ENHANCING iRAP INVESTMENT PLANS FOR VULNERABLE ROAD USERS

D2 – LITERATURE REVIEW

ROAD SAFETY FOUNDATION

About the Road Safety Foundation

The Road Safety Foundation is a UK charity founded in 1986 which focuses on road casualty reduction through simultaneous action on all components of a Safe System approach: safe roads, safe vehicles, safe speeds, safe road use and post-crash care.

The charity has enabled work across each of these components. Several of the charity's published reports have provided the basis of new legislation or government policy.

With 1.35 million now killed annually on the world's roads, the charity helps ensure that the UK can provide a global model of what can be achieved with an evidence based Safe System approach.

The charity led the establishment of the European Road Assessment Programme (EuroRAP) in 1999 which in turn received a Prince Michael International Road Safety Award for establishing the global International Road Assessment Programme (iRAP). iRAP's protocols have been applied in more than 100 countries as part of the UN road safety collaboration led by the World Health Organisation.

In Britain, the Foundation plays a pivotal role in raising awareness and understanding of the importance of road infrastructure safety through:

- annual publication of EuroRAP safety rating measures which can be understood by the general public, policy makers and professionals alike;
- issuing guidance on the use of RAP protocols and working with road authorities to improve the safety of the road infrastructure for which they are responsible; and
- proposing the strategies and goals that the Government might set in order to save tens of thousands of lives and disabling injuries.

The Road Safety Foundation frequently supports others abroad and is a founder member of the global philanthropy, the FIA Foundation.

The charity works closely in the UK with government, authorities, insurers and other road safety organisations and professional bodies such as ADEPT. Its Board of Trustees is chaired by former Roads Minister, Lord Whitty, and includes former CEOs of TRL, FTA and other leaders in relevant fields such as marketing. Its annual report tracking UK infrastructure safety performance to the EuroRAP Crash Risk Mapping protocol in the UK has been sponsored by major motor insurer Ageas UK since 2012.

Recently, the charity has

- supported DfT's Safer Roads Fund helping train 30 authorities in developing a £100m portfolio of 50 schemes to address the 50 highest risk Local Authority 'A' roads;
- undertaken the strategic analysis of infrastructure safety performance in 12 European countries in the EU SENSOR project which provided unique evidence underpinning the extension of the revised European Road Infrastructure Safety Management Directive now in force; and
- led the Older Drivers Task Force report with government support to develop the national Older Driver Strategy *Supporting Safe Driving into Old Age*.

For more information

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Contents

Table of Figures

List of tables

Acronyms

AADT	Average Annual Daily Traffic
ADEPT	Association of Directors of Environment, Economy, Planning & Transport
CIHT	Chartered Institution of Highways & Transportation
CLG	UK Ministry of Housing, Communities and Local Government's (formerly the Department for Communities and Local Government
CMF	Crash modification factor
COVID-19	The 2019 coronavirus pandemic
CROW	A non-profit agency advising Directorate-General for Public Works and Water Management (The Netherlands)
DFT	Department for Transport
DMRB	Design Manual for Roads and Bridges
EMBARQ	WRI Ross Center for Sustainable Cities' sustainable urban mobility initiative
EU	European Union
FHWA	Federal Highway Administration (US)
FSI	Fatality and serious injury
FTA	Freight Transport Association
GTC	Global Technical Committee
HE	Highways England
ITE	Institute of Transport Engineers
LPI	Leading Pedestrian Intervals
LTN	Local Traffic Note
NACTO-GDCI	National Association of City Transportation Officials' Global Designing Cities Initiative
PTG	Parsons Transportation Group
RAP	Road Assessment Programme
RSF	Road Safety Foundation
SENSOR	'South East Neighbourhood Safe Routes' project
SRIP	Safer Road Investment Plan
SRS	Star Rating Score
SSD	Stopping sight distance
SWOV	Institute for Road Safety Research (The Netherlands)
TØI	Transportøkonomisk institutt (Norway)

TRL	Transport Research Laboratory (TRL) is a subsidiary of the Transport Research Foundation (TRF)
UK	United Kingdom
UN	United Nations
US	United States
VRU	Vulnerable Road User
WRI	World Resources Institute

1. INTRODUCTION

There has been a considerable shift in recent years which recognises the shortfalls of traditional car-centric road designs in urban areas. Some major cities across the world have fundamentally changed their approach to designing and managing their urban road networks, which prioritises safety and mobility for pedestrians and cyclists. Changes to road user groups themselves, such as increased cycling and micro-mobility, are also prompting cities to look for ways to provide safer urban road environments for all road users.

As a result of this shift, there is now an emerging body of knowledge which captures the safety outcomes of the innovative treatments of these new approaches to urban road design. Much of it has already been documented in road safety manuals and guides such as the National Association of City Transportation Officials' Global Designing Cities Initiative's (NACTO-GDCI) *Global Street Design Guide*, the World Resource Institute's *Safer Streets by Design* and other road safety manuals.

The International Road Assessment Programme (iRAP) tools provide various outputs that are useful when reviewing the safety of a road network. The Star Ratings and fatal and serious injury estimation functionality allows authorities to gain an understanding of how risk changes along an individual road section or across a network, based on the safety performance of the infrastructure itself.

There is an opportunity to build on this progress and capture the latest innovative treatments for vulnerable road users (VRUs) that can be immediately deployed through the well-established activities of the Road Safety Foundation (RSF) in the UK, EuroRAP across Europe, and iRAP with its global programme reaching over 100 countries. Importantly, this work closely links to the UN Member State Global Road Safety Performance Targets which will inform and influence road safety policy and practice in the UK and internationally.

The objective of this project is to improve the Safer Roads Investment Plans (SRIPs) generated by the iRAP approach, to ensure the latest thinking and innovation for safety measures for vulnerable road users (VRUs)—pedestrians, bicyclists and motorcyclists—in urban environments are fully embedded thus allowing road authorities to better make the case for investment to prevent VRU fatal and serious injuries.

About this literature review

The aim of this exercise is to review existing literature and standards to consider the effectiveness of urban VRU treatments in different scenarios with view to expanding the range of urban-specific safety treatments which can be applied by the iRAP protocols. It includes a review of literature relating to self-explaining roads, shared space, safe speed, traffic calming and will cover a review of future technologies. The evidence documented in this literature review will be presented to the iRAP Global Technical Committee (GTC) as the basis for any recommended changes to the iRAP model.

Methodology

A number of the leading, best-practice design guides formed the basis for the review. These included those that were identified in the project proposal, and others which were identified during the course of the review, particularly those relevant to the UK context.

Publications included in this review[1] were:

- The NACTO-GDCI *Global Street Design Guide* (2016) and *Designing Streets for Kids* (2020)
- WRI Ross Centre for Sustainable Cities' *Cities Safer by Design* (2015)
- Transport for London's (TfL) Streetscape Guidance (2019)
- The UK *Design Manual for Roads and Bridges* (DMRB), *CD143 Designing for walking, cycling and horse-riding* and *CD195 Designing for cycling traffic*
- Chartered Institution of Highways & Transportation's (CIHT) *Designing for walking* (2015)
- UK Department for Transport and Communities and Local Government's *Manual for Streets* Section 6.3 (2007)
- UK Local Transport Note 1/20 (Cycling Infrastructure Design)
- UK Local Transport Note 1/07 (Traffic Calming)
- Institute of Transport Engineers' (ITE) Technical Resources on Traffic Calming Measures.

More information on each of these documents is provided in the next section. Additional studies and publications were identified and consulted for their relevance to particular issues. The review concludes with discussion and recommendations for urban-specific countermeasures appropriate for application in the iRAP methodology, namely the Safer Road Investment Plan (SRIP).

The learnings gathered from this literature review will be used in the SRIP to:

- Recommend countermeasures more appropriate to the urban environment and desirable outcomes
- Recommend more specific types of countermeasures based on road characteristics, user flows and land use, for example, crossing types appropriate to the road context
- Review countermeasure triggers, minimum length, minimum spacing and hierarchy rules, and
- Identify new countermeasures where appropriate.

Document structure

The document has the following sections:

1. Introduction (this section) – Describes the project, the aims and methodology of the literature review.
2. Background – Provides the contextual information for this review.
3. Review of countermeasures which relate to pedestrian and bicyclist safety in urban areas. This section is organised by countermeasure type.

[1] Many of the documents included more or less contain detailed specifications and guidance pertaining to the design of various facilities. Unless otherwise stated, this review does not compare the specifics of design unless it is relevant to a specific outcome or application of a safety treatment.

4. Discussion and recommendations.

Summary of discussion and recommendations

The iRAP model generates countermeasures that are economically tested and that will reduce road user risk.

The need for urban-specific countermeasures is underpinned by a move to reduce urban traffic speeds for the safety of road users other than vehicles. The 2020 UN Stockholm Declaration focuses on speed management, including 30 km/h (20mph) speed limits where vulnerable road users and vehicles mix.[2]

This calls for a rethinking (much of which is represented in the guidance documents reviewed here) of the engineering measures used in road design which encourage lower speeds and create streets as more equitable and accessible places.

Based on the review, there are nine recommendations proposed which could be further investigated as part of the possible development of an urban-specific Safer Road Investment Plan:

1. Introduce speed reduction as a countermeasure which accounts for the traffic calming measures appropriate to the target speed (and other characteristics of the road)
2. Recommend appropriate traffic calming measures for all urban roads where pedestrians and bicyclists are present.
3. Consider the introduction of traffic volume reduction as a countermeasure through area-wide traffic calming measures such as diverters, closures and street conversions
4. Broaden the types of pedestrian/bicycle crossing types
5. Enhance 'upgrade crossing quality' with a specific list of recommended measures
6. Update the minimum length, minimum spacing and hierarchy rules in line with current best-practice
7. Introduce measures to reduce legs on intersections or close intersections to vehicular traffic
8. Update trigger sets and hierarchy rules so that recommendations align with current best practice for traffic calming in urban areas
9. Enable more than two countermeasure outcomes

[2] https://www.roadsafetysweden.com/contentassets/b37f0951c837443eb9661668d5be439e/stockholm-declaration-english.pdf

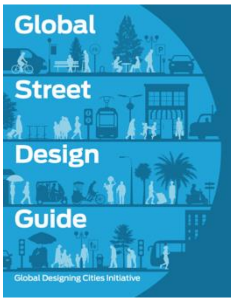
2. BACKGROUND

Cities, and the design guidance that shapes them, are constantly evolving. The last decade has been no exception. The design guidance which has emerged since 2010 represents a strong shift toward 'design' elements of urban space and in doing so, is consistent in the following principles:

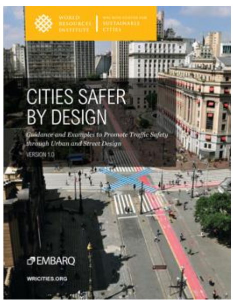
- Embracing the multi-faceted life of streets, their users and their needs, and that urban road networks require a different approach to rural roads and highways
- A shift in the priority toward sustainable modes of transport, particularly bicycling and walking (but also transit and mobility) and moving the efficient mobility of *people* over vehicles
- A strong focus on safety, liveability and environmental sustainability and the health outcomes of urban residents, including the role of active travel, and
- A shift away from siloed, single purpose and disconnected zoning, design and development toward holistic and multi-disciplinary approach.

About the publications reviewed in this report

The publications selected for review in this study are those which are considered landmark documents representative of this evolution and current 'best-practice, and which are applicable globally or are specific to the UK context.

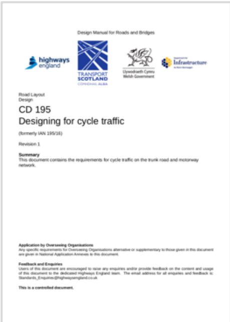


NACTO-GDCI's *Global Street Design Guide* built on NACTO's *Urban Street Design Guide* and the *Bikeway Design Guide*. It draws from over 70 cities in 40 countries. In 2020, NACTO-GDCI published a design guide specific to children's needs, *Designing Streets for Kids* which expands on the content in the Global Street Design Guide.



Through its EMBARQ sustainable urban mobility initiative, WRI Ross Center for Sustainable Cities published *Safer Cities by Design* in 2015 to "provide real-world examples and evidence-based techniques to improve safety through neighborhood and street design that emphasizes pedestrians, bicycling, and mass transport, and reduces speeds and unnecessary use of vehicles" (WRI, 2015).

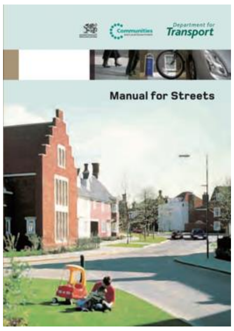
The fourth edition of Transport for London's (TfL) *Streetscape Guidance* was released in 2019. The purpose of *Streetscape Guidance*, which forms part of a larger *Streets Toolkit*, is to "set a high standard for the design of London's streets and spaces by applying best practice design principles" (TfL, 2019).



The *Design Manual for Roads and Bridges* (DMRB) contains information about current standards relating to the design, assessment and operation of motorways and all-purpose trunk roads in the United Kingdom.

CD143 Designing for walking, cycling and horse-riding provides requirements and advice for the design of walking, cycling and horse-riding facilities on and/or adjacent to the motorway and all-purpose trunk road network.

CD195 Designing for cycling traffic sets out the Highways England specific requirements for cycle traffic on the trunk road and motorway network. It is intended to be used by highway design professionals to facilitate the convenient and safe movement of cycle traffic, where cycling is legally permitted.

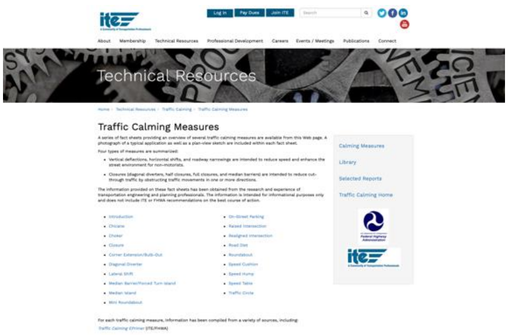


Manual for Streets was produced in 2007 by a team led by consultants WSP, with Llewelyn Davies Yeang, Phil Jones Associates and TRL Limited on behalf of the Department for Transport, and Communities and Local Government to provide design guidance to enhance low volume residential streets.[3]

[3] In 2010, CIHT published *Manual for Streets 2* specific to high volume trunk roads. Both manuals remain current. For infrastructure relating to pedestrian and bicyclist infrastructure, the latter references the 2007 publication.

Chartered Institution of Highways & Transportation's (CIHT) publication, *Designing for Walking*, was released in 2015. The guide explains how facilities for walking should be designed by setting out the design considerations that affect the quality of the walking environment. It is recommended that this document is read in conjunction with Section 6.3 of *Manual for Streets* (DfT & CLG, 2007).

