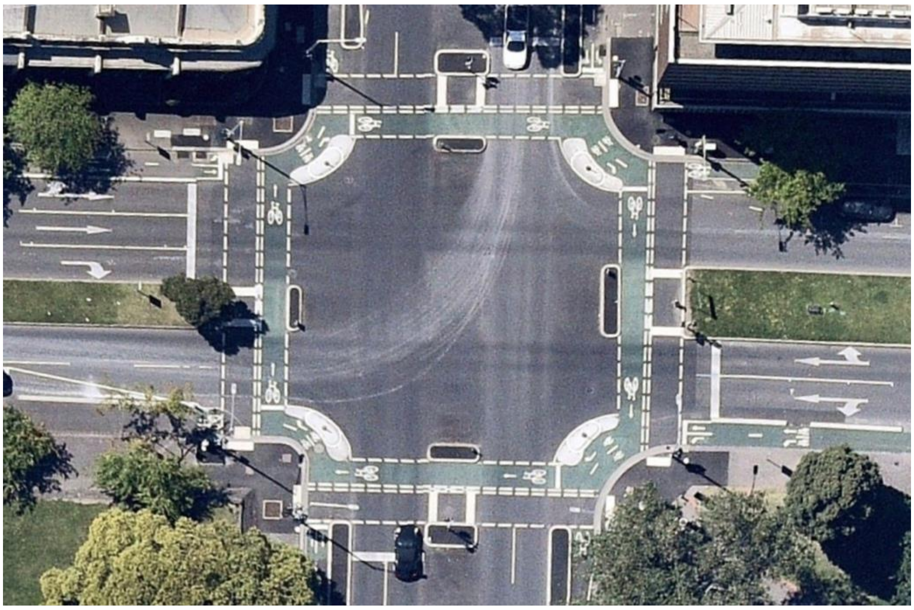

Figure 17. Protected intersection in East Melbourne, Victoria. Image credit: Nearmap.com

Dutch roundabouts

In many countries, roundabouts are used in place of road junctions, due to the significant safety benefits for motor vehicles (Robinson et al., 2000, p. 112). Pedestrians and cyclists do not share these benefits – in NSW, for example, a cyclist is three times more likely to be injured in a roundabout than at a cross intersection (Patterson, 2010). Of these bicycle crashes in roundabouts, an estimated 70% occur when a motor vehicle enters the roundabout and hits a circulating cyclist. This real risk is compounded by bicyclists' perceived risk in roundabouts, especially where the cyclist perceives the predictability of other users and their own level of control to be low (Møller & Hels, 2008). Interviews of cyclists have indicated that dedicated cycle facilities and reduced motor vehicle speed and volume would improve their perceptions of safety and comfort (Møller & Hels, 2008, p. 1060). Importantly, however, these bicycle facilities should not be on-roadway. Studies have shown crash rates in roundabouts with on-roadway bicycle lanes are as much as double that of roundabouts with separated facilities (Poudel & Singleton, 2021, p. 632).

Roundabouts with separated pedestrian and bicycle movements have been used extensively in Dutch and Danish cities and towns, and have been shown to be safer and preferable for Interested but Concerned cyclists (Poudel & Singleton, 2021, pp. 635-636). This was an important evolution – prior to 2000 Dutch roundabouts were built with bicycle lanes around the outer edge, delineated by paint, but this design was found to be more dangerous than no bicycle infrastructure at all (Jensen, 2017). Key design features of a "protected roundabout" are similar to protected intersections using physical designs to slow motor vehicle traffic entering, circulating, and exiting the roundabout; providing enough separation between cycle paths and motor vehicle lanes to improve visibility and provide a storage area for cars where they can wait safely for cyclists to pass; and providing clear and consistent policy, signage, and markings to manage priority of different users (Figure 18).

