

The Urban Streetspace Book

210 SOLUTIONS TO REDESIGN,
REALLOCATE, OR REGULATE STREET SPACE



Paulo Anciaes

THE URBAN STREETSPACE BOOK

210 SOLUTIONS TO REDESIGN,
REALLOCATE, OR REGULATE
STREETSPACE IN CITIES

FIRST EDITION

Paulo Anciaes



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Foreword

Urban streets have a wide variety of users, each with different needs. Street uses can be related to two functions of the street: one which is usually acknowledged (movement) and another which tends to be forgotten (“place”). The place function includes vehicle-based activities (e.g. parking, loading) and people-based activities (e.g. waiting for buses, window shopping, sitting). Street uses can have positive and negative impacts not only on the respective street users but also on the wider economic, social, and environmental context, affecting the area next to the street and, in some cases, the whole city and beyond.

This book is a compendium of 210 possible options for policy interventions to redesign, reallocate, or regulate streetspace, providing information on how these interventions address the needs of the different street users and potentially meet economic, social, and environmental policy objectives. This information was previously scattered across design guidelines, academic studies, technical reports, and websites. In most cases, each source of information focused on specific case studies, looking at a single street use and policy objective. This book brings together the existing information and classifies it in a systematic way, providing planners and the public with a better understanding of the characteristics of different types of interventions in comparison with alternatives, using standardized information. The book also goes beyond technical aspects, looking at equity among street users and trade-offs among policy objectives.

The book can assist planners to identify effective options that address user needs and policy objectives, while considering the local conditions and technical constraints. This allows planners to present a comprehensive and balanced set of options for public consultation and modelling, which not only increases the probability of finding more effective interventions but can also increase the political acceptability of the options that are eventually chosen.

The contents of this book are also available as an interactive tool where users, instead of browsing through options, can select the most adequate options using their own criteria. The tool is available from <https://ifpedestrians.org/roadoptions/public>.

Acknowledgements

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The author benefited from feedback from other partners of the MORE consortium. Colleagues representing the International Federation of Pedestrians, European Cyclists Federation, International Association of Public Transport (UITP), and Alliance for Logistics Innovation through Collaboration in Europe (ALICE) made valuable suggestions on the parts of the book on pedestrians, cyclists, buses, and freight transport, respectively.

The project consortium also included the governments of five cities in Europe: Lisbon, London, Malmö, Budapest, and Constanta. Planners from these cities used the information provided in this book to generate ideas to improve stress sections of busy urban streets in their cities. The feedback received was used by the author to refine the information provided in this book.

Other partners of the consortium provided valuable comments and suggestions during the course of the project. These include universities (Technical University of Dresden, Sciences Po - Paris Institute of Political Studies), a network of European cities (POLIS), consultancy companies (European Integrated Projects, Vectos) and other private companies (Buchanan Computing, Dynqq, PTV).

The web version of the tool (<https://ifpedestrians.org/roadoptions/public>) was developed by Buchanan Computing. Thanks go to the International Federation of Pedestrians for making it available in their website.

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PART 1

Measures aimed at pedestrians (walking)

Pedestrianisation



Podgorica, Montenegro ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Street for the exclusive use of pedestrians. It usually has level surfaces, seating, on-street commercial areas (e.g. kiosks, outdoor cafes, stands), street furniture (e.g. information boards, bins), public art, greenery, and good-quality lighting.

Pedestrianised areas are common in city centres and high-density mixed used areas, especially in shopping streets. The success of these streets depends on existence of cycle parking and good access to public transport at entrances.

The movement of cyclists may be allowed (in some places and/or times), but rarely. In these cases, cycle paths can be defined, with signs and markings. In most cases, cyclists have to dismount. Micromobility vehicles may also be allowed.

Residents and emergency vehicles can use the road. Service and delivery vehicles may also be allowed in early morning or other quiet times. In some cases, low-frequency bus services may be allowed in one direction, especially electric buses.

A clear path should be kept for the access of all vehicles that may need to use the street. Pedestrianised streets also require cleaning and waste collection (in busy areas, more than once a day) and regular repair and maintenance of street furniture.

EXAMPLES

The Lijnbaan, in the Rotterdam city centre, opened in 1953, and was one of the first purpose-built pedestrianized shopping streets in a large city.

Starting in the early 1960s, most of the streets and squares in the city centre of Copenhagen were pedestrianized, including the main, long, shopping street, Stroget.

Nowadays, there are pedestrianized cities in the majority of cities and towns in all continents. In many cases, the city's main shopping street, and streets used by tourists, are pedestrianized.

EVIDENCE

Pedestrianisation of the Copenhagen city centre led to a dramatic increase in pedestrian flows, use of streets as social spaces, and local business revenue

Gehl 2004 Public Spaces - Public Life. Danish Architectural Press, Copenhagen.

In contrast, in the USA, many pedestrianised shopping streets declined, as shops could not compete with suburban shopping centres. They were demolished and reverted into high-traffic roads

Matuke et al 2010 The rise and fall of the American pedestrian mall. Journal of Urbanism. <https://doi.org/10.1080/17549175.2020.1793804>

A study of 8 cases in European cities found that pedestrianisation reduced air pollution and increased the number of bus and pedestrian trips.

European Commission 2004 Reclaiming city streets for people - Chaos or quality of life?

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Part-time pedestrianisation



Tirana, Albania ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Streets for the exclusive use of pedestrians at certain hours of the day or days of the week. At other times, the street is open to motorised traffic, including private cars. However, car parking may be banned.

In shopping streets, the pedestrianised times may be mornings and afternoons, when shops are open. In leisure areas, pedestrianised times may be weekends and evenings, when bars and restaurants are open.

Cyclists and micromobility users may be allowed during the pedestrianised times. Emergency vehicles and resident vehicles are always allowed. Service and delivery vehicles are only allowed in the non-pedestrianised times

These streets have more resistant pavements and more separation between pedestrians and vehicles (e.g. kerbed footways) than permanently pedestrianised streets. Pedestrianisation is enforced with signs, movable barriers, or depressible bollards.

Time-based pedestrianisation can be used as trial for permanent pedestrianisation. Different variants can be trialled, varying pedestrianised times and spatial limits, and exemptions.

EXAMPLES

From the year 2000, a shopping/leisure street in a busy area in Hong Kong was pedestrianised on evenings and weekends. This scheme was cancelled in 2012 because of many noise complaints.

Since 2013, several streets in Singapore have started to be pedestrianized on weekend evenings. More streets have been added to the scheme, given its success.

Several cities have temporarily pedestrianized some streets during the COVID-19 pandemic in 2020 to facilitate social distancing for pedestrians and people sitting in outdoor cafes.

EVIDENCE

The evening and weekend pedestrianisation of a busy shopping and leisure street in Hong Kong lead to a 17% increase in the rental value of retail shops.

Yiu 2011 The impact of a pedestrianisation scheme on retail rent: an empirical test in Hong Kong. Journal of Place Management and Development 4, 231-242.

Evening pedestrianisation of a tourist street in Bangkok increased rental values and sales, and was well-accepted by business owners and street users.

Kumar and Ross 2006 Effects of pedestrianisation on the commercial and retail areas: study in Khao San Road, Bangkok. World Transport Policy and Practice 13, 38-50.

In a stated preference in four sites in the UK, participants were willing to pay more for day-time pedestrianisation (£74) than for full-time pedestrianisation (£64)

ITS University of Leeds and Atkins 2011 Valuation of townscapes and pedestrianisation. Report for UK Department for Transport.

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Walkways



Southend-on-Sea, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Space for walking separated from the road carriageway, often elevated or underground, or across buildings. Elevated walkways are also known as skywalks. Some sections can be moving walkways or escalators. Many at-level and elevated walkways are covered.

Walkways can form a network, connecting stations, shopping centres, and public buildings. They may completely replace at-grade footways and crossings (especially in complex junctions). Some may close at night, especially if they cross private buildings.

Walkways completely separate motorised vehicles from pedestrians, while also offering pedestrians direct routes to major destinations and some protection against the weather. Cyclists and micromobility users are usually not allowed in walkways.

Walkways can be intimidating for pedestrians because of their isolation and in some cases, because of poor design, poor state of repair/maintenance, and vandalism. Pedestrians may also become disoriented when returning to the street level.

Many walkways act as shopping and leisure spaces, both formal (e.g. passages across shopping centres, shops and stands in public walkways) and informal (vendors, performers). Walking on elevated walkways can be considered a leisure activity in itself.

EXAMPLES

The Minneapolis Skyway System is the oldest (1962) and the longest (18km) network of elevated walkways. Other North American cities (Houston, Toronto, Montreal) also have long walkway networks.

Hong Kong has an extensive network of connected walkways at various levels, including footbridges across roads or linking buildings and passages across shopping centres and underground stations

There was a plan for a network of elevated walkways in London's financial district, but it was never finished and the fragments were always underused.

EVIDENCE

Walkways attract investment along them and in the places they connect. As an example, the Central–Mid-Levels walkway in Hong Kong led to large real-estate investment and economic activity

Zacharias (2013) The central-mid-levels escalator as urban regenerator in Hong Kong. Journal of Urban Design 18, 583-593.

Pedestrians are not necessarily less exposure to air pollution when using elevated walkways. That depends on the walkway design and orientation in relation to the road

Wang et al 2020 Particulate matter inside and around elevated walkways. Science of the Total Environment 699: 134256.

Reviews of the impacts of walkways on social interaction and segregation, and visual environment, are mixed, but in most cases negative

Cui et al 2013 The development of grade separation pedestrian system: a review. Tunnelling and Underground Space Technology 38, 151-160.

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Greenways



Hangzhou, China ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Path for pedestrians running independently of motorised traffic, along parks, waterfronts, canal towpaths, or disused rail corridors (at-grade or elevated). There are regular connections to the street network (less if elevated or along canal).

The space is usually shared by pedestrians, cyclists, and micromobility users. The space allocated to pedestrians may be marked. When the whole space is shared, pedestrians have priority, although there are often conflicts in narrow greenways.

Greenways often form a network, connecting with parks, leisure areas, and other greenways. They can even connect with other cities, running along long distances. At intersections with major roads or railways, the greenway may use footbridge or underpass.

Greenways are used for transport and leisure and are habitats for plants and animals. However, even with good lighting and surveillance, they pose personal security problems, and so are underused after dark.

Greenways do not completely replace footways along roads, but rather offer an alternative route for walking routes, along a quieter and cleaner environment. This alternative route may be longer or shorter than walking along roads.

EXAMPLES

The High Line in New York and the Promenade Plantée in Paris are two of the most famous examples of linear parks using disused elevated railway lines.

The Cheonggyecheon in Seoul is a greenway along a stream that was previously underground, under a multi-level motorway. The motorway was demolished in 2005.

London has an extensive system of canal towpaths, shared by pedestrians and cyclists. Many canals cross through central areas and connect major stations and shopping/leisure areas.

EVIDENCE

Studies consistently find a positive relationship between urban greenways and physical activity levels among the population in surrounding areas

Hunter et al 2015 The impact of interventions to promote physical activity in urban green space: a systematic review and recommendations. Social Science and Medicine 124, 246-256.

Studies also tend to find a positive impact of urban greenways on prices of nearby properties. Large-scale investments, such as the High Line in New York lead to massive increases (of up to 50%).

Crompton and Nicholls 2019 The Impact of greenways and trails on proximate property values: an updated review. Journal of Park and Recreation Administration 37, 89-109.

Users of urban greenways also have a positive perception of them, believing they contribute to their health, quality of life, and sense of community, while also providing good access to places

Shafer et al 2000 A tale of three greenway trails: user perceptions related to quality of life. Landscape and Urban Planning 49, 163-178.

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Widen footway



Praia, Cabo Verde ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Increase the width of the footway, reallocating space from other sections of the road. This can be achieved by extending the footway to the kerbside area of the carriageway, removing car parking, or removing or reorganising kerbside street furniture.

It can also be achieved by a more general reallocation of space, reducing the width of traffic lanes or removing lanes (reducing the number of lanes on both directions, changing the road to one-way traffic, or removing slip lanes for vehicles turning)

Footways should be widened where they do not meet standards (minimum 1.5-2m). Wider footways also provide for pedestrians in groups and accompanying children and those who are visually-impaired or use a mobility aid (e.g. wheelchair) or carry luggage.

The extended footway adds to the pedestrians' clear zone for movement, and provides space for trees and street furniture, place activities, and to add or widen buffers from the clear zone to buildings and the road carriageway.

Wider footways are needed in shopping areas, near hospitals, schools, parks, care homes, and public transport nodes, and in roads with tall buildings and high volumes of vehicles and pedestrians.

EXAMPLES

Many wide avenues tend to have wide footways. The footway in the Bund in Shanghai is one of the widest in the world, but it still suffers from pedestrian congestion in the evenings.

The redesign of Götgatan in Stockholm in 2013/14 involved widening footways. Space was gained by removing two traffic lanes.

During the COVID-19 pandemic in 2020, the authorities in many cities have widened footways, extending them to car parking spaces or slip roads, using temporary barriers.

EVIDENCE

In a study in South Korea, footway width was one of the main factors influencing pedestrians' satisfaction with walking environment

Wang et al 2012 Exploring determinants of pedestrians' satisfaction with sidewalk environments: case study in Korea. Journal of Urban Planning and Development 138, 166-172.

Footway width is linked with increased stationary and social activities on a neighbourhood's commercial streets

Mehta 2007 Lively streets determining environmental characteristics to support social behavior. Journal of Planning Education and Research 27, 165-187.

An international review found that widening footways, reducing space for private motorised traffic, tends to reduce overall traffic levels, considering the altered road and alternative roads.

Cairns et al 2002 Disappearing traffic? The story so far. Municipal Engineer 151, 13-22.

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Raised/kerbed footway



Lima, Peru ©Paulo Anciaes

TYPE: Design

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Footway at a higher level than the carriageway, raised with kerbs. Raised footways can be provided in roads where previously there was no footway at all, or in roads where the footway was not physically segregated from the carriageway.

Kerbs separate pedestrians from the carriageway, reducing risk of collision with moving vehicles and the use of the footway to park vehicles. They also allow level access to buses. However, they are a barrier to people using wheelchairs or pushing prams.

To reduce their barrier effect, kerbs should be dropped (with ramps) at places where pedestrians need to cross to other side, and across side roads. As an alternative, the carriageway can be raised to the level of the footway.

The footway should be wide enough to avoid pedestrians from being forced onto the carriageway when passing other pedestrians. Tactile paving is also required where kerbs end, to assist pedestrians with mobility restrictions.

Raised kerbs facilitate the management of surface water run-off but impede the direct access of emergency, service, and delivery vehicles. They may also be a barrier to cyclists, when they are forced towards the footway by cars.

EXAMPLES

Kerbed footways have been used since ancient times but have become more common from the 18th century, with London one of the first cities building them in a systematic manner.

Kerbed footways are now common in urban areas around the world. However, many urban roads in developing countries, and rural roads everywhere, often lack raised kerbs.

In the USA there is sometimes resistance from local residents to providing kerbs in suburban roads, on the grounds that they attract strangers into residential areas.

EVIDENCE

A study in the USA found that the existence of kerbed footways encourages walking, increasing distance walked or cycled. It has a benefit-cost ratio of 1.87 (considering health benefits)

Guo and Gandavarapu 2010 An economic evaluation of health-promotive built environment changes. Preventive Medicine 50, S44-49.

Data from 495 locations in 5 cities in the USA showed that in residential or mixed use areas, pedestrian collisions were more than 2 times as likely to occur where there are no kerbed footways.

Knoblauch et al 1987 Investigation of exposure-based pedestrian accident areas: crosswalks, sidewalks, local streets, and major arterials. US Department of Transport Report FHWA-RD-87-038.

The existence of kerbs, and the depth of the surface, does not necessarily assist visually-impaired people. Tactile pavement is more important.

Ståhl et al 2010 Detection of warning surfaces in pedestrian environments: The importance for blind people of kerbs, depth, and structure of tactile surfaces. Disability and Rehabilitation 32, 469-482.

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Level footway



Blois, France ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Footway at the same level as the carriageway, not raised with kerbs. They are usually provided as a part of the redesign of the road, allocating more space and giving priority to pedestrians, and removing separations between different types of road users.

The footway can be marked or identified with a different pavement colour or texture from the one used in the carriageway. Complementary measures are often applied to reduce traffic speed (e.g. ramps, lower speed limits).

Low barriers, bollards, planters, benches, and other street furniture can be used to prevent encroachment from moving or parked vehicles on footways. Parking spaces can also be deployed to increase separation between pedestrians and moving vehicles.

Level footways facilitate the movement of pedestrians across the road but may be confusing and dangerous for pedestrians with mobility restrictions, if tactile warnings are not provided.

Level footways facilitate the direct access of emergency, service, and delivery vehicles to properties, but complicate drainage of surface water run-off. Lack of kerbs facilitates the movement of cyclists, but also encourage them to use footway space.

EXAMPLES

Rural roads and urban roads in developing and car-oriented countries lack a kerb separating vehicles and pedestrians. This is not by design but because the roads have no formal footways at all.

Level footways have become more common in central areas of many cities as part of shared spaces, part-time pedestrianisation, cycle streets, low-speed zones, and pedestrian-priority schemes.

One of the most well-known examples is Exhibition Road in London, which was transformed in 2012, removing kerbs and other separations between different types of road users.

EVIDENCE

Evidence on level footways comes mainly from studies on shared spaces. An international review of shapes where kerbs were removed was not conclusive: collisions decreased in most, but not all cases.

MVA 2009 Appraisal of Shared Space - Report to UK Department for Transport.

Level footways are problematic for pedestrians with visual, hearing, mobility, and cognitive impairments.

Hammond and Musselwhite 2013 The attitudes, perceptions and concerns of pedestrians and vulnerable road users to shared space: a case study from the UK. Journal of Urban Design 18, 78-97

A stated preference survey in London found that pedestrians were willing to pay £2.79/year as extra tax for not having kerbs on a given street - but in the context of pedestrians wanting to cross the road

Sheldon et al 2007 Valuing urban realm - business cases in public spaces. Association for European Transport Papers Repository.

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Walkable median strip



Tiraspol, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Also known as (walkable) central reservation. Space in the middle of the road (between the carriageways in the two directions) that is wide enough for pedestrians to walk along them (rather than simply using them as a traffic refuge while crossing).

Walkable medians require a suitable width along their length, including buffers to traffic, to protect pedestrians. They should also be continuous, without gaps (including those for vehicles making U-turns). They cannot be provided across road junctions.

They are usually raised from the carriageway. But they are distinct from kerbed median strips used to separate traffic lanes, because they have good-quality, smooth pavements suitable for walking and no obstacles such as lamp posts and traffic signs.

Walkable medians also enable pedestrians to stop and cross in two stages. In the places where many pedestrians cross (and at all designated crossing facilities), the walkable median should have dropped kerbs.

The median is often shared between pedestrians and cyclists. The space for both can be marked. Medians are often lined with trees or other greenery. Very wide medians are parks in themselves, with trees, water fountain, statues, and street furniture.

EXAMPLES

One of the most famous walkable median strips is Barcelona's La Rambla, which has a wide median used by many residents and visitors to stroll. It also includes many on-street shops.

Avenida da Liberdade in Lisbon is a long boulevard with a wide walkable median strip with seating areas, greenery, and public art.

Some cities have a large network of walkable media strips. As an example, many of the long, wide roads in the city centre of Tirana (Albania) have a wide walkable median strips, shared with cyclists.

EVIDENCE

A walkable median has similar benefits as a wide footway, in terms of reduced walking distance, crossing risk and delay, and improved street environment, regardless of assumptions of pedestrian route choice.

Anciaes and Jones 2016 Effectiveness of changes in street layout and design for reducing barriers to walking. Transportation Research Record 586, 39-47.

The redesign of a 4-lane road in New Jersey, adding a raised wide median, reduced pedestrian exposure risk, had a slight effect on vehicle speeds, and a negligible effect on traffic volume.

King et al 2003 Pedestrian safety through a raised median and redesigned intersections. Transportation Research Record 1828, p56-66.

Adding a median strip to a road has an estimated monetary benefit for pedestrians crossing the road of £1.08 for each walking trip. However, this was in the context of crossing the road.

Anciaes and Jones 2018 A stated preference model to value reductions in community severance caused by roads. Transport Policy 64, 10-19.

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Pedestrian fast/slow lanes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Separation of the walking area in footways or walkable median strips into different sub-areas, for pedestrians walking at different speeds. This type of arrangement is very rare but could be useful in areas that have many and diverse types of pedestrians

Fast lanes could be used by commuters - useful on routes leading to busy stations or employment centres. Another possibility is lanes for joggers or for micromobility users - useful in recreational areas such as waterfront roads or wide boulevards.

Slow lanes could be used by people looking at mobile phones, strolling, or window shopping; tourists (especially if in large groups); people carrying luggage/shopping bags, pushing prams or using/pushing wheelchairs; and all those who walk slowly

The separation between fast/slow lanes could be achieved simply by markings on the pavement. If pedestrian flows are high, space for a new fast or slow lane could be taken from the kerbside area, substituting car parking space.

The idea of pedestrian fast/slow lanes has generated some discussion but has usually been met with scepticism because of doubts about whether pedestrians will comply and walk in the lane assigned to their speed.

EXAMPLES

There have been reports of short-term trials of slow walking lanes for mobile phone users in some Chinese, Belgium, British, and American cities.

Information about these initiatives is scant and unreliable (mostly reported by tabloids). Initiatives have not been result of public policies but marketing strategies or social experiments.

As an example, a marketing strategy by a department store in Liverpool (UK) in 2015 involved a short-term implementation of a pedestrian fast lane in a shopping street.

EVIDENCE

There is no reliable evidence on the impacts of separating footways into fast/slow lanes for pedestrians

There is much evidence, however, on the impact of distracted walking by pedestrians looking at their mobile phones.

Scopatz and Zhou 2016 Effect of electronic device use on pedestrian safety: a literature review. Report DOT HS 812 256. National Highway Traffic Safety Administration.

There is also evidence that pedestrians walk at different speeds depending on the activity they are performing (with baggage, using phone) and purpose (going somewhere, doing exercise)

Ratogi et al 2011 Design implications of walking speed for pedestrian facilities. Journal of Transportation Engineering 137, 687-696.

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Add/improve street furniture



Skopje, North Macedonia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Street furniture includes structures providing shade/shelter for pedestrians/bus users, seating areas, public toilets, information boards, lighting, bins, utility boxes, cycle parking/rental, traffic signs/signals, water fountains, and public art.

Adding more street furniture, or improving the quality of materials and appearance of existing furniture can enhance the experience of the road for its different users and contribute to sense of place. But it can also create visual clutter

Street furniture on the footway can obstruct the movement and visibility of pedestrians. At the kerbside, it can obstruct service/emergency vehicles. Most street furniture requires more space than its physical size, for its (intended and unintended) uses.