The UK Government Department of Transport's *Local Transport Note 1/20 Cycle Infrastructure Design* and *Local Transport Note 1/07 Traffic Calming* were both included in this review.



Institute of Transport Engineers' (ITE) Technical Resources on Traffic Calming Measures website includes a set of factsheets based on the from the research and experience of transportation engineering and planning professionals, including [Traffic Calming EPrimer] (ITE/FHWA)

A number of other publications were reviewed for specific countermeasures and treatment types. These are included in the list of references at the end of the document.

What are Safer Road Investment Plans?

A Safer Road Investment Plan (SRIP) is a prioritised list of countermeasures (safety treatments) that can cost-effectively improve Star Ratings and reduce infrastructure-related risk. Currently, there are a total of 94 countermeasures which are included in the iRAP model.

For each countermeasure, there is up to two 'outcomes.' This refers to the road attribute code that is applied at the 100-metre segment of road when the countermeasure is applied. For example, where a tree is recorded as the roadside hazard, the countermeasure outcome would be the installation of a safety barrier.

Countermeasures may be triggered when a combination of attributes are present. Different countermeasures may be triggered for urban and rural areas.

Countermeasures for crash types

Infrastructure-related risk is measured in the iRAP model in terms of crash types. Overall, there are 12 crash types used in the model.[4] This review will focus on countermeasures for crash types relating to bicyclists and pedestrians, and specifically, and those measures that can reduce the likelihood or severity of conflict with vehicles[5] as indicated in the red box.[6]

Figure 1 Crash types included in the Star Rating models

Vehicle occupants	Motorcyclists	Bicyclists	Pedestrians
• Run-off road • Head-on • Intersections and access points	• Run-off road • Head-on • Intersections and access points • Moving along the road	• Travelling along road • Intersections • Run-off road	• Walking along road • Crossing road

There are currently 94 countermeasures applied in the iRAP models.[7]

The current countermeasures which relate to the crash types focussed on in this review[8] are:

I. Bicycle lanes (on road and off road)

II. Pedestrian crossing facilities

  A. Grade separated pedestrian facility (inspected road/side road)

  B. Signalised crossing (inspected road/side road)

  C. Unsignalised raised crossing (inspected road/side road)

  D. School zone - crossing guard or supervisor

  E. Unsignalised crossing (inspected road/side road)

  F. Refuge Island

[4] See *iRAP Methodology Factsheet 4 Crash Types*, available at www.irap.org/methodology

[5] Note that the iRAP model also includes bicyclist run-off crash (i.e. not involving vehicles). This crash type only involves threats which are posed by roadside hazards recorded, and not the threat of the road lane itself. It would apply, for example, where a cliff is recorded as the roadside hazard. However, countermeasures for this crash type are not considered a priority for this review.

[6] Note that the iRAP model also includes bicyclist run-off crash (i.e. not involving vehicles). This crash type only involves threats which are posed by roadside hazards recorded, and not the threat of the road lane itself. It would apply, for example, where a cliff is recorded as the roadside hazard. However, countermeasures for this crash type are not considered a priority for this review.

[7] For the full list of countermeasures, please see *iRAP Methodology Factsheet 11 Countermeasures*, available at www.irap.org/methodology

[8] It is only possible for a SRIP to produce countermeasures which directly influence those crash types included in the model. Those infrastructure features which do not impact on the crash types within the models (e.g. tripping or surface hazards) and/or do not have a direct safety impact are not included in this review. However, this is not to say they are unimportant. Countermeasure implementation should take care to ensure good design principles are applied in a way that considers all aspects of street use and functions, from safety through to seasonal effects, water management, personal security and so on.

III. Upgrade pedestrian facility quality

IV. Footway provision driver/passenger side

   A. With physical barrier

   B. With non-physical separation >3m

   C. Footway provision adjacent to road

   D. Informal path >1m

V. Pedestrian fencing

VI. Street lighting (intersection/ped crossing/mid-block)

VII. Sight distance (obstruction removal)

VIII. School zone warning

   A. Flashing beacons

   B. Signs and markings

Countermeasures are ‘applied’ per 100m road segment. Which countermeasure is applied depends in part on what conditions are present to ‘trigger’ that countermeasure. The triggers are often a function of one or more of:

- Road attribute, such if a pedestrian crossing were to be recorded as being ‘not present’
- Star Rating, which are based on a Star Rating Score (SRS)
- Vehicle (or road user) flow.

The triggers help to ensure that the countermeasure recommendations align with established engineering practice and are logical.

Minimum length, minimum spacing and hierarchy rules

Countermeasures are also subject to some minimum length, minimum spacing and hierarchy rules. These help to ensure that the countermeasure recommendations are practical. An example of a minimum length rule is:

Examples of minimum spacing rules are:

- Grade-separated pedestrian crossings must be at least one kilometre apart
- New signalised pedestrian crossings (non-intersection facilities) must be at least 600 metres apart.

3. REVIEW OF COUNTERMEASURES

This review focuses on countermeasures for crash types relating to bicyclists and pedestrians, and specifically, and those measures that can reduce the likelihood or severity of conflict with vehicles[9]. These include:

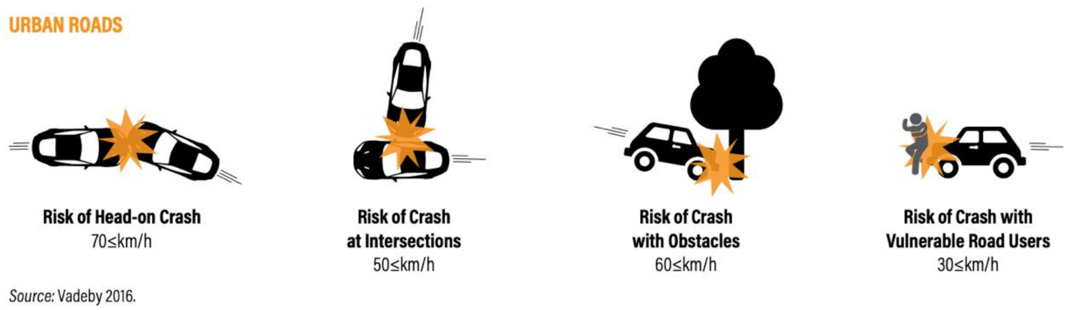
- Measures which reduce the severity of all types of vehicle-bicycle and vehicle-pedestrian crashes – namely speed reduction and traffic calming
- Measures to reduce mixed traffic conflict, such as footways, bicycle facilities and shared zones
- Measures to reduce vehicles deviating into the path of pedestrians (i.e. footway) and/or bicyclists (i.e. shared path, bike lane or path), and measures to prevent vehicles obstructing pedestrian and bicyclist facilities and crossings
- Measures to reduce conflict at intersections, vehicle access points and pedestrian and bicyclist crossings.

Speed reduction measures

Speed reduction is critical for the safety of vulnerable road users (Rosen and Sander, 2009). The 2020 UN Stockholm Declaration focuses on speed management, including 30 km/h (20mph) speed limits where vulnerable road users and vehicles mix.[10]

Speed limits are of themselves a speed reduction measure, even if not all drivers obey them (WRI, 2019). Appropriate speed limits should reflect what is 'safe' (the point before which FSI injury risk substantially increases) within the road environment and for the road users present.

Figure 2 Speed at which FSI risk substantially increases for different crash types[11]



[9] Note that the iRAP model also includes bicyclist run-off crash (i.e. not involving vehicles). This crash type only involves threats which are posed by roadside hazards recorded, and not the threat of the road lane itself. It would apply, for example, where a cliff is recorded as the roadside hazard. However, countermeasures for this crash type are not considered a priority for this review.

[10] https://www.roadsafetysweden.com/contentassets/b37f0951c837443eb9661668d5be439e/stockholm-declaration-english.pdf

[11] Image from WRI, 2019 using data from Vadeby, 2016.

For example, roads with no dividing median which increases the likelihood of head-on crashes between vehicles should be no more than 70km/h. Roads with intersections which could result in side impact crashes or where there are poles and trees beside the road (which could result in single vehicle crashes) should have limits of no more than 50km/h and 60km/h respectively. Roads where pedestrians, bicyclists and other vulnerable road users are present should be no more than 30km/h (WRI, 2019).

Speed limits must not only be safe, but also credible—that is, drivers are likely to adhere to the posted limit. It is well understood speed limits and enforcement are only part of the solution, and that the design of the road should reinforce safe speeds (NACTO-GDCI, 2016). Traffic calming measures, which alter physical features of the road, are designed to reinforce safe vehicle speeds, increase driver awareness, reduce crashes and improve conditions for walking and cycling (WRI, 2018).

The term 'traffic calming' is also used to refer to network-level initiatives to reduce motor vehicle speeds and volumes in support of other modes, with objectives such as improving traffic safety, increasing liveability, and protecting the environment (Eriksson et al., 2003).

For the purposes of this review, only street level (engineering) traffic calming measures were reviewed as opposed to other strategies such as network structure.[12] However, it is noted that street level traffic calming measures are more effective when:

- Implemented as part of an area-wide approach (Eriksson et al., 2003; Bellefleur & Gagnon, 2011), that is, measures are applied across a network of streets rather than just a few corridors or sections of the roadway.
- Spaced at intervals which encourage consistently low speeds rather than enabling vehicles to accelerate between traffic calming features. The *Manual for Streets* (2007) says that evidence from traffic-calming schemes suggests that speed-controlling features are required at intervals of no more than 70m in order to achieve speeds of 20 mph (~30km/h) or less, and therefore straight and uninterrupted links should be limited to around 70 m to help ensure that the arrangement has a natural traffic-calming effect (DfT & CLG, 2007).
- Traffic calming is inherent to the road designs, as exemplified by the NACTO-GDCI Global Street Design Guide renderings, and similar to other design principles such as pedestrian accessibility. The *Manual for Streets* (2007) says that, "ideally, designers should aim to create streets that control vehicle speeds naturally rather than having to rely on unsympathetic traffic-calming measures" (DfT & CLG, 2007).

Further, effective traffic calming design uses a combination of measures. The example of traffic calming in a residential street below shows the combined application of measures. Combinations can also form their own 'category' of treatment, such as side road threshold treatments, entry treatments or home zones.

[12] Some area wide traffic calming measures, such as intersection closures and diverters, are covered in the section on Measures to reduce conflict at intersections, vehicle access points and pedestrian and bicyclist crossings.

Figure 3 Before and after combined application of engineering traffic calming measures on a residential street (Charlotte Street, Morice Town, UK)

In this example specifically, mean speed fell by 7.7 mph (approx. 12km/h) from 22.8 mph 'before' (approx. 37km/h) to 15.1 mph 'after' (approx. 24km/h). The 85th percentile speed fell by 9.2 mph (approx. 15km/h) from 28.5 mph 'before' (approx. 46km/h) to 19.3 mph 'after' (31km/h). Pictures: Before image from Wheeler (2005); after image by Adrian Trim, Morice Town Project Manager.

The engineering treatments reviewed include:

- Vertical traffic calming, such as speed humps, cushions and tables. These may be integrated with pedestrian crossings or with the intersection design
- Horizontal traffic calming, such as chicanes, chokers and roundabouts
- Reducing intersection size and curve radii
- Road diets
- Auditory, vibratory, and other coloured and/or textured surfaces
- Removing signs and lines
- Vehicle activated signs and speed cameras.

It should be noted that in almost all cases, traffic calming measures which use deflection (vertical or horizontal) are only appropriate for application on lower speed roads with a single lane of traffic (per direction) and must consider the implications for vehicle noise and emergency vehicle access.

Traffic calming for higher speed and multi-lane roads require a different set of tools. These may include:

- Road diets (reduction of number of lanes and lane width). A common application in the US is the reduction of a four-lane road (two lanes in each direction) to three lanes (one lane in each direction plus a continuous central turning lane) (ITE, 2018a).
- Spacing signalised intersections and roundabouts at intervals along a road to maintain a target speed. Note that timing of signals must be synchronised accordingly.

- Measures which reduce sight distance, increase peripheral vision flow and increase environmental complexity to reduce speeds (Elliot et al. 2003)[13] such as trees, on-street parking and locating buildings closer to the road, medians, pedestrian refuges, painted markings and others.
- Vehicle activated signs and speed cameras.

The UK's Local Transport Note for Traffic Calming describes appropriate measures for different speed zones. These are summarised in the table below.

Table 1 Summary of traffic calming measures for target speed in the UK (DfT, 2007)

TARGET SPEED	TRAFFIC CALMING MEASURES	OPTIMAL SPACING
20MPH (~30KM/H)	Entry treatments Vertical and horizontal deflection* Narrowings (3.5m or less)	60-70m apart
30MPH (~50KM/H)	Vertical and horizontal deflection* Vehicle activated signs and speed cameras Gateway treatment	60-90m
40MPH (~65KM/H)	No vertical deflection Vehicle activated signs and speed cameras Some horizontal deflection (build-outs, chicanes, pinch points, narrowings, islands, pedestrian refuges, gateways and roundabouts) and rumble devices. Signs and markings	<100m
ABOVE 40MPH (>65KM/H)	No vertical or horizontal deflection. it is recommended that chicanes or other measures with sudden kerb build-outs are not used. Vehicle activated signs and speed cameras Islands, pedestrian refuges, hatching, coloured surfaces and rumble devices.	

** Vertical and horizontal deflection design needs to correspond to the target speed.*

[13] The TRL report by Elliot et al. (2003) undertook a thorough study of road design measures which reduces speed using 'psychological' measures', which covers a significant number of features and specifics. Like many traffic calming features, it was stated that the effect is greatest when multiple features are present.

Vertical deflection

Speed humps

Speed humps are either a narrow or wide raised section which spans the traffic lane. They can be used on a range of streets, from residential and local streets through to arterial roads (WRI, 2015). Speed humps should be used at midblock locations (unless being incorporated as a raised pedestrian crossing). WRI (2018) warns against using speed humps where sight distance is limited or the road has a steep grade (presumably to reduce the risk of vehicles and motorcycles hitting a speed hump at speed).

The geometry of the speed hump determines the speed at which traffic can travel over it (WRI, 2015), so the type and geometry of the speed hump should correspond with the desired outcome speed. Speed humps should also be spaced at intervals to maintain desired speed (WRI, 2015). Gaps of 100m or more significantly increase average speeds (LTN, 2007).

Speed cushions

Speed cushions, which are narrow humps in the centre of the lane, are designed to reduce the speed of cars, but allow larger vehicles, such as buses and emergency vehicles, to pass unimpeded (WRI, 2015). Similar to speed humps, they can be designed for different speed outcomes (WRI, 2015). Speed cushions are usually a more cost-effective option but have been found to be just as effective as speed humps, with the exception of 2-wheel motorbikes (Berthod, 2011).