Figure 18. Dutch-style roundabout in Cambridge, UK. Image credit: Cambridgeshire Live (www.cambridge-news.co.uk/)

Path priority crossings

Where separated bicycle paths cross side streets, driveways, or other vehicular accessways, clear communication of rights of way are important to ensure cyclist safety. Where bicycle paths are completely segregated from vehicular lanes (in parks and open space, for example) bicycle paths can be given priority where they cross roads. This design is well established in road regulations in Australia (National Traffic Commission, 2021) and used in practice in many countries (CROW-Fietsberaad, 2007, p. 145). Depending on the motor vehicle traffic speed and volume on the road, the priority crossing can be communicated using lane marking and signage (Figure 19) or signalisation. Centre refuge islands and kerb extensions can make these crossings more comfortable on high-volume streets.

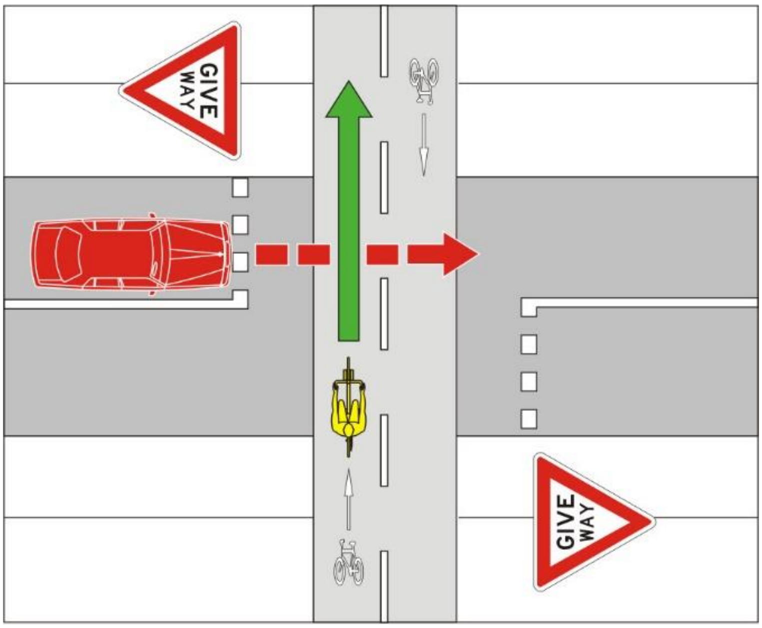

Figure 19: Path priority crossing at segregated bicycle path.
Image credit: Australian Road Rule 71.

Where a bicycle path runs parallel to motor vehicle lanes, the bicycle path priority should mirror the priority of parallel motor vehicle lanes. It is important that bicycle paths retain priority over motor vehicle traffic on side roads or driveways, and that this priority is clearly communicated. This is important to cyclist safety and also to reduce the number of stops and starts required of cyclists, as maintaining a consistent speed contributes to cyclist comfort and reduces physical exertion.

Path priority crossing designs fall into two primary categories – bent-out crossings and shared environment crossings.[10] In both cases, pedestrian and bicycle traffic in the facility have priority over motor vehicles and bicycles crossing the facility.

In a bent-out crossing, the bicycle path is diverted away from the parallel motor vehicle lane before it crosses the road. This allows motor vehicles to turn into the side street before reaching the facility, which increases visibility of crossing cyclists and pedestrians. It also creates a holding area for motor vehicles where drivers can safely yield to crossing cyclists and pedestrians without blocking traffic on the main road. Signage, coloured pavement and raised platforms (typically combined with a wombat crossing for pedestrians) clearly communicate to all users the priority of pedestrians and cyclists in the crossing (Figure 20). Bent-out crossing intersections are used widely around the world, and have been found to be safer than designs where the bicycle path does not diverge from the motor vehicle lanes (Schepers et al., 2011).

Figure 20: Bent-out crossing on Bourke Street Cycleway. Image credit: Group GSA/ Simon Wood.