If on footway, it should be aligned, or placed in footway extensions, leaving a clear zone for pedestrians moving along the road. Street furniture should be between pedestrians and the carriageway, acting as a buffer, and allowing access to buildings.

The organisation/harmonization of the different types of street furniture is complex because it requires coordination of different agencies, each responsible for different street furniture.

EXAMPLES

Street furniture is a feature of most roads used by pedestrians. Many cities have started to improve street furniture due to increased awareness of its role enhancing pedestrian experience

Skopje (North Macedonia) implemented a large, costly, and controversial program (Skopje 2014) for installing a large amount of street art (together with new buildings and monuments).

Some street furniture has become unnecessary recently (e.g. phone boxes), while other has become more common (e.g. digital information boards) and 'smarter' (equipped with sensors)

EVIDENCE

Street furniture contributes to sense of place and perceived quality of street. Interaction with street furniture enhances the use of the street and contributed to urban quality of life

Siu and Wan 2011 Roles of street furniture in a constructed environment. International Journal of the Constructed Environment 1 183-203.

A stated preference survey in London found that pedestrians were willing to pay £2.23/year for having plants and public art on a given street (compared with £1.65/year for having only plants).

Sheldon et al 2007 Valuing urban realm - business cases in public spaces. Association for European Transport Papers Repository.

A model of pedestrian activity in New York found that the number of pedestrians on a street is positively associated with the number of pieces of street furniture - after controlling for other factors.

Ewing et al 2016 Streetscape features related to pedestrian activity. Journal of Planning Education and Research 36, 5-15.

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Add/improve street lights



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Structures illuminating the road carriageway and footway. They should be placed along the road and at junctions, and illuminate bus stops, cycle parking, pedestrian crossings, and the pedestrian refuges in the middle of the road.

Lighting enables the movement of pedestrians at night, illuminating the footway, obstacles, and other pedestrians. It also increases the intervisibility of all road users, reducing the risks of collisions. But it increases traffic speeds.

Lighting posts can be placed on the footway or along the kerbside area of the carriageway. But they should not reduce the clear path for pedestrians and cause clutter and obstruct movement. As an alternative, lights can be attached to buildings.

The height of the lights depends on the type of area and mix of different users. Lower-level lights are better for pedestrians than higher-level lights and cause less intrusion on residences.

Lighting levels depend on volumes of pedestrians and cyclists. They should be regular along the road (to avoid dark spots) and consistent (to help the visually-impaired). Lighting levels can be adjusted dynamically to the ambient light levels.

EXAMPLES

Street lighting has been used since Ancient times but has become more common from the 18th century, with London one of the first cities to use it in a systematic manner.

Street lighting has evolved, as it incorporated new technologies. The use of LED lighting is growing - it is cheaper and less intrusive. Milan has switched 100,000 street lights to LED in 2015.

Lyon was the first European city to develop a lighting master plan. In the main street, facade lighting emphasises historical buildings and public spaces.

EVIDENCE

Street lighting leads to reductions in crime and fear of crime and increase pedestrian use of the streets after dark.

Painter 1996 The influence of street lighting improvements on crime, fear and pedestrian street use, after dark. Landscape and Urban Planning 35, 193-201.

A stated preference study found that improved street lighting generates a benefit (in terms of less accidents and crime, and better environment) of £3/person/year.

Willis et al 2005 Estimating the value of improved street lighting: a factor analytical discrete choice approach. Transportation Research Record 42, 2289-2303.

In a study in Norway, traffic speeds increased significantly by 3.6 km/h after road lighting was installed and were 5% higher than in a control road section.

Assum et al 1999 Risk compensation - the case of road lighting. Accident Analysis and Prevention 31, 545-553.

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Add/improve rest points



Bender, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Structures for pedestrians to sit in public areas along the street. Includes benches and blocks. They can be located along the footway or in plazas. Some seating can be movable (e.g. chairs), for temporary use across a designated area.

Seating allow pedestrians to break their trips, especially for older and disabled people. They also provide opportunity to spend time. Rest points are usually under a tree. In some cases, they are designed to offer protection from sun and rain.

Rest points should be installed at appropriate intervals (25-150m, depending on the type of street), in areas with many pedestrians. In shopping areas, they allow pedestrians to rest when carrying shopping bags.

Rest points can also obstruct the movement and visibility of pedestrians, especially those with visual impairments. To prevent this, they can be placed on footway extensions, possibly replacing car parking spaces.

Private outdoor cafes and restaurants, benches in bus stop shelters, and informal seating areas (steps, low walls) should complement, not substitute, rest points in public areas.

EXAMPLES

Street benches have become common from the 19th century and are a feature of most cities, in different variants and conditions. They are less frequent in car-dominated societies such as the USA.

There is a movement for cities to provide benches with unique designs that increase sense of place. Technology has also been added (e.g. wi-fi, phone charging, lighting).

At the same time, there are many examples of authorities removing street benches, or making them more uncomfortable to dissuade homeless people from using them.

EVIDENCE

The presence of public seating facilities contributes to stationary and social activities on neighbourhood commercial streets

Mehta 2007 Lively streets determining environmental characteristics to support social behavior. Journal of Planning Education and Research 27, 165-187.

The availability of seating is positively associated with the walking for transport among older people. The evidence is stronger for the 75+ age group.

Cerin et al 2017 The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. International Journal of Behavioral Nutrition and Physical Activity 14:15.

A stated preference survey in London found that pedestrians were willing to pay £3.07/year as extra tax for having seating areas on a given street.

Sheldon et al 2007 Valuing urban realm - business cases in public spaces. Association for European Transport Papers Repository.

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Declutter footway



Bardejov, Slovakia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Reduce physical and visual clutter caused by design elements (bus stops, cycle parking, bollards), street furniture (benches, lighting poles, post boxes, litter bins), traffic equipment (signs, lights), utilities, and advertising boards.

Decluttering can be achieved by reducing or removing unnecessary objects, align them outside the clear path for pedestrians, group them (e.g., into a single pole), fix them to walls or buildings (rather than posts), or relocate them in footway extensions.

Clutter can also be reduced by mounting lights onto buildings and placing utility boxes and household bins within buildings. Traffic signs can be placed on footway extensions, rather than on the clear path for pedestrians.

Reducing clutter is difficult because each design element on the footway serves the needs of some road user or function (e.g. traffic signs for users moving, cycling parking, bus stops, and benches for users not moving).

Removing elements or harmonising their arrangement and appearance is complex because it requires the agreement of different agencies, each responsible for different objects

EXAMPLES

There is a trend in many countries to declutter footways by removing unnecessary street furniture. The need to declutter has been included in many national and city-level guidance documents.

As an example, Transport for London had been including decluttering within all transport schemes since 2016, removing thousands of unnecessary signs, bollards, and guard railing.

Decluttering footways is often a step for the transformation of streets into shared spaces, which are becoming increasingly common in Europe.

EVIDENCE

Street clutter is one of the main factors enhancing the quality of city streets for pedestrians.

Davis 2002 Street clutter: what can be done? Municipal Engineer 151, 231-240.

Decluttering footways contributes to social inclusion: cluttered footways were identified as one of the reasons why older people do not visit shopping areas in London.

London Travel Watch 2015 Inclusive Streets.

Schemes to improve the urban realm, including decluttering, tend to increase pedestrian volumes, retail sales, and property prices - but it is difficult to isolate the role of decluttering in that impact.

Heart Foundation 2011 Good for business - the benefits of making streets more walking and cycling friendly. Discussion paper.

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Shared space



Trondheim, Norway ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Design approach that aims at a balanced distribution of space by removing formal demarcations between different types of road users. The hypothesis is that road users become more aware of each other and behave more cautiously.

Shared spaces remove all barriers separating pedestrians from vehicles, traffic signs, and most road markings. They are more suitable in places with low volumes of vehicles and high volumes of pedestrians.

The implementation of a share space is usually accompanied by bans to car parking, time restrictions to loading, removal of unnecessary street furniture, lower speed limits (to 20-30 km/h) and improvement of the public realm (e.g. high-quality pavements).

Shared space requires an adequate provision for pedestrians with visual and mobility impairments (e.g. tactile pavement), lighting, and water drainage. Cycle parking is provided, but often at the edges of the space, to reduce obstructions.

The shared space approach has been criticized because it does not go far enough in reducing the role of motorised vehicles and it does not address the needs of blind and partially-sighted people and those with cognitive difficulties.

EXAMPLES

The concept of shared space originated in the Netherlands in the late 1990s. One of the first example was the Laweiplein in Drachten. There are many examples in Dutch cities.

In Shared Zones in Australia and New Zealand, space is shared by vehicles and pedestrians and the latter have priority. Unlike shared spaces elsewhere, there is no major redesign of the road.

There was growing interest in shared spaces in the UK at the beginning of the 21st century, but also protest from some road users. Official guidance on shared spaces was withdrawn in 2018

EVIDENCE

An international review of the safety impact of shared spaces did not find conclusive evidence. The implementation of share spaces decreased collisions in most, but not all, cases

MVA 2009 Appraisal of Shared Space - Report to UK Department for Transport.

Pedestrians with visual, hearing, mobility, and cognitive impairments tend to dislike these schemes because of fear of collision with cars.

Hammond and Musselwhite 2013 The attitudes, perceptions and concerns of pedestrians and vulnerable road users to shared space: a case study from the UK. Journal of Urban Design 18, 78-97

A video survey of one shared space found that the space was not used as intended. Most pedestrians did not walk in the middle of the road, and ran across the road. 80% felt less safe than before.

Moody and Melia (2014) Shared space - implications of recent research for transport policy. Proceedings of the Institution of Civil Engineers.

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Inclusive design



Thessaloniki, Greece ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (walking along road)

DESCRIPTION

Also known as universal/accessible design. Changes in road design (e.g. footway, cycling infrastructure, car parking) to provide for all people, including children, older people, and those with mobility, sensory, and cognitive impairments.

Achieving inclusive design usually includes widening the footway, providing more space for blind pedestrians with assistance, and pedestrians using a walking cane, crutches, wheelchair, or a mobility scooter.

It also includes removing obstructions, providing gentle dropped kerbs, and reducing crossing width with footway extensions and pedestrian refuges. If there is cycling infrastructure, it should accommodate tricycles, quadricycles, and hand cycles.

Other required elements include audible signals at crossings and tactile pavement and colour-contrast to separate footway from carriageway and to identify obstructions and side roads, steps, crossings, and access to public transport.

Parking spaces for disabled should be provided, with the appropriate space requirements (including space for the movement of wheelchair users), dropped kerbs for easier access to the footway, and located near to building entrances

EXAMPLES

Inclusive design has been integrated into national-level regulations in many countries, e.g. Sweden adopted a national plan in 2000 for disabled people, including improving the accessibility of public space.

There is growing interest in making streets more adequate for children, often focusing in specific low-speed zones in residential areas (play streets)

For older and disabled persons, and children, barriers to walking have increased, rather than decreased, in fast-growing cities in developing countries due to widening of roads and increase in motorised traffic.

EVIDENCE

There is consistent quantitative evidence that the quality of pedestrian infrastructure and presence of barriers are associated with the walking for transport among older people.

Cerin et al 2017 The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. International Journal of Behavioral Nutrition and Physical Activity 14:15.

There is also consistent qualitative evidence that pedestrian infrastructure, pedestrian-cyclist separation, and other design aspects, influence the propensity to walk among older people.

Moran et al 2014 Understanding the relationships between the physical environment and physical activity in older adults: a systematic review of qualitative studies. International Journal of Behavioral Nutrition Physical Activity 11:79

Improving street accessibility has a positive impact on travel and independence of disabled people

Matthews et al 2015 The impact of street accessibility on travel and independence for disabled people. 14th International Conference on Mobility and Transport for Elderly and Disabled Persons, Lisbon

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PART 2

Measures aimed at pedestrians (crossing)

Add pedestrian crossing facilities



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Installation of additional pedestrian crossing facilities along a road. These can be formal facilities, where drivers are legally required to stop (e.g. signalised or marked crossings), or informal ones (e.g. dropped kerbs and traffic islands)

Crossings can be provided by creating a gap in a section that has guardrailling or be added in a section where pedestrians cross informally. They should be provided at regular intervals along the road (80-100m) but aligned with pedestrian desire lines.

Crossing facilities are required in places with high pedestrian flows, two or more traffic lanes, or high traffic volumes (>3000/day) and speeds (>30km/h). They should also be installed near schools, hospitals, and parks.

Crossing facilities should be provided at every road junction (in all legs), and mid-block, near main pedestrian destinations (e.g. public transport nodes), to avoid detours and the propensity of pedestrians to cross in unsafe places.

The crossings should be as wide as the footway's clear path. They also require waiting areas (e.g. kerb extensions), lighting, and measures to slow down traffic. Car parking should be restricted to make drivers and pedestrians more visible.

EXAMPLES

The first pedestrian crossing was installed in London in 1868. They became widespread as motorised traffic grew in the 20th Century. Their specifications vary from country to country.

Many countries have regulations regarding where crossings need to be installed, depending on vehicle and pedestrian flows and type of area.

Fast-growing cities in developing countries tend to also expand fast their road network but pedestrian crossings are not always provided.

EVIDENCE

A study in a city with few crossing facilities (Riyadh in 2002) found that 77% of vehicle-pedestrian collisions occurred away from a crossing or in places where no crossing existed.

Al-Ghamdi 2002 Pedestrian-vehicle crashes and analytical techniques for stratified contingency tables. Accident Analysis and Prevention 34, 205-214.

A study in the US found that the existence of crossing facilities was one of the main factors explaining propensity for walking for leisure

Ginn et al 2007 Exploring associations between physical activity and perceived and objective measures of the built environment. Journal of Urban Health 84, 162-184.

Installing a new crossing facility removes or reduces the perceived barrier effect of the road for pedestrians and the associated monetary cost, with the benefit depending on the type of facility provided.

Anciaes and Jones 2020 A comprehensive approach for the appraisal of the barrier effect of roads on pedestrians. Transportation Research A 134, 227-250.

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Align pedestrian crossings with desire lines



New York City, USA ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Provision of crossing facilities in locations where many pedestrians need to cross the road and aligned with the shortest crossing path across the two sides of the road. The aim is to reduce detours and the propensity to cross in unsafe locations.

Crossing facilities should be provided near the main entrances to major pedestrian destinations (public buildings, shops, stations, parks) and be aligned with similar places, and with road junctions, bus stops, car/cycle parking spaces on the other side.

Aligning crossings with desire lines is particularly important near hospitals (to reduce detours) and schools and other places used by many children (to prevent them from dashing across the road in unsafe locations).

Crossing facilities should be provided at road junctions, in all legs, and be aligned with the footways on both sides. However, in junctions with more rounded corners, the crossings should be offset to minimise the crossing distance.

Aligning crossings with desire lines may increase conflicts with other users, if the desire lines overlap with the path of other modes. Measures are needed to slow down motorised traffic approaching the crossing.

EXAMPLES

Alignment of crossings with desire lines is routine practice in many countries and has been integrated in national-level guidance on road design (for example in the UK).

Planners often follow advice of space syntax researchers to ensure new projects satisfy desire lines - an example was the redesign of the complex Elephant and Castle junction in London in 2015.

Crossings are sometimes installed after planners observe evidence of pedestrian crossing behaviour (e.g. the paths they leave in the grass/dirt). In other cases, evidence of desire lines is ignored.

EVIDENCE

In a survey in Scotland, 15% of participants stated the reason for not using a crossing facility was that it was not on route.

Sharples and Fletcher 2000 Pedestrian perceptions of road crossing facilities. Scottish Executive Central Research Unit.

Unsatisfied desire lines (e.g. desire lines without a crossing facility) are associated with more vehicle-pedestrian collisions.

Campos and Pinedo 2017 Unsatisfied desire lines: a spatial approach to pedestrian collision analysis. Proceedings of the 11th Space Syntax Symposium.

Pedestrians will avoid making a walking trip if they have to make a detour of 16 minutes to cross the road using a crossing facility (in a road where it is impossible to cross otherwise because of barriers)

Anciaes and Jones 2018 Estimating preferences for different types of pedestrian crossing. Transportation Research F 52, 222-237.

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Footway extensions



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Widening of the footway in a specific location (not along the whole road section), narrowing the carriageway. The extensions can include street furniture, trees, planted areas, bus stops, or be used by vendors and street activities.

Footway extensions reduce crossing distance, increase the visibility of pedestrians for drivers, reduce traffic speeds, and provide space for pedestrians waiting to cross, reducing conflicts with those walking along the road.

They are known as gateways (if at the entrances of low-speed streets) or pinchpoints (if mid-block, near places where pedestrians need to cross). They should extend beyond the width of the crossing and can be combined with speed humps/tables.

Footway extensions are usually created from car parking spaces. They allow bus stops to be extended close to the crossing, without affecting sightlines. They also reduce the scope for adding slip lanes (for vehicles turning) to junctions.

Extensions can squeeze cyclists, if the remaining space still allows cars to pass them. Extensions should be wide enough for cars to pass cyclists safely or narrow enough so overtaking is impossible. They should also allow access of emergency vehicles.

EXAMPLES

Gateways are used in many residential areas in Western Europe, at entrances to low-speed areas.

The transformation of Second Avenue in New York in 2010 involved constructing footway extensions (at a first stage, marked, then kerbed)

The Creative Crosswalks and Curb Extensions program of the Portland Bureau of Transportation supports community actions to paint kerb extensions

EVIDENCE

A study in the US found that footway extensions increase the probability that drivers stop for pedestrians - explained by increased visibility of pedestrians.

Johnson 2005 Pedestrian safety impacts of curb extensions: a case study. Report for Oregon Department of Transportation SPR304-321.

A comparison of safety reduction measures found that footway extensions were the most effective in reducing traffic speed near zebra crossings

Bella and Silvestri 2015 Effects of safety measures on driver's speed behaviour at pedestrian crossings. Accident Analysis and Prevention 83. 111-124.

Kerb extensions are also associated with pedestrian safety at signalised crossings. A study in Montreal found they decrease injuries by 24%.

Stipancic et al 2020 Pedestrian safety at signalized intersections: modelling spatial effects of exposure, geometry and signalization on a large urban network. Acc. Analysis Prevention 134: 105265

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Signalised pedestrian crossings



Helsinki, Finland ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Pedestrian crossings where drivers are required to stop at an automated red signal. They can be located at road junctions or mid-block, and can be divided into two separate crossings (straight or staggered), with a refuge in the middle.

The signals usually have two main phases (green and red), with an intermediate phase when red light is flashing, indicating pedestrians should not start crossing. The crossing may include push buttons to call the green phase and countdown displays.

The legal requirement for drivers to stop can be reassuring for pedestrians, especially those with impairments. However, long waiting times can lead to risky behaviours (cross during red phase or cross in other, more dangerous, locations).

Signalised crossings are suitable in places with high volumes of vehicles and pedestrians and with high traffic speeds ($>30\text{km/h}$). The signals can be inactive at night to save energy, if the traffic volume is low

Clearance time is required before vehicles start moving. At junctions, a head start should be given to pedestrians ahead of vehicles turning. Tactile pavements and acoustical green time signals are required for the visually impaired.

EXAMPLES

Signalised pedestrian crossings have existed since the early 20th Century, but have changed over the years, incorporating new technology and adapting to transport policies and traffic management systems.

Signalised crossings are common in cities around the world, but there is a wide variation in types and lengths of signal phases, design, available facilities, and regulations.

There is a tendency in many countries to convert marked crossings (zebras) or informal crossings to signalised crossings, for safety reasons.

EVIDENCE

There is a high incidence of non-compliance by pedestrians at signalised crossings (crossing against fixed or flashing red light or far from the crossing), increasing collision risk.

King et al 2009 Illegal pedestrian crossing at signalised intersections: incidence and relative risk. Accident Analysis and Prevention 41, 485-490.

Nevertheless, the odds of severe injury are considerably lower at signalised crossings than at unsignalised ones.

Rothman et al 2012 Pedestrian crossing location influences injury severity in urban areas Injury Prevention 18, 365-370.

In a study in China, 25% of respondents stated they were not willing to use signalised crossings, the majority citing delays (walking to access the crossing and waiting for the red time)

Tanaboriboon, Y., & Jing, Q. (1994). Chinese pedestrians and their walking characteristics: Case study in Beijing. Transportation Research Record, 1441, 16-26.

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Pedestrian countdown



Santiago, Chile ©Paulo Anciaes

TYPE: Design

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Displays at pedestrian signalised crossings showing the duration of the current signal phase (red or green), informing pedestrians know how long they still have to cross (if the signal is green) and how long they have to wait (if the signal is red).

The countdown may be displayed only during the green phase for pedestrians (not the red phase), at the beginning of the green phase, or only a few seconds before the phase ends.

Countdowns are useful in multi-lane or wide roads, in busy junctions, used by many vehicles and pedestrians, and near schools. The objective is to reduce the incidence of illegal crossing behaviour, improving safety and facilitating traffic flow.

Countdowns during the green phase may encourage pedestrians to start crossing in the final seconds or to take longer to cross, if there are many seconds left. Countdowns during the red phase may encourage pedestrians to cross, if the wait is long.

The display should be clear be visible by all pedestrians, including those behind others, or far from the signal, in wide crossings. They are not useful for visually impaired pedestrians, so they need to be complemented with audible signals.

EXAMPLES

Singapore was one of the first cities in the world to install pedestrian countdown displays in signalised crossings, in the late 1990s.

Pedestrian countdowns have become popular after the 2010s and installed in cities in all sizes, with numerous examples in the North American cities.

The transport authorities in several countries (e.g. USA) have started to recommend that pedestrian countdown displays are installed by default in new signalised crossings in busy junctions.

EVIDENCE

A review of comparison and before-after studies found mixed evidence. But in most studies, countdowns were associated with an increase in proportion of pedestrians crossing in the red phase.

Kennedy and Sexton 2009 Literature review of road safety at traffic signals and signalised crossings. Transport Research Laboratory Report PPR436.

Surveys and interviews in Greece showed that pedestrians feel safe when using crossings with countdown displays and think that contributes to a more appealing urban environment.

Lambrianidou et al 2013 Can pedestrians' crossing countdown signal timers promote green and safe mobility? Sustainable Cities and Society 6 33-39.

A study of signals near schools in China found that pedestrian countdown during the green phase increased children's compliance but countdown during the red phase decreased compliance.

Fu and Zou 2016 The influence of pedestrian countdown signals on children's crossing behavior at school intersections. Accident Analysis and Prevention 94 73-79.

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Pedestrian crossings: variable crossing time



Hereford, UK ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Signalised crossing facilities with sensors to detect the presence of pedestrians in the waiting area and in the crossing. The green phase for pedestrians is extended if there are still pedestrians crossing. Flashing or yellow phases are not used.