Speed tables

A speed table[14] is where the carriageway is raised to be level with the footway and removes the implicit priority of vehicles on street (DfT & CLG, 2007; WRI, 2015, CIHT, 2015).[15] These are recommended for low speed, high pedestrian flow areas (such as outside schools) or as a full raised speed table at intersections (DfT & CLG, 2007). Speed tables typically reduce midblock traffic speeds of up to 10 percent (ITE, 2018d).

Speed tables can be used as a ‘threshold treatment’ where small side streets intersect with main arterial roads to slow traffic entering exiting the main road, and prioritise pedestrian and bicyclist movements (WRI, 2015).

Effectiveness of vertical deflection

In the UK, vertical deflection measures are generally not used where traffic speeds are posted at 40mph (~65km/h) or above (LTN, 2007). However, a study into their effectiveness in reducing FSI crash outcomes found that vertical deflection was the most effective when compared to horizontal deflection/narrowing and speed cameras. The data were drawn from a study by Mountain, Hirst, &

[14] Otherwise referred to as ‘flush crossings’ when located at a pedestrian crossing location.

[15] See also shared zones for application of this measure

Maher (2005) of 149 traffic-calming interventions on roads with 48km/h (30 mph) speed limits located throughout England.

Figure 4 Comparison of the effectiveness of three types of calming measures[16]

Calming measures	Average speed {CI 95%}	Personal injury collisions {CI 95%}	Fatal and serious collisions {CI 95%}	Number of personal injury collisions avoided (collision/km/year) {CI 95%}
Vertical deflections	-13.5 km/h* {-16.6 to -10.5}	-44%* {-54 to -34}	-35%* {-54 to -18}	-1.00* {-1.4 to -0.6}
Horizontal deflections or narrowings	-5.3 km/h* {-7.1 to -3.7}	-29%* {-48 to -8}	-14% {-44 to +32}	-0.78* {-1.6 to -0.2}
Speed cameras	-6.6 km/h* {-7.6 to -5.5}	-22%* {-30 to -13}	-11% {-26 to +6}	-1.03* {-1.4 to -0.8}

Figure 5 Examples of speed reduction measures using vertical deflection

Example of speed bump installed on a local residential street in Detroit, US
Source: https://detroit.curbed.com/2019/11/1/20944179/speed-humps-detroit-residential-street-neighborhood

[16] Table from Bellefleur & Gagnon (2011) presenting data from Mountain, Hirst, & Maher (2005).

Example of speed cushion designed to allow large vehicles, such as emergency vehicles, to pass unimpeded
Source: https://nacto.org/publication/urban-street-design-guide/street-design-elements/vertical-speed-control-elements/speed-cushion/

Example of a speed table with pedestrian crossing
Source: Ciudad para Todos (https://twitter.com/lascondesaxesos/status/930548897952485377)

Horizontal deflection

Chicanes, choke points and mini roundabouts are generally recommended as a traffic calming measure for low speed, local streets. They are generally not recommended for higher speed corridors (LTN, 2007) and may not be appropriate for larger vehicles (such as buses or fire trucks) on some residential streets, although this may be addressed with the use of overrun areas. Both chicanes and choke points offer options for increased amenities for bicyclists and pedestrians, but mini-roundabouts less so.

Chicanes

Chicanes are artificial turns designed to reduce traffic speeds recommended for low volume, low speed roads (WRI, 2015; ITE, 2018e). They can be used on a range of streets, from residential and local streets through to arterial roads, and are often integrated with on-street parking design.

Choke points

Choke points effectively reduce a two-way street to a single lane where drivers yield to oncoming vehicles (or a wide street into a narrower two-way where no yield is necessary). It is often incorporated as part of a pedestrian crossing design. Choke points are only appropriate for low volume local streets and care should be taken to ensure that the design considers cyclists needs (WRI, 2015; CIHT, 2015). Traffic calming effect is more pronounced for one lane chokers compared to two lanes, but both result in reduced traffic speed of 14% and 4% respectively (ITE, 2018f).

False roundabouts

A 'false roundabout' is a central island with no side road connections (i.e. with only two arms). This can be used, where space is available, to give good deflection of motor vehicles and could be used as part of a gateway feature, or to break up long straight sections within a traffic calming scheme (DfT, 2007).

Figure 6 Examples of speed reduction measures using horizontal deflection

Example of chicanes used to slow traffic speeds along a cycling route
Source: https://ecf.com/news-and-events/news/cycle-friendly-traffic-calming-f3-cycle-highway

Example of choke point in Lincolnshire, UK
Source: Lincolnshire Live

Example of a 'false roundabout'
Source: https://safety.fhwa.dot.gov/speedmgt/ePrimer_modules/module3pt3.cfm

Horizontal deflection at intersections

Reducing curve radii and intersection realignment

Tightening kerb radii forces turning vehicles to reduce speed at intersections. The Global Street Design Guide (NACTO-GDCI, 2016) describe three types of treatments which can be used to achieve this:

- Corner alignments, which extends the footway corner to the tightest radius possible
- Kerb extensions (or 'bulb-outs') which are generally used to narrow the carriageway at the intersection so that the footway and crossing points are extended.[17] This is often incorporated into streets with on-street parking.
- Slip lane removal, which extends the footway to include the space occupied by the lane and the traffic island.

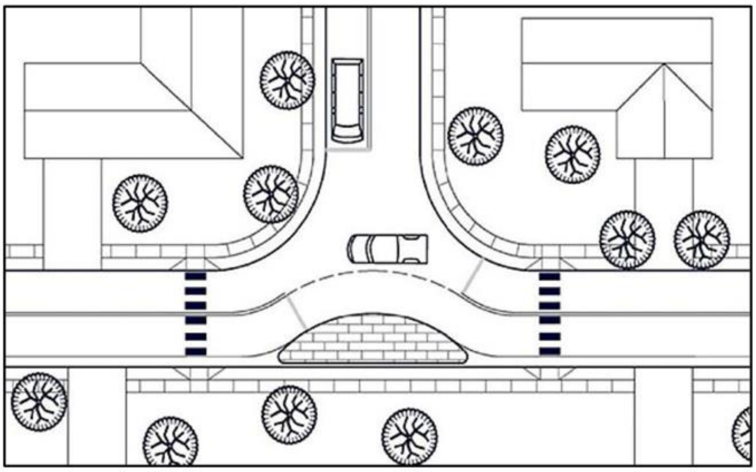
All three options have the added benefit of reducing crossing distance and exposure and improving visibility for pedestrians.[18]

Intersection realignment is where an intersection with perpendicular angles is reconfigured to skew approaches or travel paths through the intersection (ITE, 2018b). It is best used for T-intersections and appropriate for both collector or local streets, with or without on-street parking and bicycle facilities (ITE, 2018b).

[17] At a mid-block location, it is typically called a choke point

[18] See Refuge islands and footway extensions for more detail.

Figure 7 Example of intersection realignment[19]



(Source: Delaware Department of Transportation)

Roundabouts

In the UK, a roundabout is defined as having “a central islands with a diameter greater than 4 metres and between 3 and 7 arms. They may be used in both rural and urban areas, on single and dual carriageways, and may be signalised” (DfT, 2007)—although this is rare.

Roundabouts are known to reduce the frequency and severity of FSI outcomes, particularly for vehicle occupants, and are used in the iRAP model to improve intersection safety. However, how effective a roundabout is as a traffic calming measure relies on its dimensions and design. Roundabouts can create barriers for pedestrians (CIHT, 2015) and pose safety risk for both bicyclists and pedestrians.

WRI (2015) advises roundabouts to be used cautiously on roads used by bicyclists and with high pedestrian volumes.

Roundabouts are of particular risk to bicyclists (DfT, 2007).[20] Increased bicyclist crash risk is associated with the features and design of the roundabout, including presence of bicycle lanes, high vehicle speeds, multiple lanes and large size of roundabout and large curve radii of entry and exits (Høye, 2017). A Canadian study found a strong connection between higher bicyclist crash rates and small roundabouts on local streets (Harris et al. 2013).

ITE (2019) stipulates that bicycle facilities, if provided, must be separated from the circulatory roadway with physical barriers. If no facilities are present, then cyclists using the circulatory roadway must merge with vehicles (ITE, 2019).

[19] Picture: ITE (2018b) from Delaware Department of Transport.

[20] A study in Belgium following the conversion of intersections into roundabouts observed a significant 27% (overall) increase in the number of injury accidents involving bicyclists (41–46% increase in fatal and serious injury crashes, and +77% in urban areas) on or nearby the roundabouts (Daniels et al. 2008). The risk of roundabouts is also identified by Vandenbulcke et al. (2014) who found that bicycle lanes in roundabouts had more than double the number of crashes (+123%) than in bicycle lanes in light-regulated intersections.

CIHT advises that roundabouts are kept compact, with single lane entries and exits and use pedestrian crossings and speed tables to enhance pedestrian safety and access (CIHT, 2015). A study of roundabouts in Germany and the Netherlands[21] found that the designs with tighter geometry and narrow circulation reduced vehicle speed (DfT, 2007). Overrun areas used in combination with small roundabouts encourages greater deflection and reductions in speed whilst still allowing adequate space for large vehicles to pass through (DfT, 2007).

A study in Växjö[22] found a clear relationship between:

- Speed on the approach to a roundabout and the degree of deflection required to negotiate the roundabout (i.e. the bigger the deflection, the lower the speed) and
- Speed on the links between roundabouts and the distance between them (i.e. speed became lower as the distance between the roundabouts became shorter). The study also found that when the distance between the roundabouts exceeded 300 metres, there was no speed reduction on the link between (DfT, 2007).

New roundabout designs aim to improve safety for pedestrians and bicyclists which offset bicycle and pedestrian crossings from the entry and exits. See the diagram in Crossings at roundabouts.

Mini roundabout (or traffic circle)

Similar to chicanes, mini roundabouts introduce horizontal deflection at intersections which reduces traffic speed, increases intersection safety and minimise points of conflict (NACTO-GDCI, 2016) and can be installed on local streets.

In the UK, mini-roundabouts are recommended for use on urban single-carriageway roads where the speed limit is 30mph or less (DfT, 2007). They have central islands with a diameter up to 4 metres that are capable of being driven over by large vehicles (DfT, 2007).

Similar to conventional roundabouts, mini roundabouts should be used cautiously on roads used by bicyclists and with high pedestrian volumes (WRI, 2015). A Canadian study found a strong connection between higher bicyclist crash rates and small roundabouts on local streets (Harris et al. 2013).[23]

[21] Study by Morgan (1998) cited by DfT, 2007

[22] Study by Hyden et al. (1995) cited by DfT, 2007

[23] Harris et al. (2013) found that small roundabouts on local streets were 8x more likely to result in a vehicle-bicycle crash.

Figure 8 Example of a mini roundabout (or traffic circle) [24]

Road diets

Road diets may refer to either the reduction of the number of lanes and/or a reduction in lane width.

Reducing lane width is not by itself a proven traffic calming tool. A 2003 report by Parsons Transportation Group (PTG) found that there is no consensus in the literature on the relationship between lane width and speed because it was found to be impossible to isolate the effect of the lane width reduction from the other features of the road. Some studies showed speed reductions of approximately 5km/h per 30cm of lane narrowing, while other studies could only demonstrate much slighter or no effects on speeds (PTG, 2003).

Road diets are, by nature, a combination of measures. Former travel lane space is repurposed for a range of uses which may include dedicated bicycle facilities, left-turn lanes, on-street parking, raised medians, pedestrian refuge islands, footways (ITE, 2018a).

ITE (2018a) maintains that road diets are generally acceptable for nearly all roadway functional classifications, and can be applied in urban, suburban, or rural settings. Further, they are appropriate for most common urban speed limits and can be applied at/near intersections or along road segments (ITE, 2018a).

The UK's *Manual for Streets* (2007) advises that width be 2.75m for single lane traffic with vertical constraints (e.g. bollards) be no more than 3.5m apart, although it warns that widths between 2.75 m and 3.25 m could result in drivers trying to squeeze past cyclists (DfT & CLG, 2007).

Measures to provide the illusion of a narrow lane may also be effective. An overrun area often features road edges in a different colour and material (such cobblestones) to the main traffic lane. *Local Transport Note 1/07* describes overrun areas as visually narrowing the roadway while maintaining the effective width for larger vehicles (DfT, 2007). By integrating bicycle lanes, this treatment is commonly used in The Netherlands for regional and local access roads.

[24] Photo from http://www.thorprint.co.uk

Figure 9 Example of a two-way local access road in The Netherlands, which uses bicycle lanes to visually reduce the width of the road [25]

A study of the impact of 15 road diets in the United States, using the Empirical Bayes Method (23 years of data) and a "before-after" design with control sites (10 years of data), concluded that road diets can be used to reduce the number of collisions, injuries and deaths, but the authors do not indicate whether these reductions are statistically significant (Bellefleur & Gagnon, 2011).

Figure 10 Effectiveness of road diets [26]

Calming measure	Method of evaluation	Collisions per kilometre (collision density)	Collision rates (controlled for variations in volume)	Total personal injury collisions	Minor injury collisions	Fatal and serious collisions
Road diet	Bayes	-25%	-19%	-	-	-
	"Before-after" with control sites	-29%	-21%	-34%	-30%	-11%

Note: No statistical significance test mentioned.

Auditory/vibratory road surfaces

Auditory/vibratory road surface examples found in the reviewed documents (e.g. the DfT (2007) *Local Transport Note 1/07*) tend to be those employed on rural roads, and which are discouraged for use in urban areas due to the heightened road noise for surrounding residences (Bellefleur & Gagnon, 2011).

Despite this, such surfaces are used widely around the world as an integral part of traffic calmed streets in residential areas and in designs for low speed and shared zones. Research for the UK *Manual*

[25] Photo from https://www.wikiwand.com/en/Roads_in_the_Netherlands

[26] Table from Bellefleur & Gagnon (2011) presenting data from Stout, Pawlovich, Souleyrette, & Carriquiry (2006).

for Streets showed that block paving reduces traffic speeds by between 2.5 and 4.5 mph (around 4 to 7.2km/h), compared with speeds on asphalt surfaces (DfT & CLG, 2007).

DfT (2007) cites several studies which showed that block paved areas in the UK reduced operating speeds of 2-7 mph (3-11km/h) to below 20 mph (~30km/h), and a reduction in serious injury crashes. This surface treatment may also provide additional benefits due to:

- Changing the look and feel of the road which reinforce to drives that it is a 'cars as guests' area (WRI, 2015).
- The additional noise produced by the surface may be beneficial to other road users who are then more aware of the vehicle approaching.