Shared environment intersections, as discussed above, are intended for low-volume intersections of 30 vehicles per hour maximum (Transport for NSW, 2020b). In this design, a raised platform extends across the side street in which pedestrians, bicycles share space in the crossing. Ramps allow motor vehicles or bicycles to use the shared environment intersection to enter or exit the side street, but signage, paving, and kerb extensions communicate that these vehicles have a lower priority, although this priority relationship is more ambiguous with this design (Figure 21). The raised platform is often extended into the road areas to slow motor vehicles before they enter the facility and to provide a space for vehicles to stop before crossing the bicycle and pedestrian paths.

[10] These are described above in the context of the Bourke Street Cycleway in Sydney.

Figure 21: Shared environment intersection. Image credit: SKM.

5.3.3. In practice

While plans for fifteen of the twenty-two jurisdictions include general information on protected intersections, outside of the Netherlands and Denmark they remain rare. Several cities in the United States have built or planned protected intersections, with two having been built in 2015 – one in Salt Lake City, Utah and one in Davis, California (Goodyear, 2015; Stromberg, 2015). Other examples include Austin, Texas (City of Austin, no date), Chicago, Illinois (Fried, 2017), and Silver Spring, Maryland (Masters, 2019). A protected intersection has been built in Manchester in the United Kingdom (Maidment, 2020), and Ottawa, Canada had built seven as of 2019 (Marier, 2019). In Australia, protected intersection designs were described in as part of a compendium of design and planning approaches to support the Austroads Safe System framework (Austroads, 2018a), and the first protected intersection was installed in Melbourne in 2020 (Bicycle Network, 2020). Protected roundabouts outside of northern Europe are even more rare – two protected roundabouts were installed in South Melbourne in 2018, and the first in the United Kingdom was completed in August of 2020 (Metro Tunnel, 2020; Shepka, 2020). A roundabout with protected bicycle lanes but no crossing priority for bicycles was installed in San Francisco in March 2021 (Rudick, 2021). As these early examples are evaluated, there is a possibility that these infrastructure types will become more widespread and more easily justified as part of city's transportation budgets.

5.3.4. The *Cycleway Design Toolbox* in reference to international best practice

The Transport for NSW Cycleway Design Toolbox shows protected roundabout and signalised intersection designs, and highlights that these designs represent the highest quality environments

Figure 22). This positions the Toolbox at the leading edge of international best practice in promoting fully protecting cycling environments. Protected intersections are less prevalent in international practice than separated bicycle paths and quietways, with just over half of the plans reviewed including robust discussion of protected intersection design.

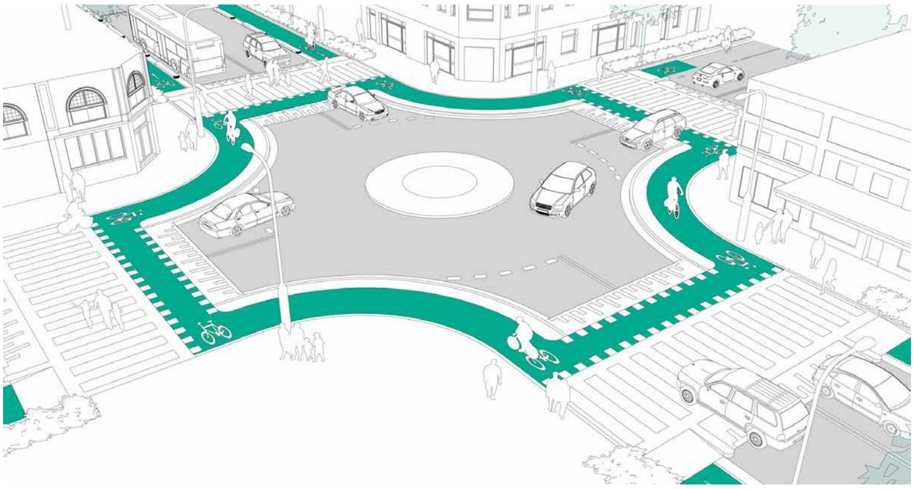

Figure 22: Design for a protected roundabout. Image credit: Transport for NSW Cycleway Design Toolbox.