The green phase is usually called by pedestrians by buttons and starts with some delay, provided pedestrians are detected in the waiting area. If pedestrians cross early or leave the waiting area, the green phase is cancelled.

The pedestrian signals are sometimes on the same side of the road, to assist visually-impaired users and encourage pedestrians to look at traffic before crossing. Audible signs during the green phase are also used.

These crossings are useful for pedestrians with a slower walking speed. They also optimize signal timings to reduce overall delays for pedestrians and vehicles, as the duration of green phases is adjusted to the demand for crossing.

The success of these crossings depends on the reliability of the detectors and the time lag between pedestrians pushing the button and the start of the green phase. The crossings are also more expensive to install/operate than conventional ones.

EXAMPLES

Puffin crossings (Pedestrian user-friendly intelligent) were introduced in the UK in the 1990s and detect pedestrians, adjusting the green phase. Signals are on the same side of the road.

Signalised crossings with automated detection of pedestrians have also been introduced in many American cities, operating similarly to puffin crossings, but with the signal on the other side.

The Ped-SCOOT system in London optimised the green phases for pedestrians across the city based on demand, estimated from detection equipment.

EVIDENCE

In four sites in the US, green light based on automatic detection of pedestrians reduced pedestrians who began to cross during the red phase in 52%-88% and pedestrian-vehicle conflicts in 40%-90%

Hughes et al 2000 Automated detection of pedestrians in conjunction with standard pedestrian push buttons at signalized intersections. Transportation Research Record 1705, 32-39.

Before-and-after studies of the replacement of conventional signalised crossings with crossings with variable crossing time have not been conclusive regarding impact on collisions.

Kennedy and Sexton 2009 Literature review of road safety at traffic signals and signalised crossings. Transport Research Laboratory Report PPR436.

In a survey in Scotland, puffin crossings were identified as the least preferred of 10 types of crossing (including "no crossing"). It was preferred by only 3% of respondents.

Sharpley and Fletcher 2000 Pedestrian perceptions of road crossing facilities. Scottish Executive Central Research Unit.

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Leading pedestrian interval



Dubai, UAE ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Also known as early release signal timing. Head start given to pedestrians ahead of vehicles turning at junctions. This is implemented through a short signal phase that is exclusive for the movement of pedestrians.

The duration of the interval depends on the site layout and volumes and types of vehicles and pedestrians. It is usually 3-7 seconds. It should be enough to allow slower pedestrians to cross one lane, to be clear from the space used by turning vehicles.

The measure is especially useful in junctions with many turning vehicles, many large vehicles in the traffic, and many children, elderly, and people with mobility impairments in the pedestrian flows.

The measure addresses the safety of pedestrians crossing from the nearside. The few seconds of head-start are usually not enough for pedestrians crossing from the farside to avoid conflicting movements with turning vehicles on the nearside.

To ensure safety, the measure still requires that vehicles and pedestrians are visible to each other - for example, by banning car parking and stopping in the approach to the junction.

EXAMPLES

Leading pedestrian interval has been implemented in USA cities since the 1960s, being first included in traffic management guidance in 1961. This measure is now common in many countries.

In some places there is a systematic process to identify junctions that require leading pedestrian intervals and assess their performance. One example is the city of Toronto (Canada)

The measure is only applied in countries where vehicles are allowed to turn during the green phase for pedestrians. In other countries, it is unnecessary.

EVIDENCE

A review of studies of the effects of leading pedestrian intervals generally show a reduction in vehicle-pedestrian conflicts and crashes

Saneinejad and Lo 2015 Leading pedestrian interval - assessment and implementation guidelines. Transportation Research Record 2519, 85-94.

As an example, a before-after analysis in 24 crossings in Pennsylvania found that advance signal control led to a reduction of 59% in pedestrian-vehicle collisions.

Fayish and Gross 2010 Safety effectiveness of leading pedestrian intervals evaluated by a before-after study with comparison groups. Transportation Research Record. 2198, 15-22.

A cost-benefit analysis of one case found a positive net benefit: the benefits of the reduction of vehicle-pedestrian risk are larger than the costs of the delays for vehicle drivers.

Sharma et al 2017 Leading pedestrian intervals: treating the decision to implement as a marginal benefit-cost problem. Transportation Research Record 2620, 96-104.

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Decrease waiting time at pedestrian crossings



London, UK ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Reduction of waiting time for pedestrians crossing the road. This is achieved, at signalised crossings, by shortening the red phase, and at all crossings, by reducing the number of crossing stages (removing the need to wait in the median strip).

At signalised crossings, waiting time can be reduced simply by shortening the whole traffic signal cycle. However, this may imply a shorter time for pedestrians to cross.

At road junctions, a new phase for pedestrians can be introduced in-between the phases for vehicles. An exclusive, longer, pedestrian phase will imply longer waiting times, as a minimum of two stages would be required for the movement of vehicles.

Waiting time for pedestrians can also be decreased using sensors to automatically detect pedestrians waiting, and activating the green phase. Buttons can be provided for pedestrians to request the green phase.

The measure may be applied at some times of day only, depending on the flows of pedestrians and vehicles. Waiting times may also be reduced when schools close, to prevent children from running across the road on a red signal.

EXAMPLES

In 2017 Dubai Road and Transport Authority replaced signalised crossings in the city centre, using sensors that detect pedestrians and reduce waiting times for pedestrians.

Crossings where pedestrians can push buttons to reduce waiting time. Some (e.g. puffin crossings in the UK) combine that functionality with detection of pedestrians in waiting area.

Transport for London's Signal Timing Review Programme has reviewed 606 signals in 2019, saving an estimated 1256 hours a day to pedestrians.

EVIDENCE

Decreasing waiting time increases pedestrian safety. Long waiting times lead to dangerous crossing behaviour by pedestrians (crossing during the red phase)

Brosseau et al 2013 The impact of waiting time and other factors on dangerous pedestrian crossings and violations at signalized intersections. Transportation Research F 21, 159-172.

A study of two crossings in Florida found that the shorter the waiting time, the higher the rate of pedestrian compliance, especially in the crossing with lower traffic volumes

Van Houten et al 2007 Effects of various minimum green times on percentage of pedestrians waiting for midblock "walk" signal. Transportation Research Record 2002, 78-83.

Long waiting times cause delays. In busy roads, delays affect even pedestrians who arrive during the green phase and those who do not comply with the signals

Li et al 2005 Pedestrian delay estimation at signalized intersections in developing cities. Transportation Research A 39, 61-73.

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Increase time to cross at pedestrian crossings



Chisinau, Moldova ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Increase of the duration of the green phase for pedestrians at signalised pedestrian crossings. This can be achieved by extending the whole traffic signal (which implies an increase waiting time for pedestrians) or just the pedestrian phase.

The time to cross can also be increased based on actual use of the crossing, using sensors to automatically detect pedestrians that have not completed crossing, and automatically extending the green phase until they do.

Longer green phases enable pedestrians to cross in one stage, reducing the risk of still being in the carriageway when vehicles start moving, or the frustration of being stranded in the median strip and having to wait for the next phase.

Longer times to cross are useful when there are many pedestrians crossing at same time (especially when from both sides of the road), as it allows all pedestrians to complete crossing within the green phase.

The measure should be applied near hospitals and care homes, and in locations with many pedestrians walking slowly (e.g. parks). The measure may be applied at some times of day only, depending on the flows of pedestrians and vehicles.

EXAMPLES

From 2019, the UK government recommended traffic engineers to reduce the assumed walking speed for the clearance time on signalised crossings from 1.2m/s to 1m/s

In Bangalore (India) there was a programme started in 2015 to allocate more time to pedestrians in crossings in the centre, increasing time to cross from only 10 seconds

There are systems in Hong Kong and Singapore that allow older/disabled pedestrians to extend green time by tapping a traffic pole with a personalised card

EVIDENCE

Reducing time to cross benefits older pedestrians. Evidence shows that time to cross at signalised crossings is not enough for older pedestrians, as it is not consistent with their usual walking speeds.

Asber et al 2012 Most older pedestrians are unable to cross the road in time: a cross-sectional study. Age and Ageing 41, 690-694.

In roads with cycling infrastructure, it is more difficult for older people to finish crossing during the green phase, as found in a study of 135 crossings in Montreal.

Lachapelle and Cloutier 2017 On the complexity of finishing a crossing on time: elderly pedestrians, timing and cycling infrastructure. Transportation Research A 96, 54-63.

Some studies show different evidence: a study of vehicle-pedestrian collisions in Lima (Peru) shows that a longer pedestrian phase was associated with a higher collision risk.

Quistberg et al 2014 Pedestrian signalization and the risk of pedestrian-motor vehicle collisions in Lima, Peru. Accident Analysis and Prevention 70, 273-281.

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Two-step/staggered pedestrian crossings



Hull, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Separation of a pedestrian crossing into two crossings. Pedestrians wait in the middle of the road, at a refuge or median strip, often surrounded by guard railings. The crossings are usually signalised, stopping traffic in each direction separately.

Compared with straight crossings, staggered crossings increase crossing distance (due to the detour in the middle) and crossing time (due to the need to wait twice). They also use more roadspace, as they require facilities in the median strip.

Staggered crossings increase driver-pedestrian intervisibility. Pedestrians can face the direction of oncoming vehicles at each stage. The signals in the middle and the two sides should not be too aligned to avoid confusion for pedestrians.

These crossings are more suitable in road sections with wide carriageways (>11m) and high traffic volumes and speeds. They are provided mainly in two-way roads. Staggered crossings are more expensive to install than straight crossings.

The refuge in the middle should be wide enough (>3m) to accommodate all pedestrians crossing from both directions. To make the crossings more convenient, the signal phases can be coordinated so pedestrians do not have to wait in the middle.

EXAMPLES

Staggered crossings are common in the UK in multilane roads, often replacing, or complementing footbridges.

Staggered crossings are also common in the USA and Australia, where they are known as Danish Offsets.

In many cities in developing countries, footbridges and underpasses are usually the preferred solution in urban busy roads.

EVIDENCE

A stated preference study found that on average pedestrians do not have a preference for using staggered, rather than straight signalised crossings. However, women prefer staggered crossings.

Anciaes and Jones 2018 Estimating preferences for different types of pedestrian crossing. Transportation Research F 52, 222-237.

In a study in Portland (USA), only 52% of pedestrians followed the staggered crossing pattern, with the others crossing in a direct path, over the median kerb.

Foster et al 2014 Evaluating driver and pedestrian behaviors at enhanced, multilane, midblock pedestrian crossings. Case study in Portland, Oregon. Transportation Research Record 2464, 59-66.

A staggered design increases the probability that drivers will stop for pedestrians at unsignalised crossings.

Pulugurtha et al 2012 Evaluating effectiveness of infrastructure-based countermeasures for pedestrian safety. Transportation Research Record 2299, 100-109.

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Zebras (marked crosswalks)



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Also known as marked crosswalks or simply crosswalks. Pedestrian crossing facilities not controlled by automated traffic signals. In most countries, drivers are legally required to give way to pedestrians at zebra crossings.

Zebra crossings are identified by a set of standardized elements, such as stripes (usually white), signs, posts with flashing lights, road markings (e.g. zigzag lines on the approach to the crossing, dotted lines across the carriageway)

These crossings can be divided into two separate facilities, with a pedestrian refuge in the middle. The width of zebra crossings should be 2.4-10m, depending on pedestrian demand. Refuge islands can be used.

Zebra crossings are suitable when traffic speeds are low and the volumes of pedestrians and motorised vehicles are below the level that would justify the costs of signalisation. They require measures to slow down traffic approaching the crossing.

Zebra crossings should be visible to drivers and have adequate lighting. Flashing beacons can be used to increase visibility and reduce traffic speed. Car parking and stopping should be banned to ensure visibility of pedestrians.

EXAMPLES

Zebra crossings were introduced in the UK in 1934 and are one of the most common types of pedestrian crossing facilities around the world, although their characteristics and regulation vary.

In some countries, zebra crossings consist only of white stripes across the road. In others, white stripes are used even in non-zebra crossings (e.g. signalised crossings).

In Sweden, many zebra crossings were removed (and replaced by informal or courtesy crossings), for safety reasons. In the UK, new crossings in busy areas tend to be signalised, not zebra crossings.

EVIDENCE

The safety record of zebra crossings tends to be poor, because drivers do not always stop for pedestrians and pedestrians may have an unwarranted sense of safety

Gitelman et al 2012 Characterization of pedestrian accidents and an examination of infrastructure measures to improve pedestrian safety in Israel. Accident Analysis and Prevention 44, 63-73.

However, removing zebra crossings without providing any other pedestrian crossing facilities may decrease safety even more

Mitman et al 2008 Marked-crosswalk dilemma - uncovering some missing links in a 35-year debate. Transportation Research Record 2073, 86-93.

The propensity of drivers to yield to pedestrians depends on many design characteristics of the crossings, especially the visibility of the crossing.

Turner et al 2006 Motorist yielding to pedestrians at unsignalized intersections - findings from a national study on improving pedestrian safety. Transportation Research Record 1982, 1-12.

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Informal/unmarked pedestrian crossings



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Pedestrian crossings that are not signalised nor marked (like zebras). At a minimum, they include dropped kerbs, and in some cases kerb extensions and a pedestrian refuge in the middle of the road. Drivers are not legally required to stop but can do so.

Usually there are no signs identifying the crossing, for drivers or pedestrians. At the footway, dropped kerbs are identified with colour contrast and/or tactile paving. They should be aligned with those on the other side of the carriageway.

It should be clear to drivers that informal crossings are a place used by pedestrians to cross. The crossing should be visible and illuminated at night and the carriageway paving can have a different colour or texture.

Car parking and stopping should be banned to ensure intervisibility between drivers and pedestrians. Complementary measures are also needed to slow down the traffic approaching the crossing, such as speed humps, and narrow carriageway.

Informal crossings are suitable in roads with low traffic volumes and speeds (<30km/h). Their location should be matched with desire lines (i.e. places where many pedestrians need to cross).

EXAMPLES

The provision of informal crossings varies with the regulations of each country. In some countries, crossing outside designated signalised or marked crossing is illegal.

In countries where informal crossing is legal (e.g. UK) there is a wide variety of types of informal crossings. They are often provided in quiet roads but sometimes in multilane busy roads.

In some countries (Sweden, Israel), marked crossings have been removed for safety reasons and in some cases replaced with informal crossings.

EVIDENCE

Replacing zebras with informal crossings makes pedestrians more cautious when crossing. However, drivers yield to pedestrians less frequently. Waiting times to cross the road increase

Gitelman et al 2017 An examination of the influence of crosswalk marking removal on pedestrian safety as reflected in road user behaviours. Transportation Research F 46, 342-355

A comparison of 1000 informal and 1000 marked crossings in the USA found no difference in collision rates in low-traffic roads. In busier roads, collision rates were lower in informal crossings.

Zegeer et al 2002 Safety effects of marked versus unmarked crosswalks at uncontrolled locations - analysis of pedestrian crashes in 30 cities. Transportation Research Record 1773, 56-68.

Pedestrians do not always know how to behave at these crossings and may mistakenly think they have right-of-way. A study found this to be the case for many older pedestrians and in rural areas.

Hatfield et al 2007 Misunderstanding of right-of-way rules at various pedestrian crossing types: observational study and survey. Accident Analysis and Prevention 39, 833-842.

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Courtesy crossing



Guarda, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Pedestrian crossings where drivers are not legally required to stop, but are encouraged to do so by design elements such as stripes, coloured or textured road surfaces, visual narrowing of the carriageway, and ramps.

For pedestrians, the crossings are identified with dropped kerbs and colour contrast and/or tactile warnings at the kerbside. Usually there are no signs. In roads with more than one lane, a pedestrian refuge can be installed in the middle.

Courtesy crossings are consistent with the shared space design approach, which removes formal demarcations between different types of road users. Drivers and pedestrians are expected to become aware of each other.

Courtesy crossings are more suitable in locations where the volumes of pedestrians and motorised vehicles do not meet the minimum criteria for a signalised crossing or a zebra (marked crosswalk).

They should be in locations where it is easy for drivers to stop, and require complementary measures such as traffic calming, the reduction of speed limit, banning car parking/stopping, and adequate lighting.

EXAMPLES

Courtesy crossings are usually a feature of shared spaces, in the countries applying this design approach.

In many countries, informal crossings (with design elements helping pedestrians to cross, e.g. dropped kerbs and refuges) are often treated by drivers as courtesy crossings.

In some countries (e.g. UK, New Zealand) there is a tendency to provide more courtesy crossings when redesigning low-traffic roads. They are usually new crossings, not replacements of zebras.

EVIDENCE

A review of 11 courtesy crossings in the UK found that the yielding rates of drivers to pedestrians varied from almost 0% to almost 100%

CIHT (2018) Creating Better Streets: Inclusive and Accessible Places. Reviewing Shared Space. CIHT, London.

The more different elements are included in the design of the crossing (stripes, coloured/textured surface, visual narrowing, and ramps) the higher the propensity of drivers to stop

Anciaes et al 2020 Factors explaining driver yielding behaviour towards pedestrians at courtesy crossings. Transportation Research F 73 453-469

Drivers and pedestrians often feel confused and are not sure how to behave at courtesy crossings

Moody, S., Melia, S. (2014) Shared space - research, policy and problems. Proceedings of the Institution of Civil Engineers - Transport 167, 384-392.

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Pedestrian refuge



Guarda, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Also known as pedestrian island. Space for pedestrians to stop while crossing. It can include kerbs, or bollards on the sides to protect pedestrians. It is usually located in the median strip, but it can be between a cycle track and the carriageway.

Refuges are suitable in roads with more than two lanes and high traffic volume and speed. In principle, they should be only to allow slower pedestrians to rest and wait for next light. All other pedestrians should be able to cross in one stage.

Refuges can be located mid-block or at junctions. At junctions, they often have extensions (e.g. planted areas) that protect pedestrians from vehicles turning. The extensions should align with the footway edges.

Pedestrian refuges should be as wide as the clear path for pedestrians on the footway, and deep enough to accommodate pedestrians with a wheelchair or pushing a pram, at least 1.5m. They should be visible for drivers.

They can squeeze cyclists, if the remaining carriageway space is still wide enough for cars to pass them. Large refuges require bollards to prevent vehicles from parking or manoeuvring on them.

EXAMPLES

Refuges are common in many cities, in wide roads, and in different types of crossing facilities (signalised, unsignalised) or in places without any facility.

Some Asian countries (Japan, South Korea, Singapore) have created Silver Zones in areas used by elderly pedestrians. Pedestrian refuges are one of the main design features of these zones.

Pedestrian Refuges are one of the measures in the US Federal Highway Administration Safe Transportation for Every Pedestrian (STEP) program.

EVIDENCE

Data from 2000 crossings in the US showed that collision rates in crossings with refuges were 50% of those without (in marked crossings) and 60% in unmarked crossings.

Zegeer et al 2001 Safety effects of marked versus unmarked crosswalks at uncontrolled locations. Transportation Research Record 1723, 56-68.

Pedestrian refuges are an effective as a measure of psychological traffic calming, reducing traffic speeds

Kennedy et al 2005 Psychological traffic calming. Transport Research Laboratory Report 641

Refuges do not remove the inconvenience and danger of crossing the road. The estimated monetary cost of using refuges is £0.11 per walking trip - or more if pedestrians need to wait to cross.

Anciaes and Jones 2020 A comprehensive approach for the appraisal of the barrier effect of roads on pedestrians. Transportation Research A 134, 227-250.

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Footbridge



Praia, Cabo Verde ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Structure for pedestrians to cross above the road. They can be accessed from steps, ramps, lifts, or escalators. In some cases, they are connected with buildings (e.g. stations, shopping centres), at a higher level, and are a part of a walkway network.

Footbridges are most suitable in roads restricted to pedestrians and multilane busy roads, as they remove potential conflicts between vehicles and pedestrians, addressing safety and reducing congestion. However, this depends on pedestrian compliance.

Footbridges increase distance, time, and effort to cross the road and are visually intrusive. They are also unsuitable for people with fear of heights. The entrances to the footbridge also use footway space, for stairs and long approaches for ramps.

Footbridges are expensive to build and require regular maintenance and cleaning, adequate lighting, and active surveillance. Some footbridges are covered above to protect users from elements, or on the sides to protect from pollution and falls

The space on the bridge is often used for formal or informal businesses or leisure activities (e.g. performers), if the width is large enough and the bridge is covered.

EXAMPLES

Footbridges are one of two solutions (the other being underpasses) in roads restricted to pedestrians, such as motorways, and are used widely around the world.

In many cities in fast-growing developing countries, they are also used in non-motorway roads if they have many lanes or high traffic volumes and speeds, even when they cross central areas used by many pedestrians.

In Bogotá, footbridges are provided along many roads due to the barrier effect caused by the physical segregation of the city's bus rapid transit system.

EVIDENCE

Footbridges are inconvenient and usually associated with poor personal security, especially at night and if lighting is poor, and for some groups including women and older adults.

Räsänen et al 2007 Pedestrian self-reports of factors influencing the use of pedestrian bridges. Accident Analysis and Prevention, 39, 969-973

Pedestrians prefer to walk further to avoid footbridges and cross at-grade - an estimated 2.4 minutes. Women and older pedestrians are willing to walk more.

Anciaes and Jones 2018 Estimating preferences for different types of pedestrian crossing. Transportation Research F 52, 222-237.

Footbridges are underused, even if pedestrians think crossing at-grade is dangerous, and so collision risk does not always decrease after adding a footbridge in high traffic roads.

Oviedo-Trespalacios and Scott-Parker 2017 Footbridge usage in high-traffic flow highways: the intersection of safety and security in pedestrian decision-making. Transportation Research F 49, 177-187

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Underpass



Chisinau, Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Also known as pedestrian subway. Structure for pedestrians to cross under the road. They are sometimes connected to underground stations or to the basement level of shopping centres. They can also be part of a walkway network.

Underpasses are most suitable in roads restricted to pedestrians and multilane busy roads, as they remove potential conflicts between vehicles and pedestrians, addressing safety and reducing congestion. However, this depends on pedestrian compliance.

Underpasses can be accessed from steps, ramps, lifts, or escalators. They increase distance, time, and effort to cross the road. The entrances to the underpass also use footway space, for stairs and long approaches for ramps.

Underpasses are expensive to build and require regular maintenance and cleaning, adequate lighting, and active surveillance. For security reasons, they may close after dark. In this case, pedestrians need to cross the road at grade.

The space on the underpass is often used for formal or informal businesses or leisure activities (e.g. performers), especially when they connect with busy stations and shopping centres.

EXAMPLES

Underpasses are one of two solutions (the other being overpasses) in roads restricted to pedestrians, such as motorways, and are used widely around the world.

Despite their disadvantages, underpasses are still being built in many cities, especially in fast-growing cities in developing countries, often as a part of accesses to new underground stations.