Figure 11 Example of cobblestones being used to reduce traffic speed in Philadelphia, US [27]

Removing signs and lines

The removal of lines and signs on roads has been shown to reduce driver operating speeds (Elliot et al., 2003). The approach, sometimes referred to as 'naked streets', was pioneered by Hans Monderman, a Dutch road engineer, in the 1970s and has been applied in places around the world. The basic premise was to replace the typical features of the street with which "creates a higher level of perceived risk of accident, and corresponding increase in risk-mitigation behaviour" (Thomas, 2014).

Village trials in the UK have found that speeds were reduced during the trial but returned to their previous level when the signs and markings were reinstated. Trials in London across three sites showed a statistically significant reduction in traffic speed (TfL, 2019).

[27] Image from https://www.mdpi.com/1660-4601/16/19/3704/htm

Figure 12 Example of traffic calming a shared street in Brighton, UK through the removal of road signs and lines [28]

Vehicle activated signs and speed cameras

A study into vehicle activated signs and speed indicators, devices are used to remind drivers that they are exceeding the speed limit on a particular road segment, found that both types of signs have variable effects on traffic of speed on a given road segment (Jomaa, 2017). Speed indicator devices were relatively more effective than vehicle activated signs on local roads but not on highways (Jomaa, 2017). In the UK, speed limit repeater signs have been found to reduce mean speeds of traffic by up to 15 km/h, but were more effective when the speed limit was also reduced (DfT, 2007).

Figure 13 Example of variable speed limit sign [29]

[28] Image from https://davisla.wordpress.com/2014/01/16/new-road-brighton-shared-space/

[29] Image from http://www.vmstech.co.uk/vas.htm

Speed cameras (fixed, mobile or speed-over-distance) are subject to routine review in the UK, which has found:

- 32% reduction in drivers breaking the speed limit
- 40% reduction in the number of FSI at camera sites, and
- within this overall reduction, a 35% reduction in pedestrian FSIs (DfT, 2007).

Data which compares speed cameras with other traffic calming measures found that speed camera were similarly effective to horizontal deflection, but less effective than vertical deflection (see Effectiveness of vertical deflection).

How effective vehicle activated signs are over the long-term in reducing traffic speeds is unclear.

Combined treatments

Application of these measures were found to be particular to road function and area type and desired speed outcome. They can be applied in certain configurations to support speed limit compliance and area-wide traffic calming.

Gateways and entry treatments, for example, are used in places where vehicle drivers need to significantly lower their speed (e.g. upon entering a town or residential area). They can utilise a range of the engineering treatments discussed here, such as surface treatments (paint, rumble surface, speed humps etc) and horizontal treatments (such as pinch points or chicanes) (LTN, 2007). High impact signs and road markings may be an option if used repeatedly but are unlikely to achieve 85th percentile speeds below the posted speed limit (LTN, 2007).

Side road entry treatments are where the footway is effectively continued across the entries to small, intersecting side roads (similar to raised crossings but maintaining the look and feel of the footway). These treatments are used to emphasise pedestrian priority and indicate an entry to a low speed zone (TfL, 2019). TfL's *Streetscape Guidance* (2019) recommends the following features be used to create a sideroad entry treatment:

- Materials (e.g. paving stone) which indicates pedestrian presence and priority to drivers
- The carriageway is raised to the level of the footway
- Crossing distance is minimised
- There is a change in surface and/or vertical deflection before the intersection
- Kerb build-outs to increase pedestrian visibility and prevent vehicle parking, and
- Signage to indicate the start of a low speed zone.

This treatment is not recommended for high speed roads as turning vehicles must be able to reduce speed sufficiently (TfL, 2019).

Figure 14 Example of a gateway treatment in the village of Poynton, UK [30]

Measures to reduce mixed traffic conflict

In urban areas, streets perform a variety of functions. Further to speed reduction and traffic calming, measures to reduce conflict between road users are used depending on the environment. These include:

- Pedestrian and bicyclist-only streets
- Shared zones
- Footways and shared paths
- Bicycle lanes and paths

During the COVID epidemic in 2020, such measures were implemented widely on an emergency basis in response to the rapid changes in mobility, predominantly the reduction in the use of transit and the increase in walking and cycling.

[30] Image from http://www.poyntonweb.co.uk/visitors-centre/picture-gallery/

Pedestrian and bicyclist-only streets

Converting streets to pedestrian-only streets may be appropriate where there are very high levels of pedestrian activity (NACTO-GDCI, 2016).

The *Global Street Design Guide* recommends them for relatively short expanses ('only for a few blocks') and where types of businesses and land use supports it (NACTO-GDCI, 2016). It also notes that bicyclists should be encouraged to dismount and walk bicycles. A study in Norway showed that installing bicycle facilities on pedestrian-only streets can result in high number of bicycle-pedestrian conflicts (Bjornskau et al., 2017).

Pedestrian only streets may also be installed on a temporal basis (during set hours) using removable bollards and diverters. For streets with lower pedestrian volumes, shared street design should be considered (NACTO-GDCI, 2016).

Bicyclist-only streets, on the other hand, can be used as an area traffic calming to reduce through traffic and to encourage more cycling. Bicyclist-only streets and off-road bicycle paths are considered to be one of the safest options, however, separate facilities should be provided for pedestrians to reduce bicycle-pedestrian conflict (WRI, 2015).

Figure 15 Before and after a pedestrian and bicyclist-only street conversion in Milan[31]

Before After

Shared streets

Shared streets or zones are where the separation of footways and the carriageway is absent and pedestrians, bicyclists and vehicles share the same space (DfT & CLG, 2007). The UK *Manual for Streets* (2007) advises that shared surface schemes work best in relatively calm traffic environments, over short lengths or where streets form cul-de-sacs, where the volume of motor traffic is below 100 vehicles per hour during peak times and where parking is controlled, or it takes place in designated areas (DfT & CLG, 2007).

[31] Photos from Comune di Milano and Agenzia Mobilita Ambiente Territorio's (2020) *2020 Adaptation strategy: Open Streets Strategies, Actions and Tools for Cycling and Walking*, a guidance document for COVID response.

Figure 16 Example of a shared neighbourhood commercial street in the UK which caters well for bicyclists (DfT, 2020)

The modern concept of the shared street was pioneered by the Dutch in the 1960s in a move to reduce the volume and speed of traffic through local residential streets. The term 'woonerf' (or 'living street') were reconfigured so that typically, they were one-way streets with 15km/h speed limits.

Collarte (2012) provides the following description:

> *In a woonerf, the street is shared among pedestrians, bicyclists, and motor vehicles; however, pedestrians have priority over cars. The street is designed without a clear division between pedestrian and auto space (i.e., no continuous kerb), so motorists are forced to slow down and travel with caution. Limiting vehicular speed not only improves residents' feelings of safety, but also promotes greater use of the public space. This action allows more room for new features in the street such as street furniture (e.g., planters, street trees, benches) and areas for social interaction, bringing more people out on the streets to walk, bike, play, and interact with each other. In other words, a woonerf transforms the street into a liveable and attractive environment for a variety of activities.*

Figure 17 Example of a Woonerf[32] ('living street') in The Netherlands.

Studies of crash data in The Netherlands showed that converting streets into woonerven reduces crashes by approximately 50% (WRI, 2015[33]).

Shared surface streets are often constructed from block pavement rather than asphalt, which helps emphasise their difference from conventional streets and emphasised pedestrian priority (NACTO-GDCI, 2016) and has traffic calming effect (see Auditory/vibratory road surfaces). Speed must be low for the area to function effectively for pedestrians (DfT & CLG, 2007).

The NACTO-GDCI *Global Street Design Guide* (2016) recommends the following features and measures be applied in the shared street design to ensure the safety and access of its users:

- Speed limit of 10km/h (~6km/h)
- Surfaces which reinforce pedestrian priority
- Tactile or auditory warning strips at all entrances
- Clear path for vehicles (which may be marked with a different pavement pattern or colour)
- Street furniture to delineate the travel lane from pedestrian only areas
- Signage to educate the public on how to use the street (particularly in the early stages of conversion)
- Street lighting.

Shared bicycle streets (sometimes referred to as 'bicycle boulevards')[34] are low speed and low volume shared streets optimised for bicycle travel through the use of traffic calming, vehicle reduction and redirection, signage, pavement markings and intersection crossing treatments (WRI, 2015). In the

[32] Photo: http://www.youthforroadsafety.org/news-blog/news-blog-item/t/the_dutch_woonerf_an_example_of_safe_road_spaces

[33] Citing studies by Kraay and Bakker (1984) and Wegman (1993).

[34] See also Bicycle lanes and paths

Netherlands, a bicycle street (or 'fietstraat') operates on the principle that cars are guests (and therefore bicyclists have right of way). Fietstraats are common for small access streets where very low traffic volumes are expected.

The Dutch CROW Manual defines a fietstraat as a high-quality cycling route on an access road with no more than 500 cars per day and speed of 30km/h or less (CROW, 2007).

Figure 18 Example of a 'fietstraat' (bicycle street or bicycle boulevard) in The Netherlands[35]

Footways

Footways (also referred to as 'sidewalks' and 'footpaths') are critical for pedestrian safety and provide a dedicated space for pedestrian movements which are particularly important for children, elderly and the vision impaired. Footways are more than simply being a place to walk—poor quality, crowded and obstructed footways lead to people walking on the road.

Footway width is a key focus of many of the documents reviewed.[36] The UK's Manual for Streets specifies a minimum width of 2m and no maximum width (DfT & CLG, 2007). WRI's Safer Cities by Design (2015) specify the need to cater for pedestrian volumes. Footways should be at least 2.5m for areas with higher ped volumes with additional space for frontage zones and street furniture zones and be on both sides of the street (WRI, 2015).

NACTO-GDCI's Global Street Design Guide (2016) recommends:

- Low density quiet streets (low pedestrian volumes) have a clear path of 2m – 2.4m with a buffer 0.6m – 1.5m
- Neighbourhood main streets (moderate pedestrian volumes) have a clear path of 2.4m – 3m with approximately 3m of additional space for commercial activities, street furnishings and trees/garden beds, and
- Commercial streets (high pedestrian volumes) have a clear path of 3m – 4.2m with an additional 3m of frontage zone and 1.8m buffer zone.

[35] Picture from: https://aseasyasridingabike.wordpress.com/2013/06/12/dont-misunderstand-the-fietsstraat/. Note how this fietstraat is designed to look and feel like a street for bicycles without the use of signs, lines and aggressive traffic calming.

[36] Footway width is not a measure included in a Star Rating Assessment. However, it has been included here so that this countermeasure may be able to be applied to current attributes or be included in future.

The UK's *Design Manual for Roads and Bridges* (HE, 2020a) makes similar provision, but specifies that additional width is required if vertical features are located directly beside the path, and where a path is a shared path of over 200 users per hour (CD143, 2020, E/1-E/3). It also addresses headroom and design speed.

Shared paths (i.e. open to both bicyclists and pedestrians) are considered an option of 'last resort' given the higher likelihood of bicycle-pedestrian crashes (DfT, 2020).

Table 2 Footway dimensions according to the *Design Manual for Roads and Bridges* (CD 143)

<table>
<tr><th></th><th>Desirable width (min width)</th><th>Headroom</th><th>Design speed</th><th>Distance from carriageway</th></tr>
<tr><td>Footways</td><td>2.6m (2m) +0.25m/0.5m if vertical feature <1.2m/>1.2m present beside path</td><td rowspan="2">2.3m for paths up to 23m long
2.6m for paths over 23m long</td><td rowspan="2">30km/h with no sharp curves</td><td rowspan="2">0.5m for roads with speed limit of 40mph (~65km/h) or less
1.5m for speed limit of >40mph (~65km/h)
1.8m where horses are present</td></tr>
<tr><td>Shared paths (unsegregated)</td><td>Min width same as footways if <200 users per hour
Min 3m >200 users per hour</td></tr>
</table>

Bicycle lanes and paths

The definition of bicycle lanes and paths vary somewhat around the world. NACTO-GDCI's (2016) categories roughly equate to those used in the iRAP model and other guides. They are:

- Cycle lanes: Bicycle lanes on the roadway defined by lines, signs and other markings
- Cycle tracks: Off-road bicycle paths or those physically separated from traffic
- Cycle streets: Shared streets with no segregation between vehicles and bicycles.

As a general principle, the UK's *Manual for Streets* recommends that bicyclists generally be accommodated on the carriageway (of residential streets), and that for low traffic volumes and speeds, there should not be any need for dedicated cycle lanes (DfT & CLG, 2007). This fits with the NACTO-GDCI definition of a 'cycle street', however their *Designing Streets for Kids* manual (2020) is more specific, namely that such streets should meet the following criteria:

- have traffic speeds of below 30km/h (with traffic calming and diverters present if needed)
- be no more than a single lane in each direction
- have fewer than 2,000 vehicles per day (vpd) and less than 100 per hour during peak times
- bicyclist right of way at most intersections, and
- very low or intentionally limited large/heavy vehicle traffic.

Cycle streets can be enhanced through the use of filtering, where vehicle access on a street is intercepted, but which allows free passage of pedestrians and bicyclists. The example below shows filtering on a local street in Hackney, UK.

Figure 19 Example of 'filtering' on a residential street in Hackney, UK (DfT, 2020)

Cycle tracks are recommended for road of over 6,000 vpd, traffic speed over 30km/h and/or multiple lanes (NACTO-GDCI, 2020). The UK *Local Transport Note 1/20* recommends the size of separation between cycle tracks and the driven lane based on traffic speed, as shown in the following table.

Figure 20 Minimum recommended horizontal separation between carriageway and cycle tracks* (Table 6-1, DFT, 2020)

Speed limit (mph)	Desirable minimum horizontal separation (m)	Absolute minimum horizontal separation (m)
30	0.5	0
40	1.0	0.5
50	2.0	1.5
60	2.5	2.0
70	3.5	3.0

*Separation strip should be at least 0.5m alongside kerbside parking and 1.5m where wheelchair access is required.

Cycle lanes are considered generally appropriate for roads with traffic speeds of 40km/h or less, however, should be provided with adequate with and buffer to provide additional space between vehicle traffic and/or parked cars (NACTO-GDCI, 2016).

Other general design features recommended for accommodating bicyclists include (DfT & CLG, 2007):

- Maintaining links for bicyclists between street networks which are not open to vehicles
- Direct, barrier free routes with smooth surfaces and which do not require bicyclist to dismount
- Routes that follow bicyclist desire lines and that provide right of way over side road traffic[37]

[37] It is noted that anecdotal evidence suggests that cyclists using cycle tracks running adjacent and parallel to a main road are particularly vulnerable when they cross the mouths of side roads and that, overall, these routes can be more hazardous to cyclists than the equivalent on-road route (DfT & CLG, 2007).

- Reducing the speed and volume of streets to make on street cycling more satisfactory
- Reducing traffic speeds at junctions (via traffic calming measures such as reducing corner radii and vertical deflections).