The signalised intersection design describes signal priority phases for bicycles and shows protection for the bicycle crossing at corners. Some elements of recommended practice are missing, including deep holding areas for turning vehicles at bicycle crossings and an extension of kerbs into the intersection to minimise crossing distances and ensure that bicycles and pedestrians are in motorists' line of sight in the crossing area (Transport for NSW, 2020a, p. 28).

The protected roundabout design does include deep holding areas for vehicles exiting the roundabout, although it lacks clear indications of priority for cyclists and pedestrians at this conflict point. The design also includes sharp turning radii for bicycles moving through the facility, which will help ensure that cyclists move at safe speeds but also create potential conflict points for less experienced cyclists. The *Toolbox* also encourages readers to review City of Melbourne designs for protected roundabouts where more space is available

As discussed above in the context of the Bourke Street cycleway, path priority crossings and shared environment intersections are currently used in pedestrian and cycleway projects in NSW. The *Cycleway Design Toolbox* recognises that bent-out intersections are preferrable to shared environment intersections because of the increased clarity of priority and the higher level of service for cyclists because of the dedicated bicycle path crossing element. Shared environment intersections can be less expensive to implement, due to fewer required changes to kerbs and stormwater drainage, and perhaps because of this have been implemented more frequently than bent-out intersections. There is established precedent for priority path crossings in NSW and around Australia, and extensive international experience that suggests these strategies as an important component of safe and comfortable cycling networks that appeal to the "Interested but Concerned" cyclist. Future high-quality bicycle infrastructure projects should utilise bent-out intersections as a general strategy and can use shared environment intersections as a less-optimal option if needed.

6. Conclusion

This literature review is the first stage of a two-year research project for Transport for NSW titled Interactively visualising street design scenarios for communicating bike infrastructure options to communities and policymakers. The research project investigates how to integrate cycling facilities into urban environments in ways that address the concerns of the 48% of NSW residents who are "interested" in cycling, but "concerned" about safety. Targeting these potential riders means focusing design techniques on the aspects that these people value. This literature review aims to understand current and emerging cycling facility design practice internationally alongside Transport for NSW's *Cycleway Design Toolbox: Designing for Cycling and Micromobility* (2020a).

Roger Geller's 'four types of cyclists' categorisation (Geller, 2009) has found broad appeal in bicycle planning and has directly informed several government bicycle plans around the world. It has been verified to a close enough extent in several locations to offer a compelling model for a population-wide understanding of opportunities to increase cycling and provides clear direction on what would be required to enact a cycling mode share shift, primarily with increased safety through separation from traffic. Frameworks for identifying categories and allocating percentages of the population have been utilised in City and State Government bicycle strategies in Sydney and NSW over the past 15 years. Over this period five surveys from the City of Sydney and one from Transport for NSW have indicated majority cohorts align with being interested in cycling or cycling more often however they do not due to safety concerns of traffic. These concerns are valid. In the Australian context motorists are at fault in more than 75% of reported collisions between motorists and cyclists (Lindsay, 2013) and pedestrians and cyclists have an 80% chance of death if struck by a car travelling 50 kilometres per hour (Austroads, 2018b); the standard speed limit for local streets in Australia. Design guidelines from both the City of Sydney and more recently Transport for NSW acknowledge the barriers to cycling presented by safety concerns and provide a range of facility types in response. However, over the past 15 years delivery of separated infrastructure across Greater Sydney has been slow and fragmented.

To understand the common practices and themes of current bicycle planning internationally, thirty-nine bicycle plans from twenty-two jurisdictions (at city, state, and national levels) were reviewed. Based on this analysis three dominant themes emerged: 1) A general move to establish separated bicycle paths as standard practice, rather than an exceptional condition; 2) The formalisation of quiet ways and low-traffic neighbourhoods as a core element of local bicycle networks; and 3) A growing emphasis on the need for protected intersection design.