The tendency to remove underpasses to improve liveability is less pronounced than for footbridges. But in many cities, underpasses have been improved, with better lighting and cleanliness and new public art.

EVIDENCE

Underpasses often attract vandalism and anti-social behaviour. They tend to be underused and are often in poor state of repair and maintenance, with litter and graffiti.

James et al 2005 Understanding community severance - Part 1: Views of practitioners and communities. Report to the UK Department for Transport

Underpasses are inconvenient and usually associated with poor personal security, especially at night and if lighting is poor, and for some groups including women and older adults.

Rankavat and Timari 2016 Pedestrians perceptions for utilization of pedestrian facilities - Delhi, India. Transportation Research F 42, 495-499

Pedestrians prefer to walk further to avoid underpasses and cross at-grade - an estimated 5.2 minutes. Women and older pedestrians are willing to walk more.

Anciaes and Jones 2018 Estimating preferences for different types of pedestrian crossing. Transportation Research F 52, 222-237.

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Remove guardrails (traffic barriers)



Shanghai, China ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Removal of the vertical bars, posts, low walls, and other barriers separating sections of the road. This includes barriers separating the footway from the carriageway, and those in the median strip that separate the traffic in different directions.

Guardrails can also be removed on the approach to pedestrian crossing facilities and from two-step and staggered pedestrian crossing facilities, where they are usually placed around pedestrian refuge islands.

Removing guardrails increase the opportunities for pedestrians to cross the road, widens the footway space, removes a visually intrusive element, and reduces the chance of cyclists being crushed by motorised vehicles.

Guardrails should be removed where they block pedestrian desire lines and in places where many pedestrians walk on the carriageway to avoid them. But they should not be removed where this may lead to an increase in collisions, e.g. outside schools

This measure needs to be applied in conjunction with the reduction of traffic levels and speeds. It also requires measures to prevent cars from encroaching onto the footway. Parking and stopping may be banned

EXAMPLES

In many places, guardrails have been removed as a part of the conversion of streets into shared spaces or strategies to declutter the street.

There is a tendency to remove guardrails in many roads in London. Kensington High Street was one of the first places where guard railings were removed in 2002, as a part of the road redesign

At the same time, in fast growing cities in developing countries, guardrailing is being installed, rather than removed, as motorised traffic increases in previously quiet roads.

EVIDENCE

A study of 78 sites in the UK found that the frequency of vehicle-pedestrian collisions was 1.6 higher in sites with guardrailing than those without. But this difference was not statistically significant.

UK Department for Transport 2009 Pedestrian guardrailing. Local Transport Note 2/09

A study at 37 sites in London found no significant difference in traffic speed, pedestrian flows, and collision rates in sites with/without guardrailing

Zheng and Hall 2003 Pedestrian guard railing: a review of criteria for installation. Report to Transport for London.

The safety outcomes of guardrails depend on their characteristics. if guardrails ensure the visibility of pedestrians to drivers, then adding them reduce collisions.

Stewart 2007 A clearer vision for pedestrian guardrails. Proceedings of the Institution of Civil Engineers 160, 131-136

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Dynamic pedestrian crossing

TYPE: Time allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Crossing facility that only appears when pedestrians need to cross the road. It is implemented by detectors of pedestrian and vehicle activity, which activate LED lights embedded in the road surface. This crossing is still at the prototype phase.

The crossing automatically defines the space for pedestrians to cross the road, generating markings (e.g. white stripes) across the carriageway and a sign or other markings on the footway or kerbside area pavement.

Stop lines for vehicles are also automatically generated, as well as advance stop lines for buses and cyclists, if applicable. The crossing can include other functionalities, e.g. audible signs and sound or light alerts for distracted pedestrians.

Computer vision technology anticipate pedestrian movement. The width of the crossing can adjust to the number of pedestrians using it. The crossing should adapt quickly to unexpected situations (e.g. children running across the road)

The crossing is dynamic in time (appears only at certain times) but not in space (it always appear in the same location). It can replace informal or courtesy crossings in quiet streets that have low or irregular pedestrian flows.

EXAMPLES

There was a trial of a dynamic pedestrian crossing in London (Starling Crossing - STigmergic Adaptive Responsive LearnING Crossing) in London in 2017.

There were trials or prototypes of 3D crosswalks (white stripes appearing to float), stripes that turn red when pedestrians step on them, and lights to alert pedestrians using mobile phones.

Some roads in the USA and Europe have flashing beacons activated by presence of pedestrians, identifying the crossing to drivers.

EVIDENCE

There are no published studies evaluating fully dynamic pedestrian crossing facilities.

Automatic lighting systems identifying the crossings when pedestrians are detected increase the propensity for drivers to stop for pedestrians.

Costa et al 2020 Evaluation of an integrated lighting-warning system on motorists' yielding at unsignalized crosswalks during nighttime. Transportation Research F 68, 132-143.

There is a problem with false alarms in crossings with automatic lighting systems. In these crossings, driver yielding behaviour may not change.

Høye and Laureshyn 2019 SeeMe at the crosswalk: before-after study of a pedestrian crosswalk warning system. Transportation Research F 60, 723-733.

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Scramble crossing (diagonal pedestrian crossing)

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Also known as X-crossing or exclusive pedestrian interval/phase. Crossing facility in a road junction allowing pedestrians to cross in all directions, including to the opposite corner, in a single movement.

It is usually a signalised crossing, with phases of all-red traffic signals to vehicles. This may imply reducing the length of all signal phases in a cycle, with some time also lost in transitions between phases.

Scramble crossings remove all conflicts between pedestrians crossing and vehicles turning. However, pedestrians may have to wait long time for the all-green phase, which may lead to dangerous crossing behaviour.

Scramble crossings are suitable for road junctions with very high pedestrian flows. However, conflicts may happen if there is not enough space for pedestrians waiting on all the corners of all legs of the junction.

The diagonal path may be marked, to alert pedestrians that diagonal crossing is allowed. This can be with white stripes or dotted lines. The whole junction can have a homogenous colour and texture, different from the approaching roads.

EXAMPLES

The scramble pedestrian crossing outside Shibuya Station in Tokyo has estimated to be used by up to 2500 pedestrians at a time, in all directions, making it the world's busiest.

The scramble crossing in Oxford Circus in London, one of the busiest intersections in the world, was used in its first year (2010) by an estimated 90 million pedestrians per year.

There are many scramble crossings in large cities in several countries, with many examples in Japan and Taiwan and, more recently, in Singapore.

EVIDENCE

A study in Oakland (USA) found that a scramble crossing decreased the conflicts between pedestrians and vehicles but increased the number of pedestrians crossing during the red-phase.

Bechtel et al 2004 Pedestrian scramble signal in Chinatown neighborhood of Oakland, California: an evaluation. Transportation Research Record 1878, 19-26.

A study of several junctions in Connecticut (USA) found that those with all-green pedestrian phases had more pedestrian collisions than those who did not.

Zhang et al 2015 Safety effects of exclusive and concurrent signal phasing for pedestrian crossing. Accident Analysis and Prevention 83, 26-36.

A survey after the implementation of the scramble crossing at Oxford Circus in London found that some users feel unsafe when using diagonal crossings

Mervieca et al 2011 Integrated street design in high-volume junctions: the case study of London's Oxford Circus. Paper presented at the 1st International Conference on Access Management

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Raised pedestrian crossing



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Design

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Raised carriageway with a marked pedestrian crossing. Also known as wombat crossings. These crossings are similar to speed humps and speed tables, but priority is given to pedestrians. Raised crossings may be signalised or unsignalised.

Raised crossings reduce traffic speed and increase the visibility of pedestrians, as they cross at a higher level. To further reduce speed and facilitate crossing, footway extensions can be added to the design.

Raised crossings are suitable in places with large pedestrian volumes, low traffic volumes and speeds, and in sensitive areas (e.g. near hospitals, schools and parks) or at entrance to a minor road. They are less suitable for roads used by large vehicles.

Raised crossings may be placed at regular points along a road. They need to be visible for drivers, for example using lighting, signs, and surfaces with colours and textures different from the rest of the carriageway.

Raised crossings may be uncomfortable and cause noise. Less steep ramps are required in roads with bus and cycle lanes. Cycle lanes may be re-routed. The crossings also slow down emergency vehicles and affect drainage of water and clearing of snow.

EXAMPLES

Raised crossings are common in Australia, where they are known as wombat crossings. They are usually zebra crossings, and located in sections with low speed limits.

In the UK, informal and courtesy crossings are often raised, and have other design elements to encourage drivers to stop (e.g. different colours/textures).

The redesign of Manassas Street in Memphis in 2018 included installing a new wide raised crossing, which became popular for its coloured artistic design.

EVIDENCE

A before-after study in Israel found that raised pedestrian crossings decrease vehicle speeds and increase the propensity of drivers to yield to pedestrians.

Gitelman et al 2017 Changes in road-user behaviors following the installation of raised pedestrian crosswalks. Transportation Research F 46, 356-372.

Comparison of sites in Australia and New Zealand found that raised intersections reduce speed in 8km/h and collisions with injuries in 40%

Turner et al 2017 Safe system infrastructure on mixed use arterials. Austroads Technical Report AP-T330-17.

Raised crossings at a roundabout entrance in Melbourne reduced vehicle speeds, crossing time, and pedestrian non-compliance. Pedestrians reported increased safety and convenience.

Candappa et al 2014 Raised crosswalks on entrance to the roundabout-a case study on effectiveness of treatment on pedestrian safety and convenience. Traffic Injury Prevention 15, 631-639.

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Continuity of footways at crossovers



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Pedestrians (crossing the road)

DESCRIPTION

Ensure the continuity of the footway when this meets side roads, driveways, and direct accesses to properties. This involves a level, smooth footway and a crossover for vehicles, also known as kerb cut (wide ramp allowing vehicle access to the footway).

The ramps for vehicles should be smooth and not extend across the full width of footway, to avoid changes in level for pedestrians, especially older pedestrians and those using wheelchairs or other walking aids.

The existence of ramps often induces pedestrians to use them as a crossing point to the other side of the road, which may not be desirable if the location is unsuitable for crossing. Pedestrian crossings should be installed at the nearest safe location.

The side roads and driveways should be as narrow as possible. The corners at the junction with the main road should have tight radii, to reduce vehicle speeds entering the side roads/driveway

These designs are usually complemented with legal measures, giving pedestrians priority over vehicles crossing the footway. However, there is often a problem with drivers not complying, forcing pedestrians to wait.

EXAMPLES

Continuity of footways at vehicle crossovers have been a neglected area of road design, with kerbs being continually cut as car used increased during the 20th Century.

The number of vehicle crossovers is subject to regulations, often in the framework of planning permissions. The 1980 Highways Act in the UK started to required approval for new footway crossovers.

Many road design and access management plans now consider pedestrians. As example, a plan for the Georgia State Route 6 (in USA) included the removal or reconfiguration of several driveways.

EVIDENCE

Decreasing cross slopes of footway addresses needs of pedestrians with disabilities. An experiment found that high cross slopes increased perceived discomfort and heart rates of pedestrians using mobility aids.

Kockelman et al 2002 Sidewalk cross-slope design analysis of accessibility for persons with disabilities. Transportation Research Record 18, 108-118.

There is also much evidence that cross slopes in kerb crossovers contribute to wheelchair users avoiding of feeling insecure using streets

Cooper et al 2012 Effects of cross slopes and varying surface characteristics on the mobility of manual wheelchair users. Assistive Technology 24, 102-109.

Continuity of footways is particularly important for pedestrians in winter. Water and snow accumulated in driveways and kerb cuts are usually reported as a barrier to walking for older pedestrians.

Li et al 2012 Aging and the use of pedestrian facilities in Winter - the need for improved design and better technology. Journal of Urban Health 90, 602-617.

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PART 3

Measures aimed at place activities

Add/improve courtyards, squares, plazas



New York City, USA ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Add/improve public places along or next to urban roads, usually reconverting underused space. They usually have some greenery, seating, cycle parking, and some street furniture. Delivery vehicles may be allowed to use the space at some hours of the day.

These spaces can be created by extending footways to parking or slip lanes and junction corners. They can replace also parking lots or use the space under elevated infrastructure. Footways can be merged with pedestrian refuges, using space in-between.

The spaces can be temporary, being active at some hours or days- for example, using movable chairs and tables. They are often introduced as pilot interventions, in many cases leading to a permanent space or inspiring similar interventions in other areas.

These spaces have usually been created in areas with many pedestrians in city centres. They act as a small pedestrianised area while provides space for place activities. At junctions, they may also simplify traffic movements and reduces traffic speeds.

Enforcement (to keep moving and parked vehicles away) can be achieved by permanent or movable structures separating the space from the carriageway. The spaces also require adequate lighting and water drainage, as well as regular cleaning and maintenance.

EXAMPLES

The New York City Plaza Program and the Pavement-to-Plazas program in Vancouver are two examples of programs for creating plazas from underused space.

Most European cities have squares, of all sizes. There is a tendency to remove car parking or to close off the squares to car traffic, to increase place activities.

Japanese cities usually have plazas outside stations, mainly for pedestrian access to busy stations. Design of some plazas has improved to encourage place activities.

EVIDENCE

Evaluation studies of new plazas in New York City found that they are well-used, especially for sitting and standing, but children and older people tend to be underrepresented.

Gehl and Max Bond Center 2015 Public life and urban justice in NYC's Plazas

Evaluation of the Vancouver Pavement-to-Plaza program found that the plazas support social interaction and inclusion, and that people feel safe when using them.

Happy City 2019 Well-being assessment: pavement-to-plaza program.

Urban squares have positive psychological effects on its users in terms of stress recovery. But these effects are only moderately related to the design of the squares.

Subiza-Perez et al 2020 Welcome to your plaza: Assessing the restorative potential of urban squares through survey and objective evaluation methods. Cities 100: 102461.

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Parklets



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Also known as pocket parks. A small public place, usually extending over the kerbside, and replacing one or more car parking spaces or parking lots between properties. They are not usually located on the footway or replace space used for walking.

Parklets includes some greenery, seating areas, and tables and, in some cases, bicycle parking, electric bicycle charging, phone charging, wi-fi, play areas, and exercise equipment. They can also be covered to offer shade and protection from rain.

Some cities have developed systems of parklets, starting with pilot temporary parklets, using movable chairs and tables. Parklets can be in central, commercial, or residential areas. Some parklets are commercial spaces, operated by private businesses.

Parklets requires regular cleaning and maintenance, and physical structures or a buffer to the carriageway and to car parking spaces. Parklets should not obstruct surface water run-off and should be easily accessible from the footway, with no steps.

Parklets are a solution to provide opportunities for place activities in narrow streets where there is no footway space for seating areas. They should not be located too near to road junctions, to reduce disruption on traffic.

EXAMPLES

The concept emerged from the Park(ing) Day initiative in San Francisco in 2005 by the Rebar artists' group, replacing car parking with green parks for people for one day

San Francisco now has an integrated system of parklets (Pavement to Parks). Chicago has a similar system (Chicago's People Spots).

Parklets are now common in many cities in Europe, North America and Latin America. For example, Sao Paulo has implemented many parklets and issue a plan and guidance for their creation and maintenance.

EVIDENCE

Evaluation of three new parklets in San Francisco found that they increased number of pedestrians, stationary activities, and parked bicycles.

Pratt 2011 Parklet Impact Study - The influence of parklets on pedestrian traffic, behavior, and perception in San Francisco

Same results have been found in studies in other North American cities. However, the effect on local businesses has been mixed: not always the hypothesized increase.

UCLA and Parklet Studies 2013 Reclaiming the right-of-way - Evaluation Report

Evidence is not always positive. Parklets tend to be in neighbourhoods that are already successful, are not always fully public places, and have lower ecological value than claimed.

Little 2016 Revisiting the San Francisco parklets problematizing publicness, parks, and transferability. Urban Forestry and Urban Greening 15, 165-173.

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Part-time spaces for place activities



Lima, Peru ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Designated areas for place activities (sitting, playing, street performers) at some times only. At other times, the space may be for the movement of pedestrians, cyclists, or motorised modes, or for parking and loading.

The space may include seating (e.g. movable chairs and tables), greenery (e.g. planters) or simply be an open area for people to congregate (e.g. outside bars or concert halls). The space can also be delimited with movable structures (e.g. planters).

Some elements of the space can be dynamic. For example, the area available may depend on the number of people using it or arriving to the street. Provision and type of protection may depend to weather conditions (e.g. sunshine, rain).

These space are often on a full-time or a part-time pedestrianized street. But can also occupy a part of the footway or the kerbside zone of a non-pedestrianised street. Depending on activities, the space may require access to power and water.

The space can be available at lunch time (e.g. for markets), evening (e.g. outdoor dining areas), or on weekends or some seasons only. Enforcement is needed to ensure the space is not used to park vehicles when active.

EXAMPLES

Several streets in London are outdoor markets during the day, allowing traffic after markets close. Streets even have the same name as the market (e.g. Chapel Market, Exmouth Market).

Since 2013, several streets in Singapore have been closed to motorised traffic, for the use of pedestrians, and outdoor dining areas. More streets have been added to the scheme, given its success

Several cities have temporarily closed some streets to traffic during the COVID-19 pandemic in 2020 to facilitate social distancing for pedestrians and people sitting in outdoor cafes

EVIDENCE

The evening and weekend pedestrianisation of a busy shopping and leisure street in Hong Kong lead to a 17% increase in the rental value of retail shops.

Yiu 2011 The impact of a pedestrianisation scheme on retail rent: an empirical test in Hong Kong. Journal of Place Management and Development 4, 231-242.

Evening pedestrianisation of a tourist street in Bangkok increased rental values and sales, and was well-accepted by business owners and street users.

Kumar and Ross 2006 Effects of pedestrianisation on the commercial and retail areas: study in Khao San Road, Bangkok. World Transport Policy and Practice 13, 38-50.

Njeru and Kinoshita 2019 Mobility, space, and community: a study on the importance of Tokyo's car-free local shopping streets as social spaces for residents. Urban and Regional Planning Review 6, 45-63.

A survey in Tokyo found a street closed to traffic on afternoons was well-used for shopping, less for strolling/interaction. 63% of respondents would prefer a permanent car-free street.

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Location of space for place activities: footway



Blois, France ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Location of on-street commercial areas, public seating, or other spaces for place activities on the road footway, rather than on the kerbside area of the carriageway, median strip, or side streets.

This measure involves the creation of new footway space (by widening the footway, or building footway extensions) or by using empty spaces between street furniture, or underused space on wide footways.

This design is more suitable in roads with wide footways (>4m). The space for place activities should leave a wide enough clear path for pedestrians walking along the road. The space acts as a buffer between pedestrians and vehicles moving or parked.

The space can be delimited from the pedestrian area and the kerbside zone using movable structures (e.g. planters) or marks on the pavement. The whole surface of the space can also have a different colour or texture.

The space can be active only at some times of day, days of the week, or seasons. At other times, the space can be for walking (e.g. to accommodate higher pedestrian flows of commuters in the morning), cycling, car parking, and loading.

EXAMPLES

In Vietnam, footway space is used for walking, outdoor cafes, informal seating, and motorcycle parking. In Ho Chi Minh, authorities painted a line on the pavement to separate seating from pedestrian areas.

Food trucks have become popular in large cities in the USA and Europe in the late 2000s. Trucks occupy a kerbside space but customers queue and eat on the footway.

Outdoor cafes and dining areas on footways have long been a distinctive feature of some cities (e.g. Paris). In many cities, these establishments have been allowed to extend during the COVID-19 pandemic.

EVIDENCE

A study of street activities in Geelong (Australia), more than 75% of the activities happened around cafés on the footway. Cafes in streets with wider footways generated more activities.

Farahani and Beynon 2015 Pavement cafes as the activity zone in the social life of neighbourhood centres. Proceedings of the Conference of the Architectural Science Association, 193–202.

An observational study in Ho Chi Minn showed several people-based place activities (store spillovers, leisure, commerce, eating), using 10%-20% of footway space from 5am to 9pm. Users informally reassigned space.

Kim 2012 The mixed-use sidewalk. Journal of the American Planning Association 78, 225-238.

A study in Chicago showed that food trucks did not disrupt pedestrian flow because customers waited in the street furniture zone and, at crowded times, queued in a way that reduced disruption.

Ehrenfeucht 2017 Do food trucks and pedestrians conflict on urban streets? Journal of Urban Design 22, 273-290.

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Location of space for place activities: kerbside area



Helsinki, Finland ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Location of on-street commercial areas, public seating, or other spaces for place activities on the kerbside zone of the carriageway. The alternative is to locate the space on the footway, median strip, or side streets.

The space replaces all parking and loading bays along a road section or is alternated with them. The advantage of this design is maintaining a clear path for pedestrians walking along the footway.

This design requires a wider space than having space for place activities on the footway, to include a buffer for protection from moving traffic. Some parts of the road (e.g. too near junctions, pedestrian crossings, and bus stops) are not suitable.

The space can be delimited from traffic lanes with barriers (e.g. bollards) or movable structures (e.g. planters). The whole surface of the space can have a different colour or texture. The space should have easy access from the footway (with no steps).

The space can be active only at some hours, days, or seasons. At other times, the space can be for cycling, parking, or loading. Access to power and water, and management of drainage water, may be more difficult than spaces on the footway.

EXAMPLES

In Portugal, outdoor cafes are often allowed to have seating areas on the kerbside zone, between parking spaces. There was a large increase in the number of these areas during the COVID-19 pandemic.

Food trucks have become popular in large cities in the USA and Europe in the late 2000s. Trucks occupy a kerbside space but customers queue and eat on the footway.

Since 2005, parklets have become increasingly common in Europe, North America and Latin America. They are small public places, usually extending over the kerbside, replacing one or more car parking spaces.

EVIDENCE

A study in Chicago showed that food trucks on kerbside parking spaces do not disrupt pedestrians or other road users because customers wait and eat on the footway, in the street furniture zone.

Ehrenfeucht 2017 Do food trucks and pedestrians conflict on urban streets? Journal of Urban Design 22, 273-290.

Evaluation of three new parklets in San Francisco found that they increased number of pedestrians, stationary activities, and parked bicycles.

Pratt 2011 Parklet Impact Study - The influence of parklets on pedestrian traffic, behavior, and perception in San Francisco.

Same results have been found in studies in other North American cities. However, the effect on local businesses has been mixed: not always the hypothesized increase.

UCLA and Parklet Studies 2013 Reclaiming the right-of-way - Evaluation Report

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Location of space for place activities: median strip



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Location of on-street commercial areas, public seating, or other spaces for place activities on the median strip of the road, rather than on the footway, kerbside zone of the carriageway, or side streets.

This space may be on an existing kerbed median strip, if it is wide enough to accommodate the activities it is aimed for. Alternatively, it may be on a new median strip, created from removing or narrowing traffic lanes or strips for car parking.