For cycle tracks, the *Manual for Streets* (DfT & CLG, 2007) recommends that

- Geometry and visibility should be in accordance with the appropriate design speed (30km/h except for short distances where bicyclists need to slow down) and 40km/h for downhill gradients (DfT, 2020)
- They should be physically segregated from footways, but that a combined width of about 3.3m or more is required.
- Measures should be taken to prevent lanes and tracks from being blocked by vehicles.

Facility width

Recommended width of all the bicycle facilities is generally 1.8m – 2m per direction, but with an additional 1m buffer between it and any traffic lanes and/or parked vehicles (NACTO-GDCI, 2016). However, the safe width of paths is highly dependent on the volume of bicycle traffic and the speeds and types of vehicles being used.[38] The UK Local Transport Note 1/20 (Cycle Infrastructure Design) says that cyclists travelling side by side (on a level surface) require a minimum space of 1.0m each plus 0.5m separation between them and that additional width is required to negotiate uneven surfaces and drainage gulleys and if there are vertical features beside the path (DfT, 2020). Wider paths also allow faster bicyclists (e.g. mopeds and e-bikes) to pass other bicyclists safely.

Many places now have a vast array of light mobility vehicle types which vary in mass and speed. Research on safe widths for light vehicle mix and volumes is still emerging. Two studies in the Netherlands in 2012 found that paths over 2m (per direction) in width had fewer crashes (Hair-Buijssen & van der Horst, 2012; Goede et al., 2012), however, the studies did not discuss the speed and volume of the users by vehicle type.

Headroom

Guidance on headroom is comparable to that of footways and shared paths. Signs should be a minimum of 2.3m above cycle paths and headroom for underpasses and subways should be at least 2.4m and increased to at least 2.7m where it is longer than 23.0m (DfT, 2020).

Side hazards

Unguarded hazards (e.g. fixed objects, steep drops or water hazards), should not be permitted within 4.5m of a cycling route or where it could potentially be in the path of an out of control bicyclist (DfT, 2020).

[38] Similar to footways, bicycle facility width is not a measure included in a Star Rating Assessment. However, it has been included here so that this countermeasure may be able to be applied to current attributes or be included in future.

Coloured surfaces

Coloured surfaces for cycle facilities are used widely around the world, but evidence of their safety benefit is mixed (Høye, 2017). According to the UK Local Transport Note 1/20 (DfT, 2020), coloured surfacing can be useful for:

- Emphasising cycle lane markings and to help remind motorists that the surface is either primarily or exclusively for the use of cyclists
- Helping cyclists to follow a route or position themselves in the appropriate part of a carriageway
- Reminding pedestrians and motorists to look out for cyclists at conflict points
- Helping cyclists to follow a route or position themselves in the carriageway.

Coloured surfacing may be useful on a cycle lanes across the mouth of junctions; routes through complex junctions; cycle lanes alongside on-street car parking (in addition to the buffer strip); and advanced stop line reservoirs and their feeder lanes, particularly central feeders (or 'pocket lanes') (DfT, 2020).

Vehicle run-off prevention measures

Vehicle run-off prevention measures are an important measure to prevent vehicle run off crashes which may endanger pedestrians and bicyclists. However, conventional vehicle barriers, such as concrete, metal and wire rope barriers are not typically appropriate in the urban context, particularly where pedestrians and bicyclists are present.

Physical speed reduction measures, such as vertical or horizontal deflection, will reduce the risk of vehicles gaining enough speed with the potential of 'run-off' crashes. This allows for greater use of 'buffers' (e.g. wider footways, footway buffers using street furniture and garden beds, paved shoulders or hatching between bicycle lanes and traffic lanes)[39], hard strip and smaller and lighter vertical features (DfT, 2007).

Control barriers and bollards

Control barriers and bollards are design to prevent vehicles (sometimes including motorcycles and bicycles) from entering a walkway or laneway. They may be particularly useful in maintaining footways and pedestrian crossings clear of vehicles and protect pedestrians from vehicle run-offs (especially in areas where there are high pedestrian volumes) and can be used in conjunction with street furniture and planter boxes (NACTO-GDCI, 2016).

However, some designs, particularly those designed to prevent motorcycle and bicycle access, also exclude others, such as parents with pushchairs and people in wheelchairs (CIHT, 2015). They may also reduce visibility of pedestrians (particularly children) when viewed at an angle and reduce the usable footway width (CIHT, 2015).

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[39] See Footways

CIHT (2015) recommend that control barriers are not used (or designed) to prevent motorcycle and bicycle access in order to maintain access for all pedestrians.

Crash barriers

Crash barriers are recommended to separate pedestrian and bicyclists from vehicles where vehicle speeds are in excess of 80km/h (50mph) (DfT, 2020).

Measures to reduce conflict at intersections and crossings

Intersection layout reconfiguration

Reconfiguring intersections can reduce traffic speeds, reduce flows (i.e. as an ‘area wide’ traffic calming measure) and reduce the number of conflict points at an intersection. Common measures covered elsewhere in this document include reducing traffic speed at intersections through the use of roundabouts and mini roundabouts, and by reducing curve radii.

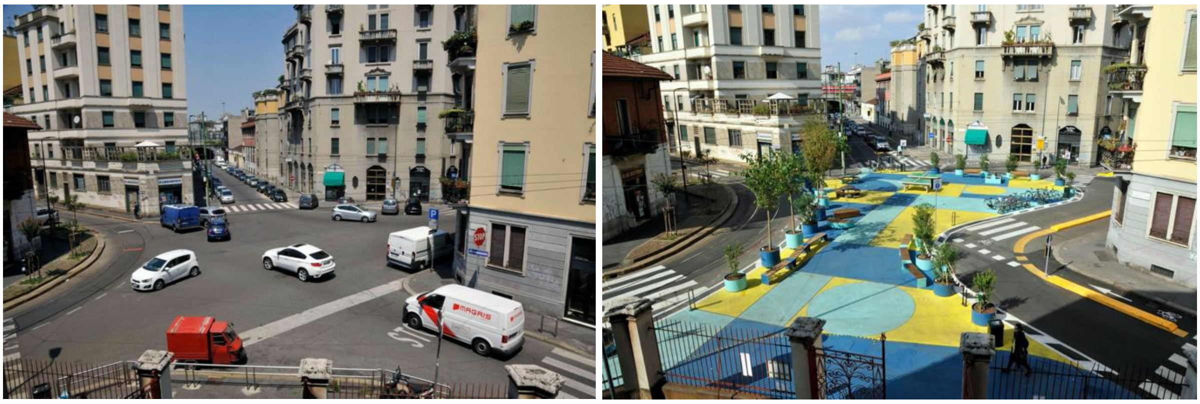
A study on vehicle-bicycle crashes found that non-orthogonal intersections had higher severity outcomes, which is thought to be a factor of higher speed of vehicles passing through the intersection (Asgarzadeh et al. 2017). The NACTO-GDCI *Global Street Design Guide* recommends that intersections be minimised through the use of kerb extensions, plazas and medians and to ‘bend streets so that they meet as close to a 90 degree angle as possible (NACTO-GDCI, 2016).

Intersection diverters

Intersection diverters are used to prevent certain turning movements at intersections for vehicles. Barriers may consist of landscaped islands, mountable features, walls, gates, side-by-side bollards, or any other obstruction that leave an opening smaller than the width of a passenger car (ITE, 2018g). Diverters should be designed to only divert large vehicles and should allow for bicycle and pedestrian access through the diverter.

- Diagonal diverters: Barriers placed diagonally across four-legged intersections, blocking through movements (sometimes referred to ‘full diverters’ or ‘diagonal road closures’) which are often used in sets to make travel through neighbourhoods more circuitous for vehicles (ITE, 2018g). Diagonal diverters allow pedestrians and bicyclists to pass directly through (as shown in the example below).

Figure 21 Before and after example of a tactical urbanism project using a diagonal diverter at a 5-way intersection in Milan, Italy[40]

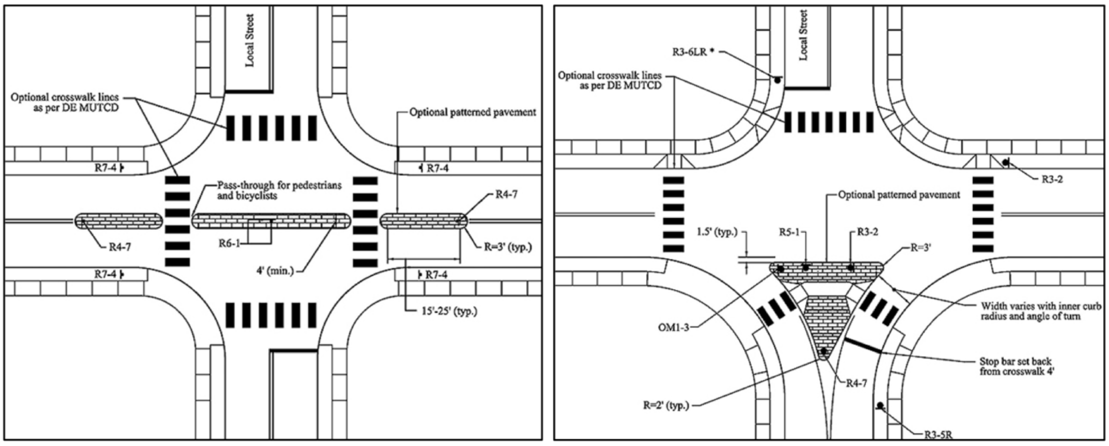


- Intersection median barriers: Physical barriers or raised islands along the centreline of a street to block cross street flow and right-hand turns (for left hand drive roads/left hand turns (on right hand drive roads) (ITE, 2018g).
- Forced turn islands: Raised islands that forces vehicles entering from a side road to turn onto the main road (and thus prevents the driver from crossing the road to enter an opposite side road (ITE, 2018g).

Intersection closures

- Half closures: Barriers that block travel in one direction (creates a one-way street) for a short distance on otherwise two-way streets (ITE, 2018i).
- Full-street closures are barriers placed across a street to completely close the street to through-traffic, usually leaving open space for pedestrians and bicyclists (ITE, 2018i).

Figure 22 Diagrams showing an example of an intersection median barrier and forced turn island[41]



[40] Comune di Milano and Agenzia Mobilita Ambiente Territorio. (2020).

[41] Picture: ITE (2018g) from Delaware Department of Transport.

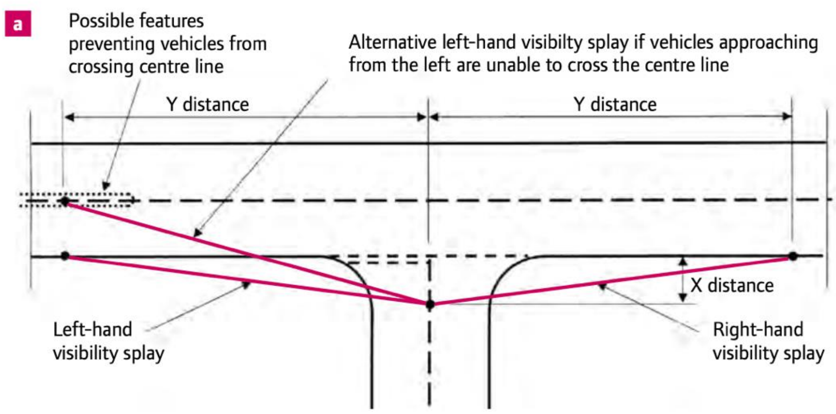
Figure 23 Example of a full intersection closure designed to allow free passage by bicyclists and pedestrians (DfT, 2020)

Visibility and sight distance

Visibility and sight distance determine how likely one road user is likely to be able to see, and stop for, an obstacle (or other road user) on the road or at an intersection. Road engineering geometry requirements tend to focus on the perspective of vehicle drivers of other vehicles, which can lead to designs which are conducive to higher speeds (DfT & CLG, 2007[42]), and may in fact reduce drivers' ability to 'see' (and respond to) other road users.

According to the UK *Manual for Streets*, the 'visibility splay' at an intersection "ensures there is adequate inter-visibility between vehicles on the major and minor arms" (DfT & CLG, 2007). The UK *Manual for Streets* recommends a standard 'X' distance of 2.4m in built up areas (with a minimum of 2m for very lightly trafficked streets) (DfT & CLG, 2007). For bicyclists, a desirable minimum 'X' distance is 4.5m (DfT, 2020).

Figure 24 Example of a 'visibility splay' at a 3-way intersection (DfT & CLG, 2007)



[42] See Appendix B UK Manual for Streets (2007) Influence of geometry and speed box

Forward visibility refers to minimum distance required for a vehicle to stop safely for an obstruction on the road and is equal to the minimum stopping sight distance (SSD).[43] For new streets, the design speed is set by the designer. For existing streets, the 85th percentile wet-weather speed is used.

Figure 25 Derived SSDs for streets from the *Manual for Streets* [44]

Speed	Kilometres per hour	16	20	24	25	30	32	40	45	48	50	60
	Miles per hour	10	12	15	16	19	20	25	28	30	31	37
SSD (metres)		9	12	15	16	20	22	31	36	40	43	56
SSD adjusted for bonnet length. See 7.6.4		11	14	17	18	23	25	33	39	43	45	59
		Additional features will be needed to achieve low speeds										

The *Manual for Streets* challenges the current SSD/forward visibility requirements specified in *Design Bulletin 32*[45] because, amongst other issues, "sites studied in the preparation of [the *Manual for Streets*], no relationship was found between SSDs and casualties, regardless of whether the sites complied with *Design Bulletin 32* or not" (DfT & CLG, 2007).

The *Global Street Design Guide* advocates for sightlines standards for intersections to be "determined using target speeds, rather than 85th percentile design speeds," and that, "designers need to proactively lower speeds near conflict points to ensure that sightlines are adequate and movements predictable" (NACTO-GDCI, 2016).

To improve visibility in urban areas, the NACTO-GDCI *Global Street Design Guide* (2016) does make a number of recommendations, including:

- Remove vehicle parking 6-8m from crossings and intersections
- Place trees at least 3m away from intersections and not obstruct traffic signs and signals
- Provide street lighting along roads and at pedestrian and bicyclist crossings, and
- Use retroreflective markings.

Pedestrian and bicyclist crossings

Crossings, in principle, should be sensitive to the needs of vulnerable road users and the road environment, and guide people toward the safest route. In most urban contexts, there is a

[43] SSD calculated from the speed of the vehicle, the time required for a driver to identify a hazard and then begin to brake (the perception–reaction time), and the vehicle's rate of deceleration (DfT & CLG, 2007).

[44] DfT & CLG (2007, p91) - Figures rounded.

[45] *Design Bulletin 32 - Residential Roads and Footways - Layout Considerations - (Second Edition)* http://www.scottishombudsmanwatch.org/files/DB32.pdf

combination of pedestrians, micro-mobility and 'bicyclists' using an increasingly large array of bicycles, pedelecs, cargo bikes, mopeds and so on.