The *Cycleway Design Toolbox* released by Transport for NSW in December 2020 provides guidance in all three themes. It is consistent with international best practice on separated bicycle paths as the standard facility forming the network's foundation. Separated one-way pairs are acknowledged as offering safety and coherence benefits over bidirectional cycleways. The bidirectional cycleway however offers more spatial pragmatism for delivery in the context of NSW, where widespread political support for bicycle infrastructure is still lacking. This is evident from the stalling of the pop-up cycleway program outside the City of Sydney where pre-prepared plans and political agreement were not sufficiently established.

The *Cycleway Design Toolbox* is consistent with international best practice on quietways in terms of devices available to slow and restrict motor vehicle movement as well as a relatively short unillustrated section on shared zones. London's *Low Traffic Neighbourhoods* program is referenced however the *Cycleway Design Toolbox* does not explicitly promote low-traffic neighbourhoods such as the London example, Dutch home zones or the compelling Barcelona Superblock strategy, and illustrate how these might take form in the local NSW context.

The *Cycleway Design Toolbox* is consistent with international best practice on protected roundabout and signalised intersection designs (although the illustrated design misses some detailed elements of recommended practice) and recognises that these designs represent the highest quality environments. This forward-looking approach demonstrates higher ambitions than many current plans internationally. Despite these ambitions, protected intersections have yet to be implemented in NSW, although there are recent examples in Victoria that are worthy of study and emulation.

For intersections at side streets the *Cycleway Design Toolbox* recognises that bent-out intersections with clear cyclist and pedestrian priority are preferrable to shared environment intersections. However, the latter has been implemented in far greater numbers to date. Cost is likely a primary reason, however international precedents for simpler design techniques are available. Such examples were originally proposed but not permitted at Bourke Street due to NSW Road Rules regarding bidirectional cycleways and a concern over a lack of storage space and control devices for turning cars (discussed in section 4).

The *Cycleway Design Toolbox* provides clear design direction for the range of bicycle facilities necessary for a network that satisfies the concerns of the “Interested but Concerned” cohort. The NSW Government’s Principle Bicycle Network proposes approximately 6,000 kilometres of bicycle routes across Greater Sydney, Newcastle, Gosford and Wollongong. However, the delivery trajectory before COVID-19 was clearly insufficient for this goal. It would therefore be prudent to view these design guidelines and their evolution alongside delivery capability at the network scale. The streamlining of design and governance processes undertaken for the pop-up program offers a productive starting point for such an approach. The next phases of this research project will assist this process by using virtual reality simulations to gather new data on what design features influence the perception of safe bike-ability of those that identify as “Interested but Concerned”.

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Interviewees

Interviews were undertaken for prior research that was drawn on for Section 4. Development of cycling infrastructure in Sydney. Views expressed in these interviews were personal opinions, given without prejudice and may not necessarily reflect government policy.

Ballm, D. (2021). Director Of Network Operations, Transport for NSW.

Campbell, F. (2020). Manager Cycling Strategy, City of Sydney.

Donaldson, B. (2020). Former Manager Bicycle Network, Roads and Traffic Authority, NSW Government.

Hammond, S. (2020). Bourke Street Lead Landscape Architect, GroupGSA.

Jung, J. (2021). Acting Manager Movement and Place, Transport for NSW.

McCabe, G. (2020). Former Manager Transport Strategy, City of Sydney.

Merchant, S. (2020). Bourke Street Design Manager, City of Sydney.

Mouy, B. (2021) Senior Manager Public Spaces, NSW Department of Planning, Industry and Environment.

Salomon, W. (2020). Bourke Street Cycling Expertise Advisor, Sustainable Transport Consultants.

Stace, S. (2020). Manager Walking and Cycling Strategy, Transport for NSW.

van den Dool, D. (2020). Bourke Street Project Director, GTA Consultants.