This design requires a wider space compared with providing for place activities on the footway, to include a buffer zone for protection from moving traffic on both sides. Some parts of the road are not suitable (e.g. too near junctions).

The space can be separated from moving traffic with kerbs or fixed or movable barriers. The surface of the space can also have a different colour or texture. To ensure safe access, pedestrian crossings are needed from the footway, with dropped kerbs.

The space can be active only at some times. At other times, the space can be for walking, cycling, or for parking and loading. Access to power and water, and management of drainage water, may be more difficult than spaces on the footway.

EXAMPLES

Barcelona's La Rambla has a wide median used by many residents and visitors to stroll. It also includes many on-street shops.

Esplanadi is one of the most popular public places in Helsinki. It is a wide park between two parallel roads, with green areas and pedestrian paths.

In 2012, a large median parking lot in Biscayne Boulevard, a busy road in Miami, was temporarily transformed into a public park with benches. This was repeated in 2017 in three blocks of median parking on the same road.

EVIDENCE

Transformation of Via Julia (Barcelona) as a boulevard with a central elevated promenade with benches and trees created a space where many social activities take place, despite the traffic noise.

Garcia-Ramon et al 2004 Urban planning, gender and the use of public space in a peripheral neighbourhood of Barcelona. Cities 21, 215-223.

A case study in Berkeley (California) showed how a narrow, grassed, median strip was transformed into an active informal gathering place, despite safety risks and presence of "keep off" signs.

Sankalia 2014 The median picnic: street design, urban informality and public space enforcement. Journal of Urban Design 19, 473-495.

Transformation of urban motorways to boulevards with tree-lined median strips tend to increase property prices in the vicinity, with little negative impacts on traffic flows.

Cervero et al 2009 From elevated freeway to surface boulevards: neighbourhood and housing price impacts in San Francisco. Journal of Urbanism 2, 31-50.

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Location of space for place activities: side streets



Guarda, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Reconvert alleyways and service roads as designated areas for outdoor commercial areas, public seating areas, or other place activities. The streets can be pedestrianized or traffic speeds limits are very low (10 km/h).

This involves using space that was previously parking and loading, service vehicles (e.g. waste collection), or access to properties. The reversion involves banning car parking and loading or restrict the hours they are allowed.

The spaces are usually on narrow streets, so a clear path should be kept for pedestrians and for the access of service and emergency vehicles, without being obstructed by chairs/tables, stands, and advertising boards.

These spaces may complement or replace spaces for place activities in the footway of the roads from where the alleyways branch off. They may replace them to release space from busy roads or to provide a quieter environment.

The space should have good lighting. It can be covered to provide shelter and protection from rain. It requires enforcement to prevent cars from using the street as shortcut to avoid congestion, as well as illegal parking.

EXAMPLES

Since the early 1990s, Melbourne has reconverted many alleyways off main roads in the city centre, banning traffic and improving public realm, encouraging the opening of cafes/bars

In 2007, Christchurch (New Zealand) developed a Lanes Plan, to reconvert old alleyways and issued a Lanes Design Guide. Many alleyways were destroyed in the 2010/11 earthquakes.

During the years of fastest economic growth, most Hutong (alleys with courtyard homes) were demolished in Beijing. A few of the remaining ones are now becoming lively shopping/leisure areas.

EVIDENCE

After the redesign of an alleyway in Hollywood, 90% of street activities (biking, dining, driving, sitting, standing, walking, working) occurred there, rather than in a control alley nearby.

Seymour and Trindle 2014 Use dimensions of an alley revitalization project. Landscape Research 40, 586-592.

Alleyways in Kuala Lumpur's Chinatown are used as social spaces, for markets and interactions, one of the reasons being because the frontage of shop buildings is exposed to heavy traffic.

Ismail and Ching 2018 Social interaction in the back lanes of China Town. Asian Journal of Behavioural Studies 3, 140-148.

The development of side streets can lead to gentrification and 'touristification' of old neighbourhoods and discontent among residents.

Huimin and Ryan 2012 Tourism destination evolution: a comparative study of Shi Cha Hai Beijing Hutong businesses' and residents' attitudes 20, 23-40.

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On-street seating area with tables (outdoor cafes)



Tiraspol, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Provision of dedicated space for outdoor seating, with tables. These spaces are usually operated by private businesses (e.g. cafes, restaurants), but can be public (e.g. seating areas with tables for picnics or playing).

Commercial spaces use movable chairs and tables that can be removed when not used. The limits of the seating area can be identified with planters or other movable structures, that can also be removed when the space is not being used.

The seating area requires a minimum of 3m of footway width and it should not be an obstruction to the clear path of pedestrians. The movement of waiters from the shop to the outdoor seating area may cause conflicts with pedestrians and cyclists.

These spaces can be located on footway, on footway extensions, or on the kerbside area (using space allocated to car parking at other times). Commercial spaces operate at some times of day, days of week, or seasons.

These areas are common in places used by many pedestrians (shopping streets and near stations, employment centres, parks, and tourist places). They require lighting, regular maintenance, cleaning, waste management, and in some cases, power.

EXAMPLES

Outdoor cafes and dining areas have long been a feature of countries with warm climates, e.g. South East Asia and the Mediterranean

They have become more common in Northern Europe. The pedestrianisation of the Copenhagen city centre showed that outdoor areas can be successful even in colder climates.

During the COVID-19 pandemic in 2020, the authorities in many cities have relaxed regulations and encouraged businesses to extend outdoor seating areas.

EVIDENCE

The number of chairs in commercial seating areas was strongly correlated (0.78) to the liveliness index (combining number and duration of activities) of a street in Cambridge (USA).

Mehta 2007 Lively streets determining environmental characteristics to support social behavior. Journal of Planning Education and Research 27, 165-187.

A study of street activities in Geelong (Australia), more than 75% of the activities happened around outdoor cafés.

Farahani and Beynon 2015 Pavement cafes as the activity zone in the social life of neighbourhood centres. Proceedings of the Conference of the Architectural Science Association, 193–202.

A study in London and Istanbul found that outdoor cafes contribute to sense of place and social life and to the location decisions of individuals and businesses.

Durmaz 2015 Analyzing the quality of place: creative clusters in Soho and Beyoğlu. Journal of Urban Design 20 93-124.

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Storefront extensions



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Provision of space for stalls and other fixed or movable structures next to the edges of buildings with ground floor businesses. The space can be used to display goods for sale, samples, menus, leaflets, advertising, and other items.

Storefront extensions require a minimum of 1.5m of footway width. Those that are used for selling may require extra space, for customers waiting. They should not exceed the length of the storefront or be an obstruction to the clear path of pedestrians.

Storefront extensions are less a road design issue than a regulatory one. Public authorities need to define the allowed uses of footway and the location and amount of space used by the structures installed by private businesses.

The regulation of the use of movable structures are usually problematic. For example, advertising boards (A-Boards) are a physical and visual obstruction as their purpose is precisely to catch pedestrians' attention.

Storefront extensions are common in streets used by many people (shopping streets and near stations, employment centres, parks, and tourist places). They are used only during the shops' opening hours, but some structures are left outside overnight.

EXAMPLES

Outdoor shop displays are common in streets in Kosovo, often occupying a large proportion of the footway. This is also common in other countries.

In New York, some streets are designated as "zero sidewalk display streets". Shops are not allowed to use displays or advertising boards on those streets.

In December 2018, Edinburgh imposed a city-wide ban to advertising boards and other movable on-street advertising.

EVIDENCE

In an observational study of a footway in Ho Chi Minh (Vietnam), storefront extensions took a variable amount of footway space throughout the day, but never more than 3%.

Kim 2012 The mixed-use sidewalk. Journal of the American Planning Association 78, 225-238.

A study in Ethiopia found that vending on the footway's frontage zone increase pedestrian density (because of waiting customers) than vending in the same amount of space in the furniture zone

Hagos et al 2020 Effect of sidewalk vendors on pedestrian movement characteristics: A microscopic simulation study of Addis Ababa, Ethiopia. Cities 103: 102769

Footway obstructions, including advertising boards, were identified as a barrier to walking by older pedestrians with disabilities.

Rosenberg et al 2013 Outdoor built environment barriers and facilitators to activity among midlife and older adults with mobility disabilities in a study in the USA. The Gerontologist 52, 268-279.

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On-street commercial areas (kiosks, stands)



Skopje, North Macedonia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Provision of space for stands, kiosks, and fixed or mobile structures on the footway used by shops and street vendors. The spaces can be isolated, distributed regularly along a street, or clustered in some locations (e.g. markets).

These areas can be dedicated spaces on the footway, footway extensions, or in kerbside area of the carriageway (in space used for car parking at other times). On the footway, they can be aligned in the street furniture zone.

On-street commercial areas require a minimum of 2m of footway width, to accommodate vending and storage space, and another 1m for customers waiting and eating/drinking. Enough space must be left for the clear path of pedestrians.

These areas can be a buffer between pedestrians and moving or parked vehicles, but require their own buffer to vehicles. They also require lighting, maintenance, cleaning, and waste management, and depending on the activities, access to power and water.

These areas are common in streets used by many people (shopping streets and near stations, employment centres, parks, and tourist places). They usually operate at some hours or days, although at other times, fixed structures still occupy space.

EXAMPLES

Kiosks were a feature of most cities in the ex-Soviet block, and continue to be common in those cities. Many sell products not usually found in kiosks elsewhere (e.g. groceries).

Streets in Southeast Asia (e.g. Thailand, Malaysia) have a large number of small fixed and mobile food stalls on footways.

The number of street food stalls in European and US cities has grown since the 2010s. Some are in street markets, others in clusters on pedestrianised streets or other streets with many pedestrians.

EVIDENCE

A study in Ethiopia found that a formal kiosk led to the same pedestrian density (because of waiting customers) than an informal vendor.

Hagos et al 2020 Effect of sidewalk vendors on pedestrian movement characteristics: A microscopic simulation study of Addis Ababa, Ethiopia. Cities 103: 102769

A study in Tel Aviv observed many activities in kiosks and nearby space, both commercial (buying) and non-commercial (eating, reading, communicating), and including illegal activities (littering, drug use)

Natapov and Grinspun 2019 Hidden in the most visible place: measuring visual accessibility and social performance of urban kiosks. Journal of Urban Design 25, 412-432.

A study in Kuala Lumpur showed that kiosks and food stalls on the streets outside a market have many economic and non-economic activities.

Qamaruz-Zaman et al 2014 Functional dimension of spillover activities towards the liveliness of Sungai Besi Market, Kuala Lumpur. Procedia - Social and Behavioral Sciences 153, 629-638.

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Restrict street vending



Temuco, Chile ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Place activities

DESCRIPTION

Ban informal street vendors from trading on the footway and other public areas on the road, enforce current bans, or use street designs that impede or discourage vending.

The objective is to reduce informal economic activity and improve the use of the street for other users by remove obstructions. These are caused by movable structures, displayed goods on the pavement, and pedestrians stopping to browse or buy.

A possible design measure is to reduce the available space for vending, by narrowing the footway or installing street furniture (e.g. benches) or cycle parking areas. Another possibility is to install regular barriers (e.g. bollards) along the footway.

Reducing footway width may not be an effective solution because street vending happens on roads that already have high demand for using the footway (e.g. shopping streets and tourist areas), as these are also the areas with more demand for street vending.

The measure can be complemented with others aimed at bringing vendors into the formal economy. This involves the provision of dedicated space and facilities (e.g. stalls, kiosks) on the road footway or in markets in nearby roads.

EXAMPLES

Since 2014, Bangkok authorities have limited street vending, under the Reclaiming Pavements for Pedestrians plan. Designated markets were provided in distant places.

Hanoi (Vietnam) banned street vending from many streets and public spaces in 2008

During the years of fastest economic growth, Chinese cities banned street vending. Since the mid 2010s many smaller cities (not Beijing and Shanghai) have been allowing it again

EVIDENCE

A study in Addis Ababa (Ethiopia) found that the presence of street vendors increase pedestrian density because of waiting customers, but not more than a formal kiosk.

Hagos et al 2020 Effect of sidewalk vendors on pedestrian movement characteristics: A microscopic simulation study of Addis Ababa, Ethiopia. Cities 103: 102769

A study in Lima (Peru) found a greater risk of pedestrian-vehicle collisions for each street vendor present on the street.

Quistberg et al 2015 The walking environment in Lima, Peru and pedestrian-motor vehicle collisions: an exploratory analysis. Traffic Injury Prevention 16, 314-321.

Banning street vending increases street crime, due to less passive surveillance of the street

Reyes 2003 Crime, street vendors and the historical downtown in post-Giuliani Mexico City. International Journal of Criminology and Sociology 2, 186-198.

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PART 4

Measures aimed at cyclists and micromobility vehicles (moving)

Advisory cycle lane



Prague, Czech Republic ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Dedicated lane for the use of micromobility vehicles, not shared with other road users. Micromobility include small vehicles such as scooters, skateboards, and other vehicles; power-assisted or not. Bicycles (power-assisted or not) are not included.

This is an alternative to share the same space with pedestrians, bicycles, pedestrians, or general traffic, reducing conflicts that arise because of different speeds. Enforcement would be required to avoid the lanes being used by other vehicles.

The lane may be segregated from general traffic with markings or barriers and can have some of the safety design features used in cycle lanes, such as protected junctions, two-stage turns, advance stop lines, advance signal timings, and cycle signals.

A lane for micromobility vehicles may simply be a section of a double cycle lane, defined with markings on the pavement. Signs at junctions, and regular symbols on the pavement help to assign bicycles and micromobility users to each lane.

Provision of these lanes depends on regulations. It may be required if micromobility vehicles are not allowed to use other spaces on the road. The lanes are also suitable in roads with high volumes of motorised vehicles, especially large vehicles.

EXAMPLES

The use of e-scooter and other micromobility vehicles has grown since 2018, when dockless scooter-sharing systems emerged. There are no examples of dedicated lanes for these vehicles.

In most cities, traffic regulations have gaps regarding the use of micromobility vehicles, and in practice they are used footways, cycling infrastructure, and carriageway.

There was a temporary scooter lane for two days in Oak Street in Kansas City in 2018

EVIDENCE

Not having enough safe places to ride was identified as one of the main barriers to scooter use in a survey in the USA.

Sanders et al 2020 To scoot or not to scoot: Findings from a recent survey about the benefits and barriers of using E-scooters for riders and non-riders. Transportation Research A 139, 217-227.

An observational study found that the users of e-scooters use the roads in a flexible manner, switching from vehicle to pedestrian role.

Tuncer et al 2020 Notes on the practices and appearances of e-scooter users in public space. Journal of Transport Geography 85: 102702.

In a study in Portland, fewer proportions used the footway as the level of protection of cycle infrastructure increased and the speed limit decreased.

PBOT 2018 E-scooter Findings Report.

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Mandatory cycle lane



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Lane for cyclists on the road carriageway for the exclusive use of cyclists and not shared with general traffic. Electric bicycles and micromobility vehicles may or may not be allowed.

Mandatory cycle lanes are segregated from general traffic by a solid or stripped line. Additional segregation can be provided by strips with different colours or materials, planters, flexible separators, or car parking spaces.

A buffer zone (>1.25m) may be added between the cycle lane and other traffic lanes, to ensure the safety of cyclists (e.g. when a vehicle is overtaking another) and to discourage drivers from using the cycle lane.

Buffer zones may also be added between the cycle lane and the kerbside area, to avoid collisions with street furniture and with vehicles parked or loading (especially when doors are open).

Mandatory cycle lanes are suitable in roads with high volumes of motorised vehicles and bicycles, high traffic speed or large proportion of large vehicles in the traffic. The requires enforcement to keep lanes clear from cars (moving or parked).

EXAMPLES

Cycle lanes started to be added to roads after the 1920s in Northern Europe, but some early lanes were removed after 1950, as car use started to grow.

Interest in cycle lanes revived in the 1970s in Europe and then elsewhere. In many cities there is now a preference for segregated cycle tracks, rather than cycle lanes.

As a part of the redesign of Götgatan in Stockholm in 2013/2014, a narrow cycle track was converted into a wide cycle lane, segregated from traffic by a car parking strip.

EVIDENCE

A study of 7 European cities showed that larger cycle networks increase cities' cycling modal share - but the study did not disaggregate results by type of infrastructure (cycle lanes or tracks)

Mueller et al 2018 Health impact assessment of cycling network expansions in European cities. Preventive Medicine 109, 62-70.

A before-after study in Toronto found that the installation of mandatory cycle lanes on a shopping street, replacing parking spaces, increased number of customers and customer spending.

Arancibia 2019 Measuring the local economic impacts of replacing on-street parking with bike lanes. Journal of the American Planning Association 85, 463-481.

In a stated preference study, mandatory cycle lanes were identified as much less desirable than quiet routes and segregated cycle tracks.

Caulfield et al 2012 Determining bicycling infrastructure preferences – a case study of Dublin. Transportation Research D 17, 413-417.

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Cycle track



Prešov, Slovakia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Lane for cyclists adjacent but not on the carriageway. The space is for the exclusive use of cyclists and is not shared with general traffic. Electric bicycles and micromobility vehicles may or may not be allowed.

Cycle tracks are physically segregated from motorised traffic with physical barriers, green areas, planters, flexible separators, or a strip with parked cars. Cycle tracks are also separated from pedestrian space.

Cycle tracks can be raised from the carriageway, at the same height of the footway or lower (known as half-height cycle tracks). This adds vertical to horizontal separation. The design of cycle tracks should allow for the drainage of surface water.

Cycle tracks should be wide enough to allow cyclists to pass others without being squeezed. If the lane is protected by parked cars, a buffer zone is needed to avoid conflicts when doors are opened.

Cycle tracks are suitable in roads with high volumes of motorised vehicles (>10,000/day) and of bicycles, high traffic speed (>50km/h) and/or proportion of large vehicles. Cyclists may be directed to carriageway at junctions to increase their visibility.

EXAMPLES

Segregated cycle tracks have a long history in the Netherlands. Half-height cycle tracks are common in Copenhagen and other Danish cities.

In large European cities such as London, Paris, and Berlin, there is a tendency to give more priority to new segregated cycle tracks, rather than cycle lanes, and to replace lanes with tracks.

In 2019, New York City announced a plan to build 400km of segregated cycle tracks.

EVIDENCE

A study of 7 European cities showed that larger cycle networks increase cities' cycling modal share - but the study did not disaggregate results by type of infrastructure (cycle lanes or tracks)

Mueller et al 2018 Health impact assessment of cycling network expansions in European cities. Preventive Medicine 109, 62-70.

A study in Montreal found that the injury risk of cycling on cycle tracks is lower than cycling in streets

Lusk et al 2010 Risk of injury for bicycling on cycle tracks versus in the street. Injury Prevention 17, 131-135.

In a stated preference study, cyclists identified segregated cycling tracks as their preferred cycling environment, ahead of quiet routes, on-road cycle lanes, and shared cycle bus-lanes.

Caulfield et al 2012 Determining bicycling infrastructure preferences – a case study of Dublin. Transportation Research D 17, 413-417.

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Cycleway



Helsinki, Finland ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Also known as bikeways or bicycle paths. Lane for cyclists running independently of motorised traffic, along quiet side streets, parks, waterfronts, and disused rail corridors. The lane is for exclusive use of cyclists, not shared with general traffic.

Electric bicycles and micromobility vehicles may or may not be allowed. In some cases, the space is shared with pedestrians. In other cases, it is physically segregated from footway or even aligned independent of pedestrian space.

Cycleways are often bidirectional. They have regular connections to the rest of the cycle network and few junctions with roads, reducing the need for cyclists need to stop.

Cycleways usually links major destinations in the city, so it can be used both for commuting and for leisure trips. Good lighting is required because the tracks often run along quiet areas. Greenery is often added.

Cycleways are suitable along corridors that have high volumes of both motorised vehicles and bicycles in the traffic, and where main roads have high traffic speed and/or a proportion of large vehicles in the traffic.

EXAMPLES

Urban cycleways are common in Japanese cities, often running along river banks. As an example, a route runs 50km along the Tamagawa River.

Cycleways have become popular in many countries during the 21st Century, mainly aimed at leisure uses, but also for transport, when crossing urban areas. They often use disused railway tracks.

Urban cycleways are often a part of long-distance cycleways. For example, the EuroVelo is a network of 45,000 km of cycling routes across Europe, often ending or crossing cities

EVIDENCE

A review of the impacts of cycle networks found a general preference of cyclists for cycleways with separate paths from the road, rather than cycling on roads with traffic.

Buehler and Dill 2016 Bikeway networks: a review of effects on cycling. Transport reviews 36, 9-27.

A second review found that the construction of cycleways increases the number and the share of cycle trips.

Heinen et al 2010 Commuting by bicycle: an overview of the literature. Transport Reviews 30, 59-96.

A third review concluded that urban greenways (shared by pedestrians and cyclists) have been consistently linked and physical activity levels among the population in surrounding areas

Hunter et al 2015 The impact of interventions to promote physical activity in urban green space: a systematic review and recommendations. Social Science and Medicine 124, 246-256.

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Quiet cycle routes



London, UK ©Paulo Ancaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Cycle routes using low-traffic streets, parks, or along rivers, canals, or disused railway corridors. They provide direct and continuous links both for longer trips for commuters and for shorter local trips.

The infrastructure is largely unsegregated except when joining busy roads or junctions. There are no turns requiring cyclists to turn across traffic lanes. Routes include direction signage, improved surface, and few obstructions (including car parking)

Routes usually ran on roads with low traffic volumes (<3000 vehicles/day) and low speed (<30kph), including in residential streets that are used by motorised vehicles mostly for access, not through movement.

The routes may run parallel to major roads, where they connect with public transport nodes, and other trip attractors. They can include contraflow lanes, allowing cyclists to use same road in both directions, even in one-way roads for cars.

Quiet cycle routes need to ensure safety and route continuity by bypassing busy junctions when possible. They also need to ensure 24h personal safety, not easy because routes across parks or along canals are too quiet at night

EXAMPLES

Copenhagen has a system of quiet routes (Green Cycle Routes) since 2000. The routes are aimed at commuters and tend to cross green areas.

London has an extensive system of managed quiet cycle routes linking outer suburbs with the city centre. They were known as Quietways but have since been debranded.

Edinburgh also has a network of quiet cycle routes (branded as QuietRoutes) comprised of radial routes linking outer suburbs with the city centre and some circular routes.

EVIDENCE

In a survey in Montreal, calm residential streets were identified as the best environment to cycle, with only 9% of respondents having negative perceptions, much lower than cycle tracks/lanes.

Wexler and El-Geneidy 2017 Keep'em separated - desire lines analysis of bidirectional cycle tracks in Montreal, Canada. Transportation Research Record 2662, 102-115.