It is important to note that, particularly for intersections and crossings, the needs of these various users can be quite different due to their relative speeds and the types of facilities being used. For example, while it is easier to assume that most pedestrians (and small micro mobility) are accessing a crossing from footway (if present) at a speed of approximately 5-10km/h, bicyclists and some faster types of mobility vehicles (>10km/h) may be using an on-road lane, a footway or a dedicated or shared facility.

The evidence shows that risk is particularly high for bicyclists crossing roads from shared paths and footways (Knowles et al. 2009; Aultman-Hall & Adams, 1998). Meta-analysis shows that the risk of bicycle crashes is about doubled on shared paths and even higher on footways (compared to mixed traffic) due to intersection crossings (Høye, 2017).

Table 3 Accessibility design principles for pedestrian crossings

General principles for the design of crossings include:

Location	• Pedestrian crossings should be located where pedestrians need to/would like to cross (commonly referred to as pedestrian 'desire lines' (WRI, 2015; NACTO-GDCI, 2016; CIHT, 2015). • Crossings should minimise crossing distance and connect with pedestrian ramps and footways on both sides of the street (DfT & CLG, 2007; NACTO-GDCI, 2016). Measures to minimise crossing distance are covered in detail in Refuge islands and footway extensions. • Intersection crossings should be provided on all legs of an intersection (NACTO-GDCI, 2016).
Spacing	• Crossing locations should be spaced at a maximum of 100m apart (DfT, 2007). NACTO-GDCI recommends 80-100m spacing and no greater than 200m, but for children reduces this to 50-100m intervals (NACTO-GDCI, 2020).
Width	• The width of a pedestrian crossings should be the same as the connecting footway, and not be less than 3m wide (NACTO-GDCI, 2016). Crossing width and waiting areas should adequately cater for demand (WRI, 2015).
Markings	• Formal crossings should be marked. The *Global Street Design Guide* (2016) recommends a pedestrian crossing is always marked, preferably by high visibility 'zebra'/ladder markings (over parallel/dashed lines).
Accessibility	• Pedestrian ramps (or 'drop kerbs') should be aligned with the crossing. Section E/4.5 of the DMRB CD 143 specifies that dropped kerbs be

	provided at all pedestrian crossings. NACTO-GDCI (2016) recommends pedestrian ramps of 2.4m width (min 1.8m) and a slope of 8% (max 10%) for wheelchair access. Pedestrian ramps and tactile paving should not be placed on the curved sections of kerbing as it makes it difficult for visually impaired pedestrians to orient themselves before crossing (DfT & CLG, 2007). • All crossings should have tactile paving to assist sight impaired pedestrians (DfT & CLG, 2007; WRI, 2015). Tactile pavement or detectable surfaces should be provided at kerb ramps and other transitions between pedestrian, vehicular and shared areas (NACTO-GDCI, 2016). Pedestrian signals should have both audible and vibrotactile walk indications (NACTO-GDCI, 2020; WRI, 2015).
Visibility	• Visibility and sight distance should be maintained so pedestrians can see and be seen. *Designing Streets for Kids* (NACTO-GDCI, 2020) makes specific recommendations including: - Prohibiting parking within 6 to 8 m of intersections - Adding kerb extensions where possible - Placing stop bars at least 3 m from crossings, and - Minimising visual obstructions within 3 to 5 m of crossings.

Protection	•	**Bollards and other measures should be used to protect pedestrians from turning vehicles and to prevent vehicles parking across the crossing (NACTO-GDCI, 2016, p.88; WRI, 2015). DMRB section E/4.2 also includes recommendations on marking posts appropriately to prevent these posing a hazard to bicyclists and partially-sighted pedestrians.**
Signage	•	Rapid-flashing beacons and pedestrian hybrid beacons, both pedestrian-activated beacon systems, have been found to increase driver yielding behaviour at pedestrian crossings in the US where compliance was low (Fitzpatrick et al. 2011).

Types of crossings

The various guides tend to categorise crossings in a number of different ways: formal/informal, controlled/uncontrolled[46], intersection/midblock and so on.

Informal crossings

An informal crossings is where a facility requires a pedestrian to cross a street when they perceive it safe to do so (i.e. vehicles have right of way) (DfT & CLG, 2007). Informal crossings tend to range from uncontrolled crossings including:

- A drop kerb aligned with one on the other side of the carriageway (DfT & CLG, 2007)
- Crossing designed with a careful use of paving materials and street furniture which "encourages slow moving traffic to give way to pedestrians" (DfT & CLG, 2007)
- Pedestrian refuges and/or kerb buildouts to reduce the crossing distance (DfT & CLG, 2007).[47]

Figure 26 Example of a kerb buildout providing a safe informal crossing point in Hammersmith and Fulham, UK [48]

[46] The terms 'controlled' and 'uncontrolled' tend to be used in slightly different ways. In the UK (e.g. CIHT's *Designing for Walking*, 2015), 'controlled' appears to relate to those crossings which, by law, provide pedestrian right of way, but outside of the UK (e.g. WRI's *Cities Safer by Design*, 2015) , it refers to signalised intersections. In this case, an unsignalised zebra crossing may be referred to as either a controlled or uncontrolled crossing.

[47] See Refuge islands and footway extensions. It is noted that if the carriageway is still wide enough for a vehicle to push past a bicyclist, this 'pinch-point' may add risk for bicyclists (DfT & CLG, 2007)

[48] Image: https://www.lbhf.gov.uk

Formal crossings

Formal crossings, where vehicle movements are regulated to provide pedestrian passage,[49] include:

- 'Zebra' or marked crossings (DfT & CLG, 2007) however, how effective these crossings are in terms of providing pedestrian right of way varies as do the rules for use by bicyclists.
- Signalised crossings. The *Manual for Streets* (2007) lists four types of signalised crossings (Pelican, Puffin, Toucan and Equestrian (Pegasus)), although it is noted that these are for mid-block crossings only. Pelican are basic signalised crossings, Puffin crossings use pedestrian detectors to match the signal length to the time it takes a pedestrian to cross the road, Toucan crossings can be used by bicycles and pedestrians and equestrian crossings allow a separate crossing for horse riders (DfT & CLG, 2007a).[50]

Figure 27 Example of Puffin crossing in the UK [51]

[49] These categories may be clear in the UK context where rules around who has right of way clearly correlate with the type of infrastructure provided, but this is not the case in many other countries, when crossings such as marked (zebra) or signalised at intersections may not provide pedestrians right of way.

[50] It should be noted that Section E/4.4 of the DRMB CD 143 specifies that standalone signal controlled crossings for pedestrians and bicyclists shall not be provided where 85th percentile exceeds 50mph (~80km/h). See Signalisation at crossings.

[51] Image: https://www.telegraph.co.uk

Flush crossings

Flush crossings, where the carriageway is raised to be level with the footway, reduces barriers to pedestrians and removes the implicit priority of vehicles on street (DfT & CLG, 2007; WRI, 2015; CIHT, 2015). These are recommended for low speed, high pedestrian areas, such as outside schools or at local intersections (as a full raised speed table at intersections) (DfT & CLG, 2007). This design is noted as being an effective speed reduction measure, bicycle friendly and improving the visibility and accessibility of pedestrians (WRI, 2015; DfS, 2015) and may be used with or without signalisation (WRI, 2015). *Designing for Walking* (2015) says ‘the provision of step-free crossings at all junctions should be the overriding aim, which will contribute to a fully accessible and walkable pedestrian network’ (p17).

Figure 28 Example of a flush crossing and bicycle path across a side street entry in The Netherlands[52]

Section 6.3.5 of the NACTO-GDCI *Global Street Design Guide* (GDCI, 2017) includes a total of six crossing types, all of which would fall into the ‘formal’ crossing category. The first two, ‘conventional crossing’ and ‘diagonal crossing’ are intended for use at intersections only. While ‘conventional crossings’ (with signalisation as appropriate) may be used for roads at all speeds and traffic volumes, signalised ‘diagonal crossings’ (also known as a pedestrian scramble) are recommended for crossings with large pedestrian and traffic volumes.

[52] Image: https://aseasyasridingabike.wordpress.com/2017/06/27/getting-side-roads-right/

Figure 29 Example of a 'pedestrian scramble' crossing in Oxford Circus, UK[53]

'Raised crossings' are recommended for both intersection and mid-block locations for crossings with medium to high pedestrian volumes and traffic speeds of <30km/h.

'Traffic calmed crossings' (where vertical traffic calming measures 5-10m before the crossing slow vehicle speeds and alert drivers to the presence of the crossing) and staggered crossings (where the crossing legs on each side of a refuge a slightly offset so the pedestrian faces the direction of the oncoming traffic) are both recommended for mid-block locations where speeds exceed 30km/h. Staggered crossings provide more waiting space if pedestrians are unable to cross in a single phase (WRI, 2015).

'Pinch point/yield' crossings (where the road is reduced to one lane at the crossing point and traffic yields to approaching vehicles) are recommended for mid-block locations with low traffic volumes and where speeds are <30km/h.

Essentially the best type of crossing depends on the road function, speed and traffic and pedestrian volumes (NACTO-GDCI, 2016; DfT, 2007; CIHT, 2015). Diagrams of each of the GDCI's *Global Street Design Guide* crossing types are each accompanied by summary of where it is appropriate and design notes. A copy of this is provided at Appendix B.

CIHT's *Designing for Walking* (2015) guide lists a number of controlled, uncontrolled and grade separated crossing types, which ranks each option by traffic flow (low, medium, high) and traffic speed (20, 30, 35, 40 and 50+ mph) according to three categories ('Generally acceptable', 'Design with

[53] Image: https://sjbcitiesprogram.wordpress.com/2012/04/30/oxford-circus-crossing-london/

caution' and 'Generally unacceptable') and lists the advantages and disadvantages of each. The full table is provided at Appendix C.

'Uncontrolled' crossings (i.e. without signalisation) should be accompanied by traffic calming measures (WRI, 2015). Traffic calming is discussed in full in Speed reduction measures.

Signalisation at crossings

Signals should be provided where:

- Vehicle speeds are above 30km/h and pedestrian volumes and crossing demands are high (NACTO-GDCI, 2016).
- At crossings of multilane roads when slow moving traffic makes it difficult to see pedestrians crossing for drivers in other lanes (CIHT, 2015, p17).

However, signalised crossings on high speed roads may also increase risk to pedestrians (who may be focussed on the 'green man' and not on the vehicles actually stopping) if not used in conjunction with traffic calming measures and/or clear signage on the approach to increase driver awareness and reduce red light running (CIHT, 2015, p17). Section E/4.4 of the DMRB CD 143 specifies that standalone signal controlled crossings for pedestrians and bicyclists shall not be provided where 85th percentile exceeds 50mph (~80km/h).

Pedestrian wait times should be kept below 40 seconds and signal duration should allow for adequate crossing time. Recommendations range from pedestrian crossing speed 0.5m/sec (NACTO-GDCI, 2020) to 1.2m/sec (WRI, 2015). Signal times should be long enough for a pedestrian to cross in one phase (WRI, 2015). Longer pedestrian phases should be provided in locations where children and the elderly are present (e.g. outside schools and retirement homes). Recommended phase length should be calculated on a walking speed of 0.5m per second) (NACTO-GDCI, 2020).

Pedestrian movement should be prioritised (i.e. given right of way) using signal patterns such as Leading Pedestrian Intervals (LPI) which give pedestrians a head start over turning vehicles and make pedestrians (including children) more visible to motorists (NACTO-GDCI, 2016; WRI, 2018, p48). 'All red time' (i.e. a dedicated pedestrian crossing phase for diagonal crossing/pedestrian scramble) can further enhance pedestrian safety (WRI, 2018, p48). Two-stage signalised crossings are recommended for particularly wide (multi-lane) roads (CIHT, 2015).

Stop lines should be used ahead of a signalised crossing (WRI, 2018, p44) and signals should be coordinated to help control vehicle speeds (WRI, 2018, p48) – see traffic calming section.

Refuge islands and footway extensions

Refuge islands and footway extensions (kerb build-outs) can be used separately or in combination at crossings to reduce crossing distance, improve visibility (of and for pedestrians crossing) (DfT, 2007) and for speed reduction.

The *Global Street Design Guide* (2016) lists three types of refuges (pedestrian refuge islands, median tips and median cut-throughs) and three types of footway extensions (corner alignments, bulb-outs and slip lane removal).

Refuge islands are normally used only on undivided carriageways at midblock or intersection locations. Median cut-throughs are provided for mid-block crossings on divided carriageways (i.e. where there is a median) and median tips are where the median is extended further into an intersection to provide a safe mid-way stopping point for pedestrians. Refuge islands are integral to some crossing types, namely the 'staggered crossing'.

It is recommended medians and refuges are present on all roads where there is a total of three or more lanes of traffic, or for two lanes roads where traffic speed and volume make it difficult and unsafe to cross in a single stage (NACTO-GDCI, 2016, p.88) or wherever there is an unsignalised crossing (WRI, 2018, p.47).

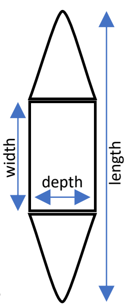
It is noted in *Cities Safer by Design* that this kind of facility has been demonstrated to decrease pedestrian crashes and casualties by 57-82% in the U.S. (FHWA Safety, 2013). Refuge islands are currently a countermeasure in the iRAP models.

Footway extensions or kerb buildouts are used with or without refuges to reduce crossing distance. There a multiple configurations and they can be used with or without signalisation.

The most common, referred to as a 'bulb-out' in the *Global Street Design Guide* (also known as 'pinch points for midblock locations), and is where the footway is extended into the parking lane or road shoulder at either an intersection or midblock location (NACTO-GDCI, 2016, p. 89). They may also reduce a two-directional road to a single lane yield point (CIHT, 2015, p.22) where vehicles need to give way to oncoming vehicles and effectively reducing the crossing distance to one lane for pedestrians.

The length of the bulb-out should be equal to the width of the crossing but ideally extend to the vehicle stop line.