In a stated preference study, cyclists identified quiet routes through parks/residential streets as the second best environment (behind segregated cycle tracks but ahead of cycle lanes)

Caulfield et al 2012 Determining bicycling infrastructure preferences – a case study of Dublin. Transportation Research D 17, 413-417.

The ability to take shortcuts on cycle trips (compared to routes available to car users) has been linked with cycling levels in a study in Austria.

Titze et al 2008 Association of built-environment, social-environment and personal factors with bicycling as a mode of transportation. Preventive Medicine 47, 252-259.

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Cycle highway



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Long-distance cycle routes aimed at commuters. They provide direct and continuous links between suburbs and city centres, reducing detours. The cycling infrastructure is usually wide and with good-quality pavement, allowing for faster speeds.

Cycle highways are mostly segregated from other road traffic with kerbs or other physical barriers. When this not possible, they run on wide mandatory cycle lanes on the road carriageway, with light segregation from other traffic.

At junctions, cyclists are separated in time and space from other traffic, to decrease delays and safety risk. This is achieved by deviation of cycle routes, cycle advance areas, cycle signals, or signal priority. Traffic calming may also be applied.

Cycle highways can use the space of disused railway corridors or run along major roads. They can include contraflow lanes, allowing cyclists to use the same road in both directions, even in one-way roads.

Micromobility vehicles may be allowed. Pedestrians and motorcycles are usually not. Cycle highways should accommodate all types of cycles, including electric and cargo bicycles, but conflicts may arise because of different speeds.

EXAMPLES

The concept of cycle highways was developed in the Netherlands (Snelfietsroutes), with the first route opening in 2004. It has since been adopted in many Northern European cities.

London's system of cycle highways includes 8 radial routes linking outer suburbs with the city centre. They were known as Superhighways but have been debranded.

Copenhagen also has an extensive system of bicycle superhighways, including several radial routes into the city centre, and a radial route. More routes are planned.

EVIDENCE

Evaluation of an upgrade of cycling infrastructure to cycle highway in Copenhagen found that use of the route increase but mostly because of relocation of cyclists from other routes, not new cycling trips

Skov-Petersen et al 2017 Effects of upgrading to cycle highways. Journal of Transport Geography 64, 203-210.

Modelling of commuter data in the Netherlands suggest that cycle highways reduce the use of motorised modes and increase cycling for commuting, especially for people living near the cycle highway

Rayaprolu et al 2018 Impact of bicycle highways on commuter mode choice: a scenario analysis. Environment and Planning B 47, 662-677.

Although the introduction of the London Cycle Superhighways led to a dramatic increase in cycling traffic volumes, it had no significant impacts on collision rates

Li et al 2017 Safety effects of the London cycle superhighways on cycle collisions. Accident Analysis and Prevention 99A, 90-101.

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Sharrows (shared lane markings)



Prague, Czech Republic ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Sharrows ("shared use arrows"), also known as shared lane markings, are pictograms (of a bicycle) on the pavement indicating that a lane is shared between motorised vehicles and cyclists. They do not indicate exclusive or preferential use for cyclists.

Sharrows confirm to cyclists that they are on cycle routes. This can be emphasized using additional measures (e.g. signs on posts). If sharrows are away from the kerb, they also encourage cyclists to keep a safe distance from parked vehicles.

Sharrows also make drivers more aware of the presence of cyclists and discourage drivers from overtaking cyclists in narrow roads. Sharrows can also be used to alert drivers and cyclists that contraflow movement by cyclists in one-way streets is allowed.

Sharrows are used when the space is too narrow to provide a cycle lane, and in roads with low traffic volume, speed, and proportion of large vehicles.

Sharrows are usually an additional measure, not the sole measure to protect cyclists, and are not enough in roads with high traffic volume/speed. Their success depends on the application of traffic calming measures.

EXAMPLES

Sharrows were introduced in Denver (USA) in 1993 and are used in several other US cities. They depict a bicycle and an arrow pointing in the direction of travel.

In Paris, sharrows depict a cyclist riding a bicycle. Unlike in other cities, sharrows are often used in quiet streets.

Sharrows are also used in cities the UK, Spain, Australia, New Zealand, and Canada, with different designs.

EVIDENCE

A study of 12 major US cities found that the density of sharrows (at the city or block level) was not significantly associated safety (for all road users) - unlike protected cycle tracks

Marshall and Ferencsik 2019 Why cities with high bicycling rates are safer for all road users. Journal of Transport and Health 13: 100539.

The introduction of sharrows in a road in Miami Beach (USA) increased the average distance between cyclists and parked cars by 26.7cm and the distance between moving/parked cars by 11.4 cm

Hunter et al 2012 Evaluation of shared lane markings in Miami Beach, Florida. Report to State of Florida Department of Transportation. University of North Carolina.

A study in Queensland (Australia) found that cyclists did not always cycle over the centre of sharrows - that position (and interactions with vehicles) depended on the width of kerbside parking space.

Nepal 2015 An assessment of existing bicycle advisory pavement marking on urban roads. Roads and Transport Research 24, 42-53.

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Light separation of cycle lanes



Brussels, Belgium © Aleksander Buczyński (European Cyclists Federation)

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Also known as light protection. Lane for cyclists on the road carriageway for the exclusive use of cyclists and not shared with general traffic, separated from other lanes with small, intermittent, and/or movable structures.

Light segregation is a low-cost solution, compared with kerb-separated cycle tracks. There are various alternatives: planters, blocks, low barriers, low poles or bollards, plastic delineators (known as armadillos).

Lightly-segregated cycle lanes are often temporary, used as trial to evaluate the level of use by cyclists, effects on other road users and policy objectives. They also help to determine the most suitable level of segregation and width.

This is a flexible design: the lane can be widened simply by moving the barriers. Additional segregation can be provided by adding more barriers. Temporary lanes can then become permanent, if the evaluation suggests they are successful

Light segregation allows cyclists to move in and out of the lane and to use more space of the cycle lane, overtaking others. It also helps pedestrians to cross the road, as they can use gaps in the barriers (unlike kerbed-separated cycle tracks).

EXAMPLES

Light segregation has been used in cities in Spain since the mid-2000s. Seville has installed 120km of these lanes in 2006-2010.

A cycle lane was added to Ninth Avenue in New York in 2008, separated from general traffic with concrete dividers with plants, flexible bollards, and parked cars.

A temporary two-way cycle lane was added to Royal College Street (London) in 2013, segregated with planters. The lane was later split into two one-way lanes, which became permanent.

EVIDENCE

A study in London found that lightly-segregated cycle lanes had higher proportions of women, older people and children than control cycle lanes.

Aldred and Dales 2017 Diversifying and normalising cycling in London, UK, An exploratory study on the influence of infrastructure. Journal of Transport and Health 4, 348-362.

Experiments showed that cyclists found different methods of light segregation as safer than no segregation (white lines only) but less safe than kerbs. They also rode closer to the traffic lanes.

Beard 2014 Alternative separation methods for cycle lanes. Transport Research Laboratory Report PPR 704.

Trials of light separation in cycle lanes in New Zealand reduced vehicle encroachment on cycle lanes and increased cyclist satisfaction.

Koorey et al 2013 Assessment of the effectiveness of narrow separators on cycle lanes. Presented at IPENZ Transportation Conference.

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Lane for electric bicycles

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Provision of dedicated lanes for the exclusive use of electric bicycles, closed to conventional bicycles and to motorcycles. Micromobility (electric) vehicles may be allowed.

This is an alternative to share the same lane with conventional bicycles, motorcyclists, or general traffic, reducing conflicts that arise because of different speeds. Enforcement is required to avoid the lanes being used by motorcycles.

The lane may be segregated from general traffic with markings or barriers and can have some of the safety design features used in cycle lanes, such as protected junctions, two-stage turns, advance stop lines, advance signal timings, and cycle signals.

A lane for electric bicycles may simply be a section of a double cycle lane, defined with markings on the pavement. Signs at junctions, and regular symbols on the pavement help to assign bicycles to each lane. Enforcement may be an issue.

Provision of these lanes depends on regulations. It may be required if electric bicycles are not allowed to use cycle lanes/tracks. The lanes are also suitable in roads with high volumes of motorcyclists and of other vehicles, especially large vehicles.

EXAMPLES

There are no examples of dedicated lanes for electric cycles (excluding conventional bicycles)

In July 2020, North Bay (Canada) City Council announced a 6-year project to build a 2m widen lane for electric bicycles in the median strip along Lakeshore Drive.

In 2017, BMW and Toji University presented a concept (Vision E3 Way) of an elevated covered tube for the exclusive use of electric bicycles, with an automated speed limit of 25km/h.

EVIDENCE

In a survey in China, less than 10% of users of electric bicycles stated their reason for using it was to be able to use a cycle lane - speed was the main reason (70-85%).

Cherry and Cervero 2007 Use characteristics and mode choice behavior of electric bike users in China. Transport Policy 14, 247-257.

Lanes for electric bicycles need more space than for conventional ones. In a study in China, electric bicycles were found to use more lateral space than conventional ones, because of moving faster.

Li et al 2017 Redesign of the cross-section of bicycle lanes considering electric bicycles. ITE Journal 170, 255-266.

Also in China, a study of users of electric bicycles found a high proportion using the motor vehicle lanes (12%), rather than using a cycle lane.

Du et al 2013 Understanding on-road practices of electric bike riders: An observational study in a developed city of China. Accident Analysis and Prevention 59, 319-326.

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Allow electric bicycles on cycling infrastructure



Beijing, China ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Allow electric bicycles to use cycling infrastructure. Micromobility (electric) vehicles may be allowed, but motorcycles are not. The lane may be segregated from general traffic or not.

Shared lanes create conflicts between electric bicycles and conventional bicycles, due to the different speeds. The lane/track must be wider (>3m) than lanes/tracks for conventional bicycles only, to allow overtaking.

Pedestrians crossing the road may also feel confused when encountering two types of vehicles, moving at different speeds. There are also potential conflicts between conventional and electric bicycles at junctions.

Drivers may also be confused at junctions. Safety measures (e.g. protected junctions, two-stage turns, advance stop lines or signal timings, and cycle signals) are needed to reduce conflicting movements.

Electric bicycles may be assigned a specific section of a double cycle lane, defined with markings on the pavement. Signs at junctions, and regular symbols on the pavement would help to assign bicycles to each lane. However, enforcement would be an issue.

EXAMPLES

Traffic regulations have gaps regarding the use of electric bicycles, and in practice they use cycling infrastructure in most countries.

New York City legalized electric bicycles in April 2020. They are allowed to use cycle lanes and cycle tracks connected with or adjacent to roads - in roads with speed limits of 30mph or less.

In Chinese cities there are wide shared lanes, used by motorcycles, electric bicycles, and conventional bicycles.

EVIDENCE

A video study of a lane shared by electric and conventional bicycles in China showed many serious conflicts caused by electric bicycles involving other electric bicycles, conventional ones, and other vehicles.

Guo et al 2019 Evaluating the safety impacts of powered two wheelers on a shared roadway in China using automated video analysis. Journal of Transportation Safety and Security 11, 414-429.

In a shared lane in China, electric bicycles moved at an average of 24km/h and always overtook other bicycles (moving at 14km/h). Electric bicycles also needed for lateral space.

Li et al 2017 Redesign of the cross-section of bicycle lanes considering electric bicycles. ITE Journal 170, 255-266.

Also in China, the comfort perception of users of conventional bicycles in a shared lane decreased with the number of electric bicycles and the proportions of electric bicycles and scooters.

Bai et al 2017 Estimating level of service of mid-block bicycle lanes considering mixed traffic flow. Transportation Research A 101, 203-217.

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Shared lane: cyclists and buses



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Bus lane that can be used by cyclists. Private cars and goods vehicle are banned. The lane is segregated from general traffic by a solid line and in some cases by a buffer zone. Micromobility users not usually allowed.

A shared bus-cyclist lane should be wider than a bus lane. It should be either narrow enough to prevent buses overtaking cyclists or wide enough to allow for safe overtaking. Cyclists should only be allowed to pass buses at bus stops.

A shared bus-cycle lane is a solution when there is no space for dedicated cycling infrastructure. This allows cyclists from avoiding the general traffic lane and being overtaken by cars on one side and buses on the other

There are possible conflicts because of different speeds of buses and cyclists. The distance between bus stops should be short to avoid high bus speed. Cyclists also dislike to stop at bus stops until boarding is completed.

A shared bus-cycle lane is suitable on road sections where the bus traffic volume and speed are low. It is not suitable in roads with steep slopes. Cycling on contra-flow bus lanes generates further conflicts at junctions.

EXAMPLES

In the UK, cyclists are generally permitted to use bus lanes. Shared bus-cycle lanes are the main or even the only cycling facilities along many roads in London.

Shared bus-cycle lanes are common in other large cities, e.g. Paris, Los Angeles, Sydney.

They are less common in countries with a more consolidated cycling culture such as the Netherlands and Denmark.

EVIDENCE

Surveys in four cities in the UK found that cyclists perceived cycling on bus lanes as safer and faster than on general lanes. However, cyclists and bus drivers had low opinions of each other

Reid and Guthrie 2004 Cycling in bus lanes. Transport Research Laboratory Report TRL 610.

In a stated preference study, shared bus-cycle lanes were preferred to cycling on general traffic lanes, but less preferred than any cycling infrastructure (lanes, tracks) or quiet routes.

Caulfield et al 2012 Determining bicycling infrastructure preferences – a case study of Dublin. Transportation Research D 17, 413-417.

An observational study found many conflicts between buses and cyclist in shared lanes, including buses overtaking and following bicycles too closely.

De Ceunynck et al 2017 Sharing is (s)caring? Interactions between buses and bicyclists on bus lanes shared with bicyclists. Transportation Research F 46B, 301-315.

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Cycle street (shared with car)



Bogotá, Colombia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Road designated for cyclists but where cars are allowed. The speed limit is low (<30 km/h). Cyclists have priority over cars, legally, or assumed because of the road design. There are no marked cycle lanes/tracks.

The status of the street as cycle street should be clear for drivers. The street can be one-way or two-way for cars. Cars can also be diverted from the street at some intervals. Car parking may or may not be allowed.

Narrow roads are preferable to cause cars to remain behind cyclists. In wider roads, cars can be prohibited from overtaking cyclists, but this may cause queues and driver irritation. The same problem may occur in hilly places.

This design is suitable when the road is important for bicycle movement (for example, as an alternative to busier roads) but less important for movement by motorised modes (<2000 vehicles/day), especially large vehicles.

This design may require additional measures to reduce traffic volume and possibly restrict the movement of large vehicles or the through-movement of all vehicles. But the success of the design depends on compliance by drivers.

EXAMPLES

Cycle streets are common in the Netherlands. As an example, Sarphatistraat (Amsterdam), the city's inner ring road, was redesigned as a cycle street in 2016.

There are several examples in other European countries (Germany, Denmark, Belgium) and in the USA, where there are known as Bicycle Boulevards,

There was a proposal to convert Dominion Road, a busy arterial road in Auckland (New Zealand) into a cycle street in 2014, but cyclists were later redirected to parallel streets.

EVIDENCE

In a study in Germany, a cycle street had a positive impact on bicycle use, but only a limited effect on car use reduction. Conflicts and car speeds in the cycle street reduced user acceptance.

Blitz et al 2020 More cycling, less driving? Findings of a cycle street intervention - Study in the Rhine-Main Metropolitan Region, Germany. Sustainability 12: 805.

In a study in California, collision rates cycle streets were 2-8 times lower than those on parallel, adjacent arterial routes.

Minikel 2012 Cyclist safety on bicycle boulevards and parallel arterial routes in Berkeley, California. Accident Analysis and Prevention 45, 251-247.

A study in Portland did not find evidence of an increase in physical activity among adults with children living near newly installed cycle streets.

Dill et al 2014 Bicycle boulevards and changes in physical activity and active transportation: findings from a natural experiment. Preventive Medicine 69, S74-S78.

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Shared path (cyclists and pedestrians)



Košice, Slovakia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Paths that can be used by cyclists and pedestrians on shared tracks that run independently of a road (i.e. not on a road's footway). Priority is given either to pedestrians or to cyclists. Electric bicycles and micromobility users may be allowed.

The paths may be along parks, waterfronts, canal towpaths, or disused rail corridors (at-grade or elevated). They have regular connections to the street network (fewer if the path is elevated or along a canal).

The paths do not completely replace footways along roads - they offer a quieter (but longer) alternative. Even with good lighting and surveillance, the paths pose personal security problems, and so are underused after dark.

The space can be completely unsegregated. Alternatively, cyclists and pedestrians may have separate paths, defined by pavement markings, a strip with tactile paving, greenery, street furniture, or kerbs.

Conflicts may arise because of different speeds and different types of movement of cyclists and pedestrians. This is particularly a problem for pedestrians with visual, hearing, or mobility impairments, and for older pedestrians.

EXAMPLES

London has an extensive system of canal towpaths, shared by pedestrians and cyclists. Many canals cross through central areas and connect major stations and shopping/leisure areas.

Cities in Sweden have paths shared by pedestrians, cyclists, and other non-motorised modes.

Paths shared by pedestrians and cyclists (but mostly used by cyclists are common in Japanese cities, often running along river banks

EVIDENCE

Urban greenways (shared by pedestrians and cyclists) have been consistently linked and physical activity levels among the population in surrounding areas

Hunter et al 2015 The impact of interventions to promote physical activity in urban green space: a systematic review and recommendations. Social Science and Medicine 124, 246-256.

A study of shared paths in three Swedish cities found that the large majority (70-95%) of users were cyclists. Bicycle speed varied from 12.5 to 26.5km/h

Eriksson et al 2019 An analysis of cyclists' speed at combined pedestrian and cycle paths. Traffic Injury Prevention 20, 56-61.

A video survey of a shared path in New York revealed many conflicts among and between pedestrians, cyclists, and street furniture.

Zheng et al 2020 Investigating factors that influence pedestrian and cyclist violations on shared use path: an observational study on the Brooklyn bridge promenade. International Journal of Sustainable Transportation 14, 503-512.

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Allow cyclists on footway



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Allow cyclists to use a pedestrianised street or the footway on a road that has a carriageway. Micromobility users may be allowed, but electric bicycles and electric micromobility vehicles should not.

The space should be wider than if used only by pedestrians or by cyclists. Street furniture or contrasting material may be used to keep cyclists from doorways and from seating areas and other places where pedestrians stop or place activities may happen.

Cyclists may be allowed only at some times, with lower pedestrian flows, e.g. at night-time. Cyclists may be allowed only in short sections, that connect cycling infrastructure, or in one-way streets that cannot accommodate a contraflow cycle lane.

This measure is suitable in old central areas with limited space, where the flows of pedestrians and cyclists are low, and where cyclists are a smaller proportion of flows than pedestrians.

Conflicts may arise because of different speeds and different types of movement of cyclists and pedestrians. This is particularly a problem for pedestrians with visual, hearing, or mobility impairments, and for older pedestrians.

EXAMPLES

In most countries, cyclists are not legally allowed to ride on the footway. This applies to Japan, but in practice, the law is not enforced, and cycling on footway is the norm.

Cyclists are allowed to ride on the footway in Seattle and in Washington DC (outside the city centre) - priority must be given to pedestrians.

Cycling on footways was legalized in Taipei's city centre in 2016, deemed to be a safer solution than cyclists sharing space with motorcycles.

EVIDENCE

A study in 3 English cities found that most cyclists slow down or dismount when pedestrian flows were high. But a minority, mostly young males, continue to cycle fast

Davies et al 2003 Cycling in vehicle restricted areas. TRL Report 583.

An experiment in China found pedestrians were influenced negatively by the number and speed of cyclists on the footway and whether they were riding against the flow of pedestrians.

Kang et al 2013 Statistical analysis of pedestrian perceptions of sidewalk level of service in the presence of bicycles. Transportation Research A 53, 10-21.

A stated preference survey in London found that pedestrians were willing to pay £2.81/year as extra tax for having no cyclists riding on the footway, on a given street.

Sheldon et al 2007 Valuing urban realm - business cases in public spaces. Association for European Transport Papers Repository.

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Increase cycle lane width



Copenhagen, Denmark ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Cycle lane should be wide enough to accommodate movements to stabilise a bicycle. It should be wider ($>2\text{m}$) if cycle volume is high, providing space for overtaking and for sociable cycling (two cyclists side-by-side).

Wider lanes also accommodate cargo bicycles, tricycles, cycle-rickshaws, pedicabs, and quadricycles (which require more space), and electric bicycles (to overtake non-electric ones).

Minimum width should be 1.25-1.5m. Shared lanes should be wider, e.g. minimum 3-3.5m (shared with motor vehicles) and 2.2 (shared with pedestrians). Buffer zones to other traffic and obstacles should be provided.

Width of shared lanes should be suitable for volume of cyclists and volume/speed of motorised traffic. Narrow widths are suitable for low cycling volumes but high traffic volume/speed.

Physical segregation is needed if cycle lane is wide, to discourage car users from driving/parking on it. Widening of cycle lanes is difficult on bridges and other pinch points.

EXAMPLES

Cycle lanes in China tend to be much wider than in other countries. Chinese guidance documents suggest a minimum of 2.5m, which is the recommended maximum elsewhere.

As a part of the redesign of Götgatan in Stockholm in 2013/2014, a narrow cycle track was converted into a wide cycle lane. Space was gained by removing two traffic lanes.

A cycle lane in Spring Street, a busy street in Los Angeles downtown, was added in 2011 but it was widened just 6 years later.

EVIDENCE

An evaluation of cycle lanes in Oslo found that cyclists feel safer in wider cycle lanes, especially when there are many large vehicles in the traffic.

Bjørnskau et al 2016 Evaluering av Sykkelfelt [Evaluation of Cycle Lanes in Oslo]. TØI rapport 1512/2016

A study in China found that cyclists feel more comfortable in wider cycling infrastructure, even when this is physically segregated from traffic.

Li et al 2012 Investigating bicyclists' perception of comfort on physically separated bicycle paths in Nanjing, China. Transportation Research Record, 2317, 76–84.

On shared cyclist-pedestrian paths, path width is associated with higher cycling speeds

Boufous et al 2018 The impact of environmental factors on cycling speed on shared paths. Accident Analysis and Prevention 110, 171-176.

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Bidirectional cycle lane/track



Melbourne, Australia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Double cycle lane/track, with two directions for bicycle movement on the same side of road or in the median strip. In roads with high volume of cyclists, two bidirectional lanes/tracks can also be provided, one on each side of the road.

The minimum width of the double lane/track should be 2-3.5m. The two directions should be separated using marked lines. The lane/track itself can be segregated from the carriageway with kerbs or other elements.

Bidirectional cycle lanes/tracks are easier and cheaper to build than two separate one-way cycle lanes/tracks. They are suitable where building frontages are on one side of the road only, on bridges, or where there is no motorised traffic.

Bidirectional cycle lanes/tracks on one side of the road can be difficult to access by cyclists coming from junctions on the other side. They can also cause congestion and conflicts among cyclists, especially at junctions.

Bidirectional cycle lanes/tracks can be confusing for motorised vehicles at junctions, and for pedestrians at crossings. But at busy junctions, they can be a better solution for cyclists, compared with separate lanes/tracks on all sides.

EXAMPLES

Some cities use bidirectional cycle lanes by default. In Malmö (Sweden), bidirectional tracks were used since the city started investing in the cycle network in the 1970s.

In Seville (Spain), bidirectional cycle tracks were provided on main roads, as a quick and inexpensive way to upgrade the cycle network in the early 2000s.

Cycle highways (e.g. London, Copenhagen) usually run on bidirectional cycling infrastructure.

EVIDENCE

A review found that bidirectional cycle tracks have higher bicycle-vehicle collision risk than unidirectional tracks, because drivers do not expect a cyclist coming from another direction.

Methorst et al 2017 Can cycling safety be improved by opening all unidirectional cycle paths for cycle traffic in both directions? Accident Analysis and Prevention 105, 38-43.

In a survey in Montreal, bidirectional cycle tracks were identified as better environments to cycle than cycle lanes, in midblock locations, but worse at intersections.

Wexler and El-Geneidy 2017 Keep'em separated - desire lines analysis of bidirectional cycle tracks in Montreal, Canada. Transportation Research Record 2662, 102-115.

In a study in Finland, the most frequent type of car/bicycle collision at crossings was a driver turning right and a bicycle coming from the driver's right side, along a cycle track.

Räsänen and Summala 1998 Attention and expectation problems in bicycle-car collisions: an in-depth study. Accident Analysis and Prevention 30, 657-666.

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Contraflow cycle lane



Paris, France ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

One-way road with a cycle lane against the flow of motorised vehicles. It may or may not have a cycle lane on the non-restricted direction (i.e. cyclists may use the general lane). Micromobility users may be allowed.

The lane can be segregated from the other lanes with a strip of car parking spaces. But rather than a formal lane, it can simply be a sign allowing cyclists. It can also be a wide contraflow lane shared with buses.

Contraflow cycle lanes reduce the propensity for cycling on the footway. A network of with-flow and contraflow cycle lanes covering a wide area improves permeability of the network for cyclists, reducing detours and delays.

Contraflow cycle lanes should be wider than similar cycle lane with the same flows. They can have coloured surfaces, to be more visible for drivers. These treatments are especially needed at junctions and across accesses to frontages.

This design is suitable in roads with low traffic volumes and speed. The use of traffic calming features (footway extensions, speed humps) in a contraflow cycle lane may cause cyclists to go onto the carriageway or vehicles to drive into the cycle lane

EXAMPLES

In the Netherlands, France, and Belgium, cyclists are allowed to move contraflow on most one-way streets with low speed limits, regardless of the existence of cycle lanes.

A network of contraflow cycle lanes started to be built in Madrid's city centre in 2016, as a part of a wider plan to expand cycling infrastructure.

There are some examples in US cities (e.g. Cambridge, Boulder, Eugene, Portland, Madison).

EVIDENCE

In a study in Belgium contraflow cycling was significantly associated with a reduction of collision risk for cyclists.

Vandenbulcke et al 2014 Predicting cycling accident risk in Brussels: A spatial case-control approach. Accident Analysis and Prevention 62, 341-357.

Cycling facing traffic was also significantly associated with fewer injuries than cycling with traffic, in a study in North Carolina.

Kim et al 2007 Bicyclist injury severities in bicycle-motor vehicle accidents. Accident Analysis and Prevention 39, 238-251.

In contrast, in a study in California, cyclists travelling against the direction of traffic in two-way lanes had a collision risk 3.6. higher than those travelling in the same direction.

Wachtel and Lewiston 1994 Risk factors for bicycle-motor vehicle collisions at intersections ITE Journal, September 1994, 30-35.

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Change cycle lane/track location: nearside



Košice, Slovakia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Location of cycling infrastructure between a traffic lane on one side and the footway or a kerbside zone used for car parking or bus stops on the other side. The alternative is location on the median strip or between parked cars and the footway.

If the road has kerbside car parking, vehicles need to cross the cycle lane when moving in and out of parking spaces, creating conflicts with cyclists. Angle car parking is particularly dangerous because of poor visibility between cyclists and drivers.

There are also potential conflicts when buses move in and out of bus stops. Buses at bus stops also restrict cyclists' sightlines. Conflicts can also happen when passengers open the vehicle doors on the cycle lane side, after parking.

With this solution, it is also more difficult for cyclists to access the footway, as parked cars are a barrier. However, cycle parking/hiring areas can be added in between car parking spaces.

Physical separation or buffer zones are required to reduce conflicts both with moving and parked vehicles. Parking should also be restricted near junctions, to ensure intervisibility between vehicles and cyclists.

EXAMPLES

Nearside cycle lanes are the most common form of cycling infrastructure in London. In many cases, cyclists share the lane with buses.

As a part of the transformation of Victoria Street in Wellington (New Zealand), a nearside cycle lane was added between traffic lanes and parked cars, with a "door zone" marked with hatched lines.

A kerbside cycle lane started to be added to 4th Avenue, a 10km avenue in Brooklyn (New York). In some sections, the cycle lane replaced car parking spaces.

EVIDENCE

Cyclists always feel less comfortable riding in roads with kerbside parking, compared with no parking, for all types of cycling infrastructure (with different degrees of separation).

Sanders 2016 We can all get along: The alignment of driver and bicyclist roadway design preferences in the San Francisco Bay Area. Transportation Research A 91, 120-133.

A review of North American studies shows that “dooring” incidents next to parking spaces account for 12%-27% of bicycle-vehicle collisions in urban areas, one of the most common types.

Schimek 2018 Bike lanes next to on-street parallel parking. Accident Analysis and Prevention 120, 74-82.

An observational study in Nanjing found that bicycle speeds decrease when a cyclist meets a bus at a bus stop where both vehicles share the same nearside lane.

De Zhao et al 2014 Evaluation of interactions between buses and bicycles at stops. Transportation Research Record 2468, 11-18.

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Cycle lane/track behind parking



Copenhagen, Denmark ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Location of cycling infrastructure (lanes/tracks) between a strip of car parking spaces and the footway. Parked vehicles act as a buffer between cyclists and moving vehicles.

This solution also reduces conflicts between cyclists and vehicles moving in/out of parking spaces, as they do not have to cross the cycle lane. But conflicts still happen when car users open vehicle doors on the cycle lane side, after parking.

Car users need to cross the cycle lane to access the footway. For the same reason, loading activities also become more difficult. This may lead to goods vehicles illegally stopping on the cycle lane, to be nearer to the kerb.

Cyclists have direct access to the footway and cycle parking areas. However, access of bus passengers to buses becomes more complicated, as the cycle lane and parked cars are in-between, unless the cycle lane is rerouted around the bus stop.

Physical separation or a buffer zone are required to reduce open-door conflicts with parked vehicles. Parking should also be restricted near junctions, to ensure intervisibility between vehicles and cyclists.

EXAMPLES

A two-way cycle lane buffered with car parking spaces was added to 15th Street NW in Washington DC in 2010, with a buffer to vehicles. Some turn movements were banned for vehicles at junctions.

The transformation of Second Avenue in New York in 2010 involved creating a new cycle lane and moving the car parking street between the cycle lane and the general traffic lanes.

A cycle lane in Spring Street, a busy street in Los Angeles, was added in 2011 but redesigned just 6 years later, moving the car parking strip between the cycle lane and the traffic lane.

EVIDENCE

In a study in five cities in the USA, cyclists gave a rating of 4.7 to level of comfort of cycle lanes protected with parked cars - equal to painted buffers, but less than kerbs (5.2), posts (5.4), and planters (5.6)

McNeil et al 2019 Influence of bike lane buffer types on perceived comfort and safety of bicyclists and potential bicyclists. Transportation Research Record 2520, 132-142.

In a study in Portland, cycle lanes protected with parking were rated higher than shared or cycle streets, unprotected or buffered lane, and contraflow lanes; and below segregated cycle lanes/tracks.

Foster et al 2019 Level-of-service model for protected bike lanes. Transportation Research Record 2520, 90-99.

After the introduction of a cycle lane buffered with parked cars in Washington, afternoon peak hour cycling levels grew 500%. 80% of pedestrians reported fewer cyclists riding on footways.

Goodno et al 2013 Evaluation of innovative bicycle facilities in Washington, D.C. Transportation Research Record 2387, 139-148.

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Change cycle lane/track location: median strip



Tirana, Albania ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Location of cycling infrastructure in the median strip of the road. This can be a cycle lane on the carriageway, between two lanes of moving traffic, or a cycle track on a kerbed median, which can also have space for pedestrians, or green areas.

Median cycle infrastructure is usually bidirectional. Compared with kerbside infrastructure, it increases intervisibility between cyclists and motorised vehicles, but it also creates several conflicting movements at junctions.

This solution eliminates conflicts between cyclists and vehicles moving in/out of kerbside parking/loading spaces, and buses stopping, as they do not have to cross cycle lanes. It also reduces risk of collisions when car users open doors after parking.

Access of cyclists to the footway and kerbside cycle parking/hire areas requires movement across traffic lanes or the use of pedestrian crossings, if legal. If cycle parking/hire is also on the median strip, cyclists can cross the road as pedestrians.

Physical separation or a buffer zone are required to reduce the risks of collision with moving vehicles. However, this reduces the scope for cyclists to access the kerbside, which can only happen at junctions.

EXAMPLES

A cycle lane was added on the median strip of Pennsylvania Avenue, a busy road in Washington DC, in 2010, with buffers on either side.

In July 2020, North Bay (Canada) City Council announced a 6-year project to build a 2m wide electric bicycle lane in the median strip along Lakeshore Drive

Section 6 Civil Boulevard in Taipei has a wide median strip with a cycle lane, space for pedestrians, greenery, and cycle parking facilities.

EVIDENCE

After the introduction of a median cycle lane in Washington DC, afternoon peak hour cycling levels grew 250%. Collisions increased, even after adjusting for increased cycling levels.

Goodno et al 2013 Evaluation of innovative bicycle facilities in Washington, D.C. Transportation Research Record 2387, 139-148.

Adding a cycle lane to a median strip that already accommodated car parking in Brasilia did not increase traffic injuries and fatalities.

Pereira and Santos 2016 Regulatory median parking: a case study on Recanto das Emas Avenue, Brasília, DF, Brazil. Transportation Research Procedia 18, 220-225.

In a study in Bogota, concentrations of particulates along bike lanes in the median strip of busy roads were found to exceed standards.

Franco et al 2016 Air pollution alongside bike-paths in Bogotá- Colombia. Frontiers in Environmental Science 4, 77

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Cycle lane/track bus stop bypass



Prešov, Slovakia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Routing of cycle lanes or tracks behind a bus stop (including bus shelter and waiting area). It requires passengers crossing the cycle lane. Zebra-like markings or other types of informal crossings can be provided.

In the case of a cycle lane on the carriageway, the cycle lane is deviated around a bus boarding island. Bus passengers need to step down into the cycle lane (which is at a lower level) and then step up to the boarding island to access buses.

In the case of a cycle track separated from the carriageway, the track is straight (i.e. no deviation) and at the footway level. Passengers cross the track from the footway and board the bus from a bus boarder on a footway extension.

This design avoids cyclists having to overtake buses on the carriageway, when buses are stopped. It can also reduce bus delays. However, it creates conflicts with bus passengers crossing the lane from/to the footway.

This design is suitable in roads with high volumes of cyclists and high volumes/speeds of motorised vehicles, and in stops with high bus frequency and with multiple buses stopping at same time.

EXAMPLES

Floating bus stops are widespread in the Netherlands, and have been installed since the 1950s.

The construction of the cycle highway network in London since 2010 created many floating bus stops. There was a legal action regarding a floating bus stop near a hospital.

As part of the Spaces for People programme, Edinburgh has built new cycle lanes, moving bus stops to islands between those lanes and the traffic lanes. This has led to protests.

EVIDENCE

In an observational study in Cambridge (UK), conflicts between cyclists and pedestrians at cycle bypasses were infrequent and of low severity.

Sustrans 2015 Cambridgeshire 'floating bus stops' interaction analysis. Report to Cambridgeshire County Council.

In a cycle bypass in Manchester (UK), average cycling speeds were 21km/h even in the busiest hour. But 86% of cyclists, 91% of bus users and 90% of pedestrians were satisfied with the design.

Transport for Greater Manchester 2016 Oxford Road Trial Bus Stop Evaluation Report.

In a study in Toronto, cycle bypasses behind bus stops were evaluated as a less safe solution than a boarding island on the carriageway, considering the conflicts between all users.

Kamaras-Garland et al 2018 Design of cycle tracks at bus stops - case study and guidelines. Proceedings of the 2018 Canadian Society for Civil Engineering Annual Conference.

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Cycle lane location: one side only



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Unidirectional cycle lane on one side of the road only, on two-way roads. On the other side of the road, cyclists use lanes shared with general traffic or with buses only.

This arrangement may be the only option when the road is narrow and there is no space for cycle lanes on both sides, but it is still desirable to have a dedicated lane on one side, for safety reasons (e.g. poor visibility).

In roads with a gradient, if there is only space for one cycle lane, this is more suitable in the uphill direction, because of the bigger difference in speed between bicycles and motorised vehicles.

A cycle lane may be provided on one side only if on the other side there is high demand for other roadspace uses (e.g. parking near schools, loading near a warehouse, pedestrians walking from/to a large concert hall).

There is a risk that cyclists use the lane contraflow, a potential hazard because other road users are not expecting a contraflow movement.

EXAMPLES

Design guidelines usually discourage cycle lanes on one side only, but recommend this as a solution when space is narrow

The solution is sometimes used in narrow hills with a gradient, with the cycle lane added in the uphill direction.

The solution is also used in narrow bridges. For example, Lambeth Bridge and most of Chelsea Bridge in London have a (narrow) cycle lane in only one direction.

EVIDENCE

In a study in Seattle, after adding a cycle lane on one side, cyclists on the other side rose closer to parked vehicles. But after adding sharrows, they rode close to the centre of the travel lane.

Hunter et al 2010 Evaluation of shared lane markings. Federal Highway Administration, Report FHWA-HRT-10-041.

There is no further evidence on roads with a cycle lane on only one side. Insights can be derived from studies about the absence on a cycle lane (which in this design, is the situation on one side of the road)

Cyclists dislike using lanes shared with motorised traffic and prefer separated cycling infrastructure. This is especially the case of women.

Aldred et al 2017 Cycling provision separated from motor traffic: a systematic review exploring whether stated preferences vary by gender and age. Transport Reviews 37, 29-55.

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Part-time cycle lane



London, UK © Aleksander Buczyński (European Cyclists Federation)

TYPE: Time allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Cycle lane that is only mandatory at some times of the day. At other times, the space can be shared with general traffic or with pedestrians. The whole lane, or some sections, can also be used for car parking, loading, or markets or cafés.

The assigned times are when cyclist flows are higher (e.g. peak times, if along commuter routes, or weekends, if near parks). The times may vary on lanes on each direction, depending on demand for cycling and other uses.

They are not suitable in roads with high traffic volume and speed. They are recommended in streets with many kerbside activities (e.g. parking and loading)

The status of the space as a cycle lane may be identified with signage and marks on the pavement. These can be fixed (indicating detailing hours of operation) or electronic (displaying the status of the space in each moment).

This design is suitable when the carriageway width cannot accommodate a cycle lane and a parking/loading lane. Compliance can be a problem: vehicles can remain parked when the cycle lane operating hours start.

EXAMPLES

There are several examples in Australia. Toorak Road in Melbourne has a cycle lane during peak-hours, when parking restrictions apply. The rest of the time, the space is used for car parking.

The first cycle lane in Trinidad in Tobago opened in 2015 in Port of Spain. It is a part-time lane in effect on weekdays 4-6AM and 20:30-22:30.

FlexKerbs, a concept developed by ARUP (private company), modelled for a London street, was a flexible design of kerbside space, widening cycle lanes at peak-times.

EVIDENCE

Simulation of the FlexKerbs concept in a street in London showed it would reduce average delay (to all users) in the morning peak from 192 to 51 seconds and at lunch time from 67 to 54 seconds.

ARUP 2018 FlexKerbs - Evolving Streets for a Driverless Future

There is no further evidence on part-time cycle lanes. Insights can be derived from studies on other flexible roadspace designs, which generally showed reductions in travel times.

Multifunctional lanes in Barcelona (with space allocated to general traffic, deliveries, and parking, at different times) reduced travel time by 12-15%. But part-time cycle lanes were not included in the design.

Hayes et al 2006 MIRACLES (Multi Initiative for Rationalised Accessibility and Clean Liveable Environments) Deliverable 4.2 Annex 3 – 2nd Implementation Report for Barcelona.

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Dynamic cycle lane

TYPE: Time allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Cycle lane that becomes active when the number of cyclists increase. At other times the lane may be for general traffic, pedestrians, or other uses. The lane can be activated based on data on volumes of cyclists in upstream traffic.

The lane can be identified with LED pavement lights and signs (indicating the lane for cyclists, and the need to move to other lanes, for other traffic). Enforcement is needed to ensure the lane is not used by motorised vehicles when active.

The transitions from/to cycle lane can cause confusion for cyclists and conflicts between them and the current users of the lane (e.g. cars, buses, motorcyclists, pedestrians). A suitable time lag is required before the lane is active.

The more dynamic the lane is, the fewer the uses it can have when it is not active. A fully dynamic lane can be a lane for general traffic or for pedestrians, but not a car or bicycle parking space, or space for place activities.

Dynamic traffic lanes can be static lanes at night-time, either inactive (if there is low demand for movement of cyclists) or active (if there is low demand for other uses).

EXAMPLES

There are no examples of dynamic cycle lanes.

There are a few examples of cycle lanes with dynamic elements. In the Netherlands, a few cycle lanes have automatic lighting, that become brighter when cyclists are approaching.

A similar design was used in Auckland (New Zealand) in the Light Path, an elevated shared elevated pedestrian-cyclist path along a former motorway ramp.

EVIDENCE

There is no evidence on dynamic cycle lanes. Insights can only be derived from studies on other dynamic street designs, e.g. dynamic pedestrian crossings and bus lanes.

Automatic lighting systems identifying the crossings when pedestrians are detected increase the propensity for drivers to stop for pedestrians.

Costa et al 2020 Evaluation of an integrated lighting-warning system on motorists' yielding at unsignalised crosswalks during nighttime. Transportation Research F 68. 132-143.

The simulation of the effects of dynamic bus lanes tend to show positive effects for bus users and few delays for other road users.

Olstam et al 2015 Dynamic bus lanes in Sweden – a pre-study. PROVDYK – Final report

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Dedicated lane/track for micromobility users

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Dedicated lane for the use of micromobility vehicles, not shared with other road users. Micromobility include small vehicles such as scooters, skateboards, and other vehicles; power-assisted or not. Bicycles (power-assisted or not) are not included.

This is an alternative to share the same space with pedestrians, bicycles, pedestrians, or general traffic, reducing conflicts that arise because of different speeds. Enforcement would be required to avoid the lanes being used by other vehicles.

The lane may be segregated from general traffic with markings or barriers and can have some of the safety design features used in cycle lanes, such as protected junctions, two-stage turns, advance stop lines, advance signal timings, and cycle signals.

A lane for micromobility vehicles may simply be a section of a double cycle lane, defined with markings on the pavement. Signs at junctions, and regular symbols on the pavement help to assign bicycles and micromobility users to each lane.

Provision of these lanes depends on regulations. It may be required if micromobility vehicles are not allowed to use other spaces on the road. The lanes are also suitable in roads with high volumes of motorised vehicles, especially large vehicles.

EXAMPLES

The use of e-scooter and other micromobility vehicles has grown since 2018, when dockless scooter-sharing systems emerged. There are no examples of dedicated lanes for these vehicles.

In most cities, traffic regulations have gaps regarding the use of micromobility vehicles, and in practice they are used footways, cycling infrastructure, and carriageway.

There was a temporary scooter lane for two days in Oak Street in Kansas City in 2018

EVIDENCE

Not having enough safe places to ride was identified as one of the main barriers to scooter use in a survey in the USA.

Sanders et al 2020 To scoot or not to scoot: Findings from a recent survey about the benefits and barriers of using E-scooters for riders and non-riders. Transportation Research A 139, 217-227.

An observational study found that the users of e-scooters use the roads in a flexible manner, switching from vehicle to pedestrian role.

Tuncer et al 2020 Notes on the practices and appearances of e-scooter users in public space. Journal of Transport Geography 85: 102702.

In a study in Portland, fewer proportions used the footway as the level of protection of cycle infrastructure increased and the speed limit decreased.

PBOT 2018 E-scooter Findings Report.

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Allow micromobility users on footway

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Allow use of micromobility vehicles on the footway, shared with pedestrians. Micromobility include small vehicles such as scooters, skateboards, and other vehicles; power-assisted or not. Bicycles (power-assisted or not) are not included.

The space should be wider than if used only by pedestrians. Street furniture or contrasting material may be used to keep micromobility users from doorways and from seating areas and other places where pedestrians stop or place activities may happen.

Conflicts arise because of different speeds and movements of micromobility users and pedestrians. The latter may fail to hear electric vehicles approaching. These conflicts particularly affect pedestrians with visual, hearing, or mobility impairments.

Footways have many structures that can be obstacles (street furniture, trees) and may not have a pavement smooth enough. This increases the risk of falls and collisions with pedestrians.

Micromobility users may be allowed only at some times, with lower pedestrian flows, e.g. at night-time, or only in short sections, that connect cycling infrastructure, or in one-way streets that cannot accommodate a contraflow cycle lane.

EXAMPLES

Traffic regulations in many cities have gaps regarding the use of micromobility vehicles. In practice, they are used on footways, cycling infrastructure, and the road carriageway.

New Zealand allows the use of micromobility vehicles on the footway, if power is under 300watts, speed is low, and priority is given to pedestrians.

In 2019, France and Singapore banned the use of e-scooters on footways.

EVIDENCE

Analysis of 80,000 e-scooter trips in Austin showed that average speeds on footway were only slightly lower than speeds on cycle infrastructure (-1.3km/h) and the carriageway (-0.9km/h).

Zuniga-Garcia et al 2020 E-scooters in urban infrastructure: understanding sidewalk, bike lane, and roadway usage from trajectory data. Presented at the 100th Transportation Research Board Annual Meeting.

44% of collisions involving e-scooters in Salt Lake City occurred on footways.

Badeau et al 2019 Emergency department visits for electric scooter-related injuries after introduction of an urban rental program. American Journal of Emergency Medicine 37, 1531-1533.