Table 4 Summary of pedestrian refuge and medians characteristics

Location	Section E/4.6 of the DMRB CD 143 specifies that refuge islands shall not be provided where the speed limit is greater than 40mph (~64km/h) except where the refuge island is incorporated into 'a single lane dualling design' (i.e. into the median). The Global Street Design Guide recommends refuge crossings on roads with more than one lane or traffic speeds of above 30km/h be signalised and/or traffic calming installed (NACTO-GDCI, 2016, p.88).
Dimensions* *Note: terminology used to describe refuge and median dimensions vary. For the purposes of this comparison, consistent terms are used. 'Width' and 'depth' refer to the space available for pedestrians /bicyclists crossing, whereas length refers to the overall length of the refuge island. 	The *Global Street Design Guide* recommends pedestrian refuge islands and median be 2.4m deep (min 1.8m) and 10-12m long to provide adequate protection at each end (NACTO-GDCI, 2016, p. 88), whereas *Cities Safer by Design* recommends a depth of 1.8m (min 1.5m) (WRI, 2018, p.47). DMRB CD 143 (E/4.7) specifies that refuge islands shall have a desired depth of 2m for pedestrians (min of 1.5m) and 3m for shared use (min 2.5) and be as wide as the connecting facility, but no less than 2m. *Designing for Walking* suggests and absolute minimum depth of 1.2m, but that this will not be accessible for those using wheelchairs, mobility scooters or pushchairs, and

	that a 2m depth (min 1.8m) should be used (CIHT, 2015, p.21). The width of a refuge should be determined by pedestrian volumes (CIHT, 2015, p.21).
Accessibility	DMRB CD 143 (E/4.8) requires refuge islands to have drop kerbs and a tactile surface for accessibility. Care should be taken to maintain bicycle access (WRI, 2018, p.47).
Visibility	Pedestrian refuges should be clearly visible, well-lit and have reflectors and appropriate signage (NACTO-GDCI, 2016, p. 88; WRI, 2018, p.47).
Protection	Pedestrian refuges should have kerbs, bollards or other features to protect people waiting to cross (NACTO-GDCI, 2016, p. 88; WRI, 2018, p.47)

Grade separated crossings

Pedestrian overpasses and underpasses[54] should be avoided unless local topography or other conditions make them necessary (DfT, 2007). Pedestrian crossings should always be provided at grade unless there is a limited-access highway, railway or natural feature such as rivers (NACTO-GDCI, 2016; WRI, 2018). Pedestrian overpasses across high speed freeways must be used in conjunction with pedestrian fencing or guardrails to effectively channel pedestrians to the overpass, as pedestrian will typically try to cross at grade rather than use overpasses and underpasses (WRI, 2018).

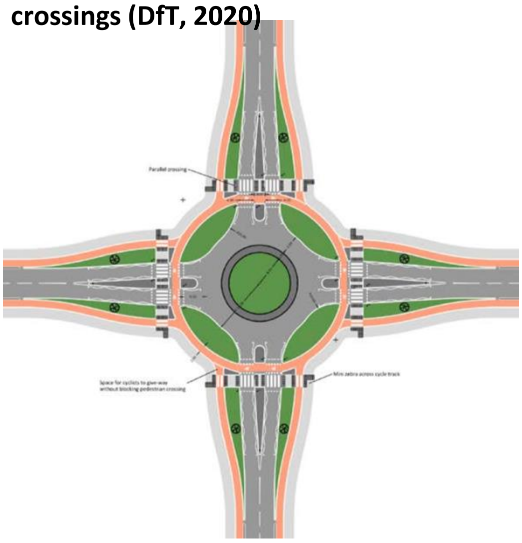
The DMRB CD143 (E/4.9-4.13) provides design dimensions for subways (pedestrian/shared use underpasses). Width provision should be 4m where pedestrians and bicyclists mix (min 3m). Where pedestrians and bicyclists are separated, the pedestrian path should be 2m wide, and the bicycling path 2.5m wide plus a 0.5 m buffer between the bicycling path and the side wall (HE, 2020a).

Crossings at roundabouts

Signalised crossings are not recommended within 20m of a roundabout lest it cause confusion for drivers (a green signal at the light may be taken to mean right of way at the roundabout) (CIHT, 2015).

The preferred solution is to provide a compact roundabout (single lane entries and exits and tight geometry to reduce traffic speeds) with marked crossings. Refuge islands and speed tables (for a raised crossing or for the whole roundabout) can provide additional protection for pedestrians (CIHT, 2015), particularly if located 2-5 m from the roundabout (Schepers, 2011).

Figure 30 Example "Dutch" design roundabout with cycle tracks and parallel crossings (DfT, 2020)



[54] Sometimes referred to as footbridge and subways, pedestrian overpasses and underpasses or pedestrian bridge.

School crossings

School crossings and patrols are designed to improve safety during times with very high pedestrian flows (school start and finish times). CIHT (2015) recommend patrol officers be involved in the design of school crossings. Some features, such as refuge islands, can make the job of a patrol officer more difficult as drivers can treat crossings each side of a refuge island as separate entities. The patrol officer therefore needs to patrol crossings on both sides of the refuge island at once, and refuge island may not be designed for large pedestrian volumes (CIHT, 2015).

Bicyclist crossings

The UK *Design Manual for Roads and Bridges* (HE, 2020b) provides a dedicated section (CD195 E/4) on crossings for bicyclists. It includes a general hierarchy of crossing type depending on traffic speed and volume and number of lanes to cross. The Local Transport Note 1/20 (DfT, 2020) also includes a detailed section on bicyclist crossings and intersections.

Any crossing above 40mph (~65km/h) with over 6000 AADT and 2 lanes, or crossing of a road with over 8000 AADT (regardless of speed or number of lanes) is recommended to be grade separated. Design of grade separation must be carefully considered to ensure bicyclist comfort and access, and should require minimal changes in level (DfT, 2020). Signal controls are acceptable as an alternative for all but the highest speed and highest volume road crossings.

Figure 31 Example of a grade separated pedestrian and bicycle crossing in the Netherlands (DfT, 2020)

Remaining crossing types are:

- Uncontrolled: cycle traffic gives way (for roundabout and higher speed road crossings)
- Uncontrolled: cycle traffic has priority (for low-speed, low volume links and side road crossings). This type of crossing should be raised and incorporate a painted lane indicating the bicycle path (HE, 2020b)
- Parallel pedestrian/cyclist crossing (all other types)

Refuge islands should be at least as wide as the connecting cycle path and no less than 3m deep (CD 195, 2020).

The amount of protection afforded to a bicyclist crossing an intersection is important. Studies into the provision of painted lanes, lines, other markings (e.g. sharrows, harlequin patterns and bicycle symbols), bicycle boxes and so forth do not provide clear conclusions on their capacity to reduce bicyclist crashes at intersections (Høye, 2017). [55]

Protective measures which have been found to reduce risk for bicyclists at intersections include:

- Off-setting the bicycle crossing by at least 5m from the intersection
- Traffic calming (such as raised crossings or speed humps)
- Two-stage crossings by means of a mid-way refuge island (Buch and Jensen, 2013, Denmark), and
- Ensuring there is right of way for bicyclists at the crossing (Schepers, 2011, The Netherlands; Gårder et al. 1998, Sweden).

Schepers (2011) found that intersections where bicycle track approaches were 2-5 meters away from the main travel way reduced crash risk by approximately half (CMF = 0.55). This is also the safest design for roundabouts for all bicyclist traffic (not just those using footways and off-road paths).[56]

Figure 32 Example of a Dutch roundabout with bicycle and pedestrian crossings with protective measures[57]

[55] See also Coloured surfaces

[56] For roundabouts, increased bicyclist crash risk is associated with the features and design of the roundabout, including presence of bicycle lanes, high vehicle speeds, multiple lanes and large size of roundabout and large curve radii of entry and exits (Høye, 2017). Vandenbulcke et al. (2014, Belgium) found that bicycle lanes in roundabouts had more than double the number of crashes (+123%) than in bicycle lanes in light-regulated intersections; and Harris et al. (2013, Canada) found a strong connection between higher bicyclist crash rates and small roundabouts on local streets (vehicle-bicycle crashes were 7.98x more likely).

[57] Image: Mark Wagenbuur @BicycleDutch May 12, 2019 (https://twitter.com/bicycledutch/status/1127580065796186119)

Pedestrian fencing

Pedestrian fencing, sometimes referred to as 'guardrails', is designed to reduce, restrict or regulate pedestrian movements across a road carriageway. However, they may also make the situation less safe for pedestrians and bicyclists. Some reasons listed by CIHT (2015) are that guardrails may:

- Reduce the usable width of the footway
- Prevent cyclists who may become trapped between vehicles and the fencing from being able to 'escape' on to the footway
- Create a side hazard for bicyclists (cyclists need to maintain distance between their handlebars and the fence, which may lead to them riding closer to passing vehicles)
- Reduce driver awareness of pedestrians and obscure the visibility of pedestrians at road crossings (particularly children because of their height)
- If poorly placed or overly long, may lead to more pedestrians walking along the road lane

Alternatives to pedestrian fencing is creating a 'buffer' or 'clutter zone' between the kerb and the 'clear path' (CIHT, 2015; NACTO-GDCI, 2016) which may include seating, poles, trees and garden beds.

Figure 33 Example of garden beds and a bicycle lane acting as a 'buffer' to reduce crossing activity[58]

[58] Image: https://greatruns.com/indianapolis-the-cultural-trail/

4. DISCUSSION

This exercise aimed to review existing literature and standards to consider the effectiveness of urban VRU treatments in different scenarios with view to expanding the range of urban-specific safety treatments which can be applied in the iRAP models.

Countermeasures are analysed by the iRAP model to generate affordable and economically sound investment that improve a road's Star Ratings and, when implemented, can save lives.

Investment Plans are based on an economic analysis of a range of countermeasures, which is undertaken by comparing the cost of implementing the countermeasure with the reduction in crash costs that would result from its implementation. They contain extensive planning and engineering information such as road attribute records, countermeasure proposals and economic assessments for 100 metre segments of a road network.

In interpreting the results of an iRAP assessment, it is important to recognise that an Investment Plan is designed to provide a network-level assessment of risk and cost-effective countermeasures. For this reason, implementation of countermeasures identified in an Investment Plan will ideally include:

1. Local examination of proposed countermeasures (including a 'value engineering' type workshop including all relevant stakeholders)
2. Preliminary scheme investigation studies, and
3. Detailed design and costing, final evaluation and construction.

User Defined Investment Plans is a current initiative of iRAP which will enable road engineers to tailor Investment Plans to better suit local conditions, their objectives for their road network and budget.

Research has demonstrated that it is crucial to ensure that local communities have an opportunity to both contribute to road designs but also understand the intended use of various road design features.

The need for urban-specific countermeasures is underpinned by a move to reduce urban traffic speeds for the safety of road users other than vehicles. The 2020 UN Stockholm Declaration focuses on speed management, including 30 km/h (20mph) speed limits where vulnerable road users and vehicles mix.[59] This calls for a rethinking (much of which is represented in the guidance documents reviewed here) of the engineering measures used in road design which encourage lower speeds and create streets as more equitable and accessible places.

There are challenges. Perhaps for a few notable exceptions, current traffic engineering specifications across the world tend to be in direct contrast to the traffic calming techniques reviewed in these manuals. Measures which were intended to improve safety on highways—for example, large visible signs, wide lanes, long sight lines—are widely implemented in urban areas. This results in higher traffic

[59] https://www.roadsafetysweden.com/contentassets/b37f0951c837443eb9661668d5be439e/stockholm-declaration-english.pdf

speeds and environments which are not safe for pedestrians, bicyclists and users of other light mobility vehicles (DfT & CLG, 2007).[60]

Expertise within local road authorities to implement effective traffic calming measures variable, even in some high-income countries. Guides such as NACTO-GCDI's *Global Street Design Guide*, WRI's *Safer Cities by Design*, and a number of the UK's guidance documents are addressing this knowledge gap directly.

Modifying Safer Road Investment Plans to include urban-specific countermeasures (as well as appropriate trigger sets and hierarchy rules) would further support local road authorities in addressing speed and providing for pedestrian and bicyclist safety more effectively.

The guides and documents which were the focus of this review reflect the growing shift away from designing urban streets as car-dominant environments to improve the safety of other road users, and reflect the increased knowledge and expertise in this area. It should be acknowledged that all of the documents were available in English and were either from a US or UK origin, although other specific studies and examples were more broadly represented. Due to the client's needs, specific attention was given to UK design documents. Because of this, some of the recommendations, specifications and guidance is tailored for the UK context and may not 'translate' elsewhere. There are also a number of specific issues which are the product of local policies. These include:

- De-segregating road users on low-speed residential streets. Road design guidelines recommend that:

  …pedestrians and cyclists should generally share streets with motor vehicles. There will be situations where it is appropriate to include routes for pedestrians and cyclists segregated from motor traffic, but they should be short, well overlooked and relatively wide to avoid any sense of confinement (DfT & CLG, 2007).

  The recommendation is in the context that residential streets are designed as low speed shared space and is contingent of well-designed traffic calmed streets.

- Reducing 'clutter' such as pedestrian railings and signage. This is dealt with extensively in many of the guides, for example, the *Manual for Streets* (DfT & CLG, 2007) and TfL's *Streetscape Guidance* (2019).
- Using 'implicit' traffic calming measures which lead to lower speeds, rather than more aggressive forms of vertical and horizontal deflection.

In addition to specific changes to the countermeasures available in a Safer Road Investment Plan, being able to customise SRIPs to align with local policies would also provide additional functionality.

The review will be presented to the iRAP Global Technical Committee (GTC) as the basis for any recommended changes to the iRAP model.

[60] See Appendix B UK Manual for Streets (2007) Influence of geometry and speed box

5. RECOMMENDATIONS AND NEXT STEPS

Recommendations for Safer Road Investment Plans

Based on the review, there are a number of recommendations proposed which could be further investigated as part of the possible development of an urban-specific Safer Road Investment Plan.

1. **Introduce speed reduction as a countermeasure which accounts for the traffic calming measures appropriate to the target speed (and other characteristics of the road)**

Reducing urban traffic speeds for the safety of road users other than vehicles is critical for safety. The 2020 UN Stockholm Declaration focuses on speed management, including 30 km/h (20mph) speed limits where vulnerable road users and vehicles mix.[61] Therefore, a default countermeasure for streets which fit this profile should be to reduce them to 30km/h or less, and recommend the appropriate traffic calming measures to support the speed reduction.

2. **Recommend appropriate traffic calming measures for all urban roads where pedestrians and bicyclists are present.**

Regardless of the type or function of the road, lowering vehicle speeds in urban areas reduces the risk of serious crashes, but also allows for urban roads and streets to become safer, healthier and more pleasant environments by:

- Increasing accessibility and encouraging walking and other sustainable modes of transport,
- Reducing vehicle emissions,
- Reducing vehicle noise and acceleration and deceleration, and
- Reducing the need for obtrusive and unsightly traffic safety devices such as crash barriers.

3. **Consider the introduction of traffic volume reduction as a countermeasure through area-wide traffic calming measures such as diverters, closures and street conversions**

Reducing vehicular traffic volumes may be useful in some cases, for example, where there is an initiative to create safe bicycling routes as part of a broader network, or where road space is being reallocated. Such measures could be particularly valuable in areas with high pedestrian and bicyclist activity, such as around schools, where the drop in vehicular traffic will increase the safety and accessibility for other road users (and enable the installation of safer pedestrian and bicyclist facilities).

[61] https://www.roadsafetysweden.com/contentassets/b37f0951c837443eb9661668d5be439e/stockholm-declaration-english.pdf

4. **Broaden the types of pedestrian/bicycle crossing types**

Pedestrian and bicycle crossings need to be appropriate to the desired traffic speeds, volumes, number of lanes on the road and pedestrian/bicyclist volumes. More specific types of crossings could be introduced to the SRIP which support improved pedestrian and bicyclist accessibility (and operate as traffic calming measures if appropriate).

5. **Enhance 'upgrade crossing quality' with a specific list of recommended measures**

Specific measure to improve quality can be recommended based on the traffic speed, volume, number of lanes on the road and pedestrian/bicyclist volumes.

6. **Update the minimum length, minimum spacing and hierarchy rules in line with current best-practice**

SRIP countermeasures are subject to minimum length, minimum spacing and hierarchy rules to ensure that countermeasure recommendations align with established engineering practice and are logical. These should be updated to reflect the best practice documented here, for example, recommended spacing between pedestrian crossings.

7. **Introduce measures to reduce legs on or close intersections to vehicular traffic**

Intersections are key points of risk on a road network. Eliminating intersections or some turning movements can reduce the risk of vehicle-vehicle conflicts and potential conflicts with pedestrians and bicyclists. The introduction of half or full intersection closures (with filtering) and diverters are measures which can be applied to reduce intersection risk.

8. **Update trigger sets and hierarchy rules so that recommendations align with current best practice for traffic calming in urban areas**

Some current countermeasures may be being triggered in urban environments which may result in a conflict with traffic calming measures. These triggers should be reviewed to ensure some countermeasures (such as increases sight distance and lane width) are only triggered where appropriate, and that hierarchy rules do not result in conflicting recommendations.

9. **Enable multi-effect countermeasures**

Many countermeasures fulfill more than one purpose. For example, particular pedestrian and bicycle crossing designs can also deliver traffic calming effects and vice versa. Such measures are seen as desirable for the urban context to simplify street design and avoid unnecessary clutter and confusion.

Next steps

The iRAP models, including the Safer Road Investment Plans, are governed by a Global Technical Committee (GTC). Based on the recommendations above, proposed changes for the countermeasures, triggers, hierarchy or minimum spacing rules would be considered by the GTC.

Any new countermeasures would require documentation of CMF values and how these translate into the road attributes, along with a review of countermeasure costs. Countermeasure cost estimates were included for some of the measures in the following documents:

- ITE Technical Resources available at https://www.ite.org/technical-resources/traffic-calming/traffic-calming-measures/
- Department for Transport. (2007). *Local Transport Note 1/07 Traffic Calming*. URL: https://www.gov.uk/government/publications/traffic-calming-ltn-107
- Bellefleur, O. and F. Gagnon. 2011. Urban Traffic Calming and Health Literature Review. Quebec National Collaborating Centre for Healthy Public Policy. URL: https://www.ncchpp.ca/docs/ReviewLiteratureTrafficCalming_En.pdf

6. APPENDICES

Appendix A UK Manual for Streets (2007) Influence of geometry and speed box

Influence of geometry on speed

Research carried out in the preparation of MfS considered the influence of geometry on vehicle speed and casualties in 20 residential and mixed-use areas in the UK. Two highway geometric factors stand out as influencing driving speed, all other things being equal. They are:

- forward visibility; and
- carriageway width.

Improved visibility and/or increased carriageway width were found to correlate with increased vehicle speeds. Increased width for a given visibility, or vice versa, were found to increase speed. These data are summarised in Fig. 7.16.

The relationship between visibility, highway width and driver speed identified on links was also found to apply at junctions. A full description of the research findings is available in TRL Report 661.[15]

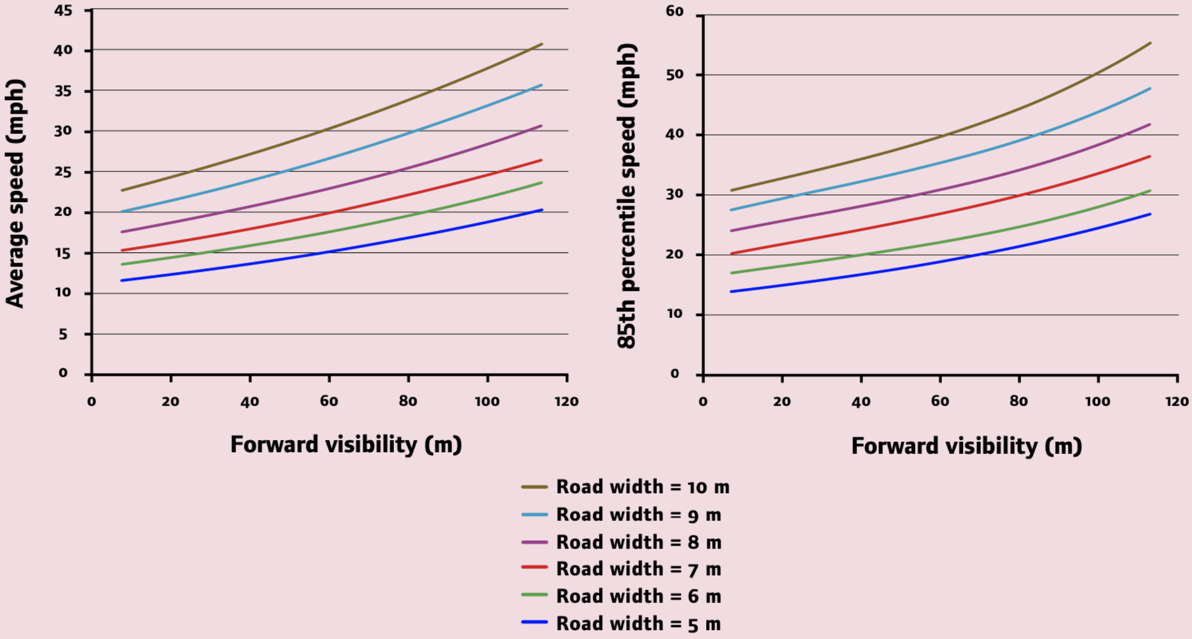
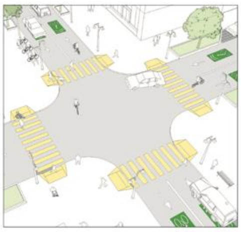


Figure 7.16 Correlation between visibility and carriageway width and vehicle speeds (a) average speeds and (b) 85th percentile speeds. These graphs can be used to give an indication of the speed at which traffic will travel for a given carriageway width/forward visibility combination.

Appendix B Global Street Design Guide (2016) crossing types

Global Street Design Guide, Section 6.3.5, pp. 86-17.

Crossing Types



Pedestrian Volumes	Low to High
Signalized	Yes
At Intersection	Yes
Mid-Block	No
Vehicular Speed	Any Speed
Vehicular Volumes	Low to High

Conventional Crossing

Pedestrian crossings should be aligned as closely as possible with the pedestrian clear path. Inconvenient deviations create an unfriendly pedestrian environment.

Many pedestrian crossings are designed using inadequate, narrow striping, setbacks from intersections, and deviations from the pedestrian clear path, resulting in considerable crossing distances.

Intersection crossings should be kept as compact as possible, facilitating eye contact by moving pedestrians directly into the driver's field of vision.

Pedestrian Volumes	High
Signalized	Yes
At Intersection	Yes
Mid-Block	No
Vehicular Speed	Any Speed
Vehicular Volumes	Medium to High

Diagonal Crossings

A diagonal crossing, also called pedestrian scramble, is a type of crossing in which a dedicated phase allows pedestrians to cross the intersection in every direction at the same time. During this phase all vehicular traffic is stopped.

This type of signalized crossing avoids conflicts between pedestrians and turning vehicles.

It should be applied only at intersections with high pedestrian volume and should be designed to provide enough space for large numbers of people to gather on the sidewalk corners.

If not well-coordinated, it can create long waiting times for both pedestrians and motorists. Reduce waiting time for pedestrians for higher compliance and increased safety.

Pedestrian Volumes	Medium to High
Signalized	No
At Intersection	Yes
Mid-Block	Yes
Vehicular Speed	Below 30 km/h
Vehicular Volumes	Medium to High

Raised Crossings

Non-signalized crossings at intersections and mid-block can be raised, extending the level of the sidewalk across the street.

This helps calm traffic, improve accessibility, and increase visibility between motorists and pedestrians.

Raised crossings can be applied in busy neighborhood main streets and commercial streets, or where small neighborhood streets with slower speeds meet larger corridors. *See 11.5 and 11.6: Small Raised Intersection and Neighborhood Gateway Intersection.*

Pedestrian Volumes	Low to Medium
Signalized	No/Actuated
At Intersection	No (prefer raised)
Mid-Block	Yes
Vehicular Speed	Above 30 km/h
Vehicular Volumes	Medium

Traffic Calmed Crossings

At mid-block crossings where motorist compliance is low, use vertical deflection measures such as speed bumps, tables, and cushions to reduce motorist speed and warn them of the presence of an upcoming pedestrian crossing.

Vertical speed control elements should be set back **5–10 m** from the crossing according to vehicular speed. A series of bumps before the crossing increases compliance levels.

Use pedestrian-activated warning lights, flashing beacons, or High Intensity Activated Crosswalks (HAWK) to increase motorists' awareness and improve pedestrian safety.

The pedestrian crossing could also be raised to increase mutual visibility between pedestrians and motorists.

In streets with high vehicular volumes, give preference to conventional crossings with fixed signalization.

Pedestrian Volumes	Low to Medium
Signalized	Actuated
At Intersection	No
Mid-Block	Yes
Vehicular Speed	Above 30 km/h
Vehicular Volumes	Medium

Staggered Crossings

Staggered crossing should only be applied when the depth of the cut-through allows full accessibility. They allow pedestrians to face the direction of oncoming vehicles, increasing visibility along the crosswalk.

The minimum width of the median should be **3 m** and the offset between the two legs of the pedestrian crossing should not exceed **1 m**, keeping crossing distances to a minimum.

The stop bars at this type of mid-block crossing should be set back **5–10 m**.

If vehicular volumes are high or compliance levels are low, other strategies, such as calming the crossing using speed bumps, tables, cushions, or implementing fixed signalization should be employed.

Pedestrian Volumes	Low
Signalized	No
At Intersection	No
Mid-Block	Yes
Vehicular Speed	Below 30 km/h
Vehicular Volumes	Low

Pinchpoint/Yield Crossings

Crossing design in conjunction with pinchpoints, provides short crossing distance at mid-blocks.

By reducing the roadway from two lanes to one lane at a mid-block, drivers are forced to reduce speed and yield to traffic coming from the opposite direction.

Maintain a lane width of **3.5 m** at the pinchpoint for emergency vehicle access.

Appendix C CIHT Designing for Walking (2015) Suitability of pedestrian crossings table

Note: Speed provided in miles per hour (mph)

Crossing Type	Traffic Flow	Traffic Speed 20	30	35	40	50+	Advantages	Disadvantages
UNCONTROLLED								
Dropped kerb Crossings	High	Acceptable	Acceptable	Caution	Unacceptable	Unacceptable	Simple to use. Low cost. Can be located flexibly. Can be located on desire lines	Intimidating at higher flows and speeds. Subjective safety an important consideration
	Medium	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
	Low	Acceptable	Acceptable	Acceptable	Acceptable	Caution		
Flat-topped road hump	High	Acceptable	Caution	Caution	Unacceptable	Unacceptable	Level crossing surface. Give and take at lower speeds	Unsuitable for heavy, fast traffic flows. Can affect local carriageway drainage
	Medium	Acceptable	Acceptable	Caution	Caution	Unacceptable		
	Low	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
Refuge/central reservation	High	Acceptable	Acceptable	Caution	Caution	Caution	Allows crossing in two stages. Can reduce traffic intimidation for some users	Can create pinch point for cyclists. Can be prone to traffic impact
	Medium	Acceptable	Acceptable	Acceptable	Caution	Caution		
	Low	Acceptable	Acceptable	Acceptable	Acceptable	Caution		
Median strip	High	Acceptable	Acceptable	Caution	Unacceptable	Unacceptable	Crossing point along length of street. Caters for multiple desire lines	Not always accessible to all users. Can impact on cycle safety over longer distances
	Medium	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
	Low	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
Build-out	High	Acceptable	Acceptable	Acceptable	Caution	Unacceptable	Improves visibility between pedestrians and traffic. Reduction in crossing Width	Can push cyclists into traffic. Traffic collision risk if not adequately conspicuous
	Medium	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
	Low	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
Side-road entry treatment	High	Acceptable	Acceptable	Acceptable	Caution	Unacceptable	Level crossing surface. Give and take at lower speeds	Can create loss of control risk for motorcycles
	Medium	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
	Low	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
Blended junction or continuous footway	High	Acceptable	Acceptable	Caution	Caution	Unacceptable	Level walking surface where drivers cross the footway, which continues across the junction	Some pedestrians may not feel comfortable with this nontraditional layout
	Medium	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
	Low	Acceptable	Acceptable	Acceptable	Caution	Unacceptable		
CONTROLLED								
Zebra crossing	High	Acceptable	Acceptable	Caution	Unacceptable	Unacceptable	Pedestrians have priority over traffic. Almost immediate access to crossing priority	Less suitable on faster roads. Can impact on traffic flow where pedestrians stream
	Medium	Acceptable	Acceptable	Caution	Unacceptable	Unacceptable		
	Low	Acceptable	Acceptable	Caution	Caution	Unacceptable		
Signal controlled (stand-alone)	High	Acceptable	Acceptable	Acceptable	Caution	Unacceptable	Favoured by many older and disabled people. Signals give clear priority to pedestrians	Can be inflexible leading to delays for both pedestrians and traffic, although puffin detection reduces issues
	Medium	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable		
	Low	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable		
Signal controlled (junction)	High	Acceptable	Acceptable	Acceptable	Acceptable	Caution	Can be used on higher speed roads. All green, pedestrian phase allows diagonal crossing	When staggered for traffic flow, pedestrians experience longer walking routes and times
	Medium	Acceptable	Acceptable	Acceptable	Acceptable	Caution		
	Low	Acceptable	Acceptable	Acceptable	Acceptable	Caution		
GRADE SEPERATED								
Bridges	High	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	No crossing delays, good subjective safety. No delays to traffic. Can be used with high traffic speeds/flows	Poor layouts with tight turns, steep ramps, steps, and long detours will exclude some people
	Medium	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		
	Low	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		
Subways/underpasses/road bridges	High	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	When open and see through, can be direct, convenient and feel safe to use	When isolated and without clear views through, can feel unsafe and less likely to be used
	Medium	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		
	Low	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		

Generally Acceptable ■ Design With Caution ■ Generally Unacceptable ■

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