In a study in Rosslyn, Virginia (USA), 56% of respondents said they felt unsafe walking around dockless e-scooter riders -higher than dockless e-bikes (29%) and docked or non-shared bicycles (11%).

James et al 2019 Pedestrians and e-scooters - an initial look at e-scooter parking and perceptions by riders and non-riders. Sustainability 11: 5591.

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Allow micromobility users on cycle infrastructure



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Allow use of micromobility vehicles on cycling infrastructure, shared with cyclists. Micromobility include small vehicles such as scooters, skateboards, and other vehicles; power-assisted or not. Bicycles (power-assisted or not) are not included.

Cycle infrastructure usually have a smoother surface than footways, allowing for faster and more comfortable movement by micromobility vehicle. But conflicts arise because of different speeds and movements of micromobility vehicles and bicycles.

Pedestrians crossing the road may also feel confused when encountering two types of vehicles, moving at different speeds. There are also potential conflicts between bicycles and micromobility users at junctions.

Drivers may also be confused at junctions. Safety measures (e.g. protected junctions, two-stage turns, advance stop lines or signal timings, and cycle signals) are needed to reduce conflicting movements.

Micromobility users may be assigned a specific section of a double cycle lane, defined with markings on the pavement. Signs at junctions, and regular symbols on the pavement would help to assign each vehicle type to each lane.

EXAMPLES

Traffic regulations in many cities have gaps regarding the use of micromobility vehicles. In practice, they are used on footways, cycling infrastructure, and the road carriageway.

New Zealand allows the use of micromobility vehicles on separated cycle tracks, but not on marked cycle lanes on the carriageway.

New York City legalized e-scooters in April 2020. They are allowed to use cycle lanes and cycle tracks connected with or adjacent to roads.

EVIDENCE

Analysis of 80,000 e-scooter trips in Austin showed that average speeds on cycle infrastructure were higher than on the footway (+1.3km/h) and slightly higher than on the carriageway (+0.4km/h).

Zuniga-Garcia et al 2020 E-scooters in urban infrastructure: understanding sidewalk, bike lane, and roadway usage from trajectory data. Presented at the 100th Transportation Research Board Annual Meeting.

A study in Washington DC found that e-scooter flows are higher in cycle infrastructure, especially at night-time

Zou et al 2020 Exploratory analysis of real-time E-scooter trip data in Washington, D.C. Transportation Research Record 2674, 285-299.

In a study in China, the comfort perception of users of conventional bicycles in a shared lane decreased with the number of electric bicycles and the proportions of electric bicycles and scooters.

Bai et al 2017 Estimating level of service of mid-block bicycle lanes considering mixed traffic flow. Transportation Research A 101, 203-217.

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Allow micromobility users on general lanes



New York City, USA ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (moving)

DESCRIPTION

Allow use of micromobility vehicles on general lanes, shared with other vehicles. Micromobility include small vehicles such as scooters, skateboards, and other vehicles; power-assisted or not. Bicycles (power-assisted or not) are not included.

Cycle infrastructure usually have a smoother surface than footways, allowing for faster and more comfortable movement by micromobility vehicle. But falls are more likely to result in severe injury, as it may lead to a collision with a motorised vehicle.

There are conflicts because of different speeds of vehicles sharing the same lane. Cars and bus drivers may not be able to overtake micromobility users, or overtake when/where it is not safe.

There are also conflicts with cars and buses moving in/out of the kerbside zone to stop for parking and stopping. At junctions, extra conflicts arise because other vehicles may not see small micromobility vehicles.

This solution is more suitable in roads with low traffic volumes and speeds and low proportions of heavy vehicles. It is not suitable in roads with steep slopes.

EXAMPLES

Traffic regulations in many cities have gaps regarding the use of micromobility vehicles. In practice, they are used on footways, cycling infrastructure, and the road carriageway.

New Zealand allows the use of micromobility vehicles on the carriageway, but must be operated as near as possible to the edge of the carriageway.

In Norway, e-scooters are treated as bicycles, and can be used on the carriageway, if their maximum achievable speed is 20km/h.

EVIDENCE

Analysis of 80,000 e-scooter trips in Austin showed that average speeds on the carriageway were higher than on the footway (+0.9km/h) and slightly lower than on cycling infrastructure (-0.4km/h).

Zuniga-Garcia et al 2020 E-scooters in urban infrastructure: understanding sidewalk, bike lane, and roadway usage from trajectory data. Presented at the 100th Transportation Research Board Annual Meeting.

In an observational study in Junming (China), e-scooter left narrower lateral distances than bicycles when overtaking cars in a shared lane.

Guo et al 2019 Examining two-wheelers' overtaking behavior and lateral distance choices at a shared roadway facility. Journal of Transportation Safety and Security 12, 1046-1066.

Analysis of e-scooter-related injury data in Austin found that 10% of injuries involved a collision with vehicle and another 6% another incident involving a motorised vehicle *Austin Public Health 2019 Dockless Electric Scooter-related Injuries Study.*

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PART 5

Measures aimed at cyclists and micromobility vehicles (at junctions)

Advanced stop lines for cyclists



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Also known as advanced stop bars. Design of signalised junctions where cyclists wait in a designated area ahead of motorised vehicles. Cyclists pass the junction before other vehicles, reducing risk of collision with turning vehicles.

A bike box is a special case, where the advance area extends across the whole carriageway width. The area is usually painted in a different colour. This design gives cyclists extra space, in junctions used by many cyclists.

Advanced stop lines are suitable in junctions with high traffic volumes, high proportions of large vehicles, and many vehicles turning. They may be combined with advance signal timings for cyclists or cycle-only signals.

Advanced stop lines are usually combined with lead-in cycle lanes at the approach to the junction, to provide cyclists with space to pass motorised vehicles. This lane may be narrower than a mandatory or advisory cycle lane (e.g. 1.5m)

Advanced stop lines can be used on -carriageway cycle lanes or roads with no dedicated cycling facility. They are less useful for segregated cycle tracks. The stop line should be at a minimum of 3m ahead of the general stop line.

EXAMPLES

Portland has installed green bike boxes at signalised junctions since 2008, but authorities have expressed concern about their safety impacts.

London has installed advance stop lines in busy junctions since 1997, now covering most busy junctions in central areas. Enforcement was increased in 2013.

Advance stop lines are not very common in countries with high proportion of cyclist and other provisions for cyclists at junctions (e.g. 2-stage turns, protected junctions), such as Denmark/The Netherlands.

EVIDENCE

A study of bike boxes at 10 junctions in Portland found that 73% of vehicles did not encroach into the bike box. Encroachment of both vehicles and bicycles into the pedestrian crossing decreased.

Dill et al 2012 Evaluation of bike boxes at signalized intersections. Accident Analysis and Prevention 44, 126-134.

A video survey of 950 cyclists in Austin found that only 20-26% of cyclists stopped in the bike box but 90% stopped in front of vehicles. But vehicle encroachment on the bike box was common.

Loskorn et al 2013 Effects of bicycle boxes on bicyclist and motorist behavior at intersections in Austin, Texas. Journal of Transportation Engineering 139, 1039-1046.

In a study in Montreal, bike boxes had a significant impact reducing the total number of cyclists' violations of the red signal. But the impact on the number of dangerous violations was not significant.

Zangenehpour et al 2013 Impact of bicycle boxes on safety of cyclists: a case study in Montreal. Presented at the 92nd Transportation Research Board Annual Meeting.

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Advance signal timings for cyclists



Amsterdam, The Netherlands © Aleksander Buczyński (European Cyclists Federation)

TYPE: Time allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Also known as early release and leading bicycle interval. Allow cyclists to pass through signalised junctions ahead of motorised vehicles. This gives a head start to cyclists and reduces the number of conflicting movements with turning vehicles.

This measure requires separate signals for cyclists, at a lower level (at cyclists eye-height). If the road does not have cycling infrastructure, it should be clear the signal applies to cyclists, not drivers, to avoid confusion.

The advance timings are only a few seconds long. They should be enough for cyclists to pass conflict points ahead of other vehicles. If the junction is used by many cyclists, some may not be able to proceed ahead of the green phase for other vehicles.

Advance signal timings can be used in conjunction with other safety measures for cyclists, such as advanced stop lines (with a lead-in cycle lane) and turn restrictions for motorised vehicles.

This measure is suitable in junctions with high traffic volumes, high proportions of large vehicles, and many vehicles turning. They are useful where cyclists use segregated cycle tracks, where they are less visible.

EXAMPLES

Advance signal timings have been provided in some junctions in London, with separate signals for cyclists, advance stop lines, and lead-in cycle lanes.

Edinburgh started to install signals with advance timings for cyclists in 2018, following a sequence of fatal collisions involving cyclists.

Melbourne's 2016-2020 Bicycle Plan included projects for early start signals for bicycles in 10 busy junctions.

EVIDENCE

In a study in London of advance signal timing for cyclists, 81-96% of cyclists were able to proceed ahead of general traffic. In two sites, around 10% of drivers proceeded during the advance timing for cyclists.

Clifford et al 2018 Low-level cycle signals - on-street observations of early release and hold the left. Transport Research Laboratory. Report PPR856.

In a simulation study in New York, advance timings for cyclists were ranked ahead of cycle phases and below conventional timings for efficiency. There was no significant evidence in terms of safety.

Kothuri et al 2018 Addressing bicycle-vehicle conflicts with alternate signal control strategies. Transportation Research and Education Center, Report NITC-RR-897.

In an experiment in Japan, bicycle signals with advanced timings has fewer conflict points but more frequent near conflicts between bicycles and vehicles, compared with advance stop line designs.

Abdul Rahimi et al 2013 Experimental research on bicycle safety measures at signalized intersections. Journal of the Eastern Asia Society for Transportation Studies 10, 1426-1445.

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Cycle signals



Dordrecht, The Netherlands © Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Separate traffic signals for cyclists at junctions. They can be a phase of the signal cycle or be activated by cyclists or automatically (using detectors). Cycle signals eliminates all conflicting movements with other road users at junctions.

Cycle signals can be used to reduce the waiting time for cyclists at junctions, by allowing longer green phases for cyclists than for motorised traffic. They can be coordinated, along the same route, to create green waves for cyclists.

They can also be used to give cyclists a head start at junctions, ahead of motorised vehicles, reducing conflicting movements. In this case, it should be clear the signal applies to cyclists, not drivers, to avoid confusion.

Cycle signals are suitable in junctions with two-way cycling lanes/tracks. They are also suitable in junctions with high traffic volumes and with many conflicting turning movements, including vehicles turning across cycle lanes/tracks.

Cycle signals are at a low level and may be separate signals or be mounted on the same columns as the main signals. They may have countdown clocks. Arrows may be added to the lights to indicate the movements allowed.

EXAMPLES

Cycle signals were introduced in the USA in 1994 in Davis (California). As of July 2020, there were 511 junctions across the country with cycle signals.

Cycle signals are sometimes introduced with new cycling infrastructure. For example, cycle lane was added to Ninth Avenue in New York in 2008, with cycle signals to protect cyclists from turning vehicles.

Cycle signals (Hold the Left) have been provided in some junctions in London, with separate green phases for cyclists and for vehicles turning left.

EVIDENCE

In a study of cycle tracks in five US cities, cyclists stated that junctions with separate bicycle signal phases were the safest of all designs. 92% felt safe in those junctions.

Monsere et al 2014 Lessons from the green lanes: evaluating protected bike lanes in the U.S. NITC Report NITC-RR-583

In a study in London of cycle signals separate from signals for turning vehicles showed compliance rates for cyclists of 77-92%. Pedestrians reported feeling confused. Only 20% looked at the cycle signals.

Clifford et al 2018 Low-level cycle signals - on-street observations of early release and hold the left. Transport Research Laboratory. Report PPR856.

A cost-benefit analysis of adding a bicycle phase to a signalised junction showed that the benefits of reduced bicycle-vehicle conflict outweighed (8:1) the costs of increased vehicle delay.

Korve and Niemeier 2002 Benefit-cost analysis of added bicycle phase at existing signalized intersection. Journal of Transportation Engineering 128

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Green wave for cyclists



Copenhagen, Denmark © Aleksander Buczyński (European Cyclists Federation)

TYPE: Time allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Integration of the cycle timings of traffic signals in a sequence of road junctions so that cyclists travelling in a given direction encounter green signals along the whole sequence.

Green waves can be created on cycle signals applying to cyclists moving on cycling infrastructure, or on general traffic signals applying to general traffic. The signal cycle assumes a certain speed for cyclists (usually 15-20km/h).

This measure reduces the number of stops and waiting times at junctions, for cyclists, also reducing their propensity to jump red lights. But it also makes the travel speed more predictable for all users, not only cyclists.

Adaptive signal control systems can be used to adjust the signals to the current speed of cyclists travelling along the green wave route, using real-time data. The direction of the wave can also be reversed based on data on flows of cyclists.

The system can be improved, if cyclists can receive information about the speed they should maintain to use the green wave; for example with LED lights on the road surface along the green wave route.

EXAMPLES

The concept of Green Wave has been used for many years to facilitate movement of cars. It has been adapted for cyclists in Copenhagen in 2007.

Green Waves have been introduced in some parts of US cities including San Francisco (2009), Portland (2011), Chicago (2015), and New York (2019).

Green waves are often a part of wider road redesign projects. For example, a green wave for cyclists was added along Götgatan, a major road in Stockholm, in 2013-14.

EVIDENCE

Evaluation of a green wave scheme at Nørrebrogade in Copenhagen showed that travel time decreased by 17% and the average number of stops decreases from 6 to less than 1.

City of Copenhagen 2014 Better mobility in Copenhagen / ITS action plan 2015-2016.

Experiments in the Netherlands found that a green wave system increased the proportion of cyclists who passed the lights without stopping from 44% to up to 72%, with minimal impact on other users.

Zhang and Blokpoel 2018 A scale-up network level study of green wave with speed advice for cycling. Proceedings of the 25th ITS World Congress.

Surveys in Italy and the Netherlands show that acceptance of green waves for systems vary with the type of interface used to transmit information to cyclists, and with the cyclists' characteristics.

Angelis et al 2019 Green wave for cyclists: users' perception and preferences. Applied Ergonomics 76, 113-121.

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Bend in



Vilvoorde, Belgium © Aleksander Buczyński (European Cyclists Federation)

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

End segregated cycling infrastructure (cycle tracks) before reaching a junction, redirecting cyclists to an unsegregated cycle lane on the road carriageway.

This solution requires less space than bend-out solutions or straight paths across the junction. It is also more direct for cyclists. However, it forces cyclists to use an unsegregated section of the carriageway.

Unlike bend-out designs, bend-in designs do not force pedestrians to any extra deviation when crossing the road where the cycle lane is or the road perpendicular to it. Footways can also be extended where the cycle track bends in to the carriageway.

Compared with a straight path across the junction, this solution reduces bicycle speeds, increases visibility between drivers and cyclists, and increases potential conflicting movements between cyclists and turning vehicles.

The transition should be with a smooth ramp. The route should also be identified with markings and pavement colours, to highlight potential conflict points with motorised vehicles.

EXAMPLES

Bend-in solutions are common in cities in the UK and Germany.

Bend-in solutions are common in narrow roads in cities in many countries, where there is little space to accommodate bend-outs.

One of London's Cycle Highways (Bow-Stratford) used bend-in solutions, with cycle tracks ending 12-20m before junctions. This has led to several fatalities.

EVIDENCE

In a comparison of junction types, 47% of cyclists felt comfortable using bend-in designs, more than bend-out (36%) or straight path (43%), but less than protected junctions (66%) and cycle signals (67%).

Monsere et al 2020 User-rated comfort and preference of separated bike lane intersection designs. Transportation Research Record, <https://doi.org/10.1177/0361198120927694>

A study in the USA showed an increase in the absolute number of collisions involving bicycles, at sites with bend-in treatments. But the study did not control for changes in traffic volume.

Rothenberg and Sundstrom 2015 Separated bike lane crash analysis. Presented at 95th Transportation Research Board Annual Meeting.

In a study in the Netherlands, collisions with cyclists were more likely where cycle tracks were not deflected from the carriageway.

Schepers et al 2011 Road factors and bicycle motor vehicle crashes at unsignalised priority intersections. Accident Analysis and Prevention 43, 853-861.

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Bend out



Tirana, Albania ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Deviate segregated cycling infrastructure (cycle tracks) away from the carriageway before reaching a junction. An island is created between the cycle track and the road.

This solution requires more space than bend-in solutions or no deviations. It is also less direct for cyclists. When crossing the perpendicular road, cyclists may use the same crossing facility as pedestrians, or a crossing adjacent to it.

This solution forces pedestrians to cross the cycle track and wait in an island before crossing the road. It also forces them to deviate, when crossing the perpendicular road, as the crossing is offset to accommodate the bent-out cycle track.

Compared with a straight path across the junction, this solution increases intervisibility and decreases potential conflicting movements between cyclists and turning vehicles.

The cycle track markings and colours can be extended across the carriageway of the perpendicular road, to increase the visibility of cyclists for drivers, and separate space for cyclists and pedestrians at the crossing.

EXAMPLES

Bend-out solutions are common in cities in Sweden, Denmark, and Netherlands

In most countries, cycle tracks along busy roads in suburban and rural areas usually use bend-out solutions, as there is more space to accommodate them.

There is a tendency in cities in Western Europe, Australia, and USA to add protected junctions, with some deflection of cycle tracks.

EVIDENCE

In a comparison of junction types, only 36% of cyclists felt comfortable using bend-in designs, less than straight path (43%), bend-in (47%), protected junctions (66%), and cycle signals (67%).

Monsere et al 2020 User-rated comfort and preference of separated bike lane intersection designs. Transportation Research Record, <https://doi.org/10.1177/0361198120927694>

In a video survey of junctions between major and minor roads, bent-out cycle tracks had much less conflicts between vehicles and cyclists than straight cycle tracks

Pedler and Davies 2000 Cycle track crossings of minor roads. Transport Research Laboratory Report 462.

In a study in the Netherlands, collisions with cyclists were 45% less likely where cycle tracks was deflected 2-5m from the carriageway, compared to an unsegregated cycle lane or no cycling infrastructure.

Schepers et al 2011 Road factors and bicycle motor vehicle crashes at unsignalized priority intersections. Accident Analysis and Prevention 43, 853-861.

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Protected junction for cyclists



's-Hertogenbosch, The Netherlands © Aleksander Buczyński (European Cyclists Federation)

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Also known as corner refuge islands. Area reserved for cyclists in corners of junctions, separated from the carriageway with kerbs or barriers. It provides space for cyclists moving ahead of turning, reducing conflicts with motorised vehicles turning.

Protected junctions reduce the corners' radius, reducing vehicle speeds, protecting cyclists and pedestrians. They also increase the visibility of cyclists for drivers turning, and prevent drivers from encroaching on cycle lanes/tracks.

The refuge island should be wide enough to accommodate all waiting cyclists within one signal phase. They should be located before pedestrian crossing facilities. Low-level greenery can be added to the refuge.

This design is suitable in roads with high traffic levels and speeds. It is also suitable where cyclists approach the junction using segregated cycle tracks, or if cyclists have to cross more than one lane to reach the turning lane.

Protected junctions can be used in conjunction with other safety measures, such as cycle signals and advanced signal timings for cyclists. They are an alternative to using advance stop lines and bike boxes.

EXAMPLES

Protected junctions were first installed in Netherlands, where there are very common. Cities in other countries (e.g. USA, UK, Australia) have begun to install them since 2015.

The first protected junction in Scotland was installed in 2020 in Glasgow (Victoria Road) and will be trialled for two years. There were previous examples in London.

The first protected junction in Melbourne (at Albert Street/Lansdowne Street) was installed in 2020, as a trial. There is a plan to install more in other junctions.

EVIDENCE

In a comparison study of different types of junctions, 66% of cyclists felt comfortable using protected junctions, similar to cycle signals, and more than all other types (bend-in, bend-out, straight path).

Monsere et al 2020 User-rated comfort and preference of separated bike lane intersection designs. Transportation Research Record, <https://doi.org/10.1177/0361198120927694>

In a study in the USA, protected intersections reduced potential collision severity: traffic speed in moderate/high-risk conflicts with bicycles decreased by 15%.

Hurwitz et al 2015 Towards elective design treatment for right turns at intersections with bicycle traffic. Report FHWA-OR-RD-16-06.

A driving simulator study found that the presence of a cyclist crossing a protected junction significantly reduced speeds of turning vehicles.

Christofa et al 2019 Dissecting the safety benefits of protected intersection design features. SAFER-SIM University Transportation Center

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Two-stage turn



Oudenaarde, Belgium © Aleksander Buczyński (European Cyclists Federation)

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Junction where cyclists can split the turning movement into two straight movements, one for each arm of the junction. This is achieved with cycle signals and marked spaces for cyclists to wait in middle of junction.

The waiting spaces allow the cyclist to be away from the path of vehicles in the first stage of the turn. This solution reduces the number of potential conflicts but it also increases the time needed for cyclists to pass the junction.

The waiting spaces should be before pedestrian crossings and be wide enough to accommodate all waiting cyclists within one signal phase. The spaces, and path leading to them, can be identified with markings, a distinct colour, and bicycle symbols.

Cycle signals, with advance timings in relation to general traffic, can be installed in the two crossing stages. In the second stage, the signal can be installed in the waiting area or on the other side of the junction (but should be visible to cyclists).

This design is suitable in roads with high traffic levels and speeds. It is also suitable where cyclists approach the junction using segregated cycle tracks, and where cyclists have to cross more than one lane to reach the turn lane.

EXAMPLES

Two-stage turns are legally required in Denmark and are so common that waiting space is not usually marked. The design is also known as "Copenhagen Left".

A right-turn design was introduced for the first time in Scotland on Edinburgh's Leith Walk in 2017. There were previous examples in London.

The redesign of the Elephant and Castle roundabout in London in 2015 included a new two-stage turn for cyclists at one of the junctions (with London Road)

EVIDENCE

In controlled off-street trials, only 25% of cyclists used the two-stage waiting area. However, the cyclists' ratings of ease of using this facility, and perceived safety, were high.

Beard 2019 Investigation of cyclist responses to a two-stage right-turn facility. Journal of Transportation Safety and Security 12, 151-177.

In a survey in Portland, 50% of cyclists stated they would modify their route if it was easier to turn, with a two-stage left turn.

Smith and Vu 2009 Negotiating left turns along the SE Hawthorne bike corridor. Portland State University USP 565.

Simulations showed that two-stage turns reduce delays for motorised vehicles but can increase delay for turning cyclists in small, low-volume junctions.

Chen and Chunfu 2014 Operational impacts of Copenhagen Left as alternative to diagonal left turns of bicycles at signalized intersections. Presented at the 93rd Transportation Research Board Annual Meeting.

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Continuity of cycle tracks over side roads



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Measures to maintain the continuity of segregated cycle tracks, without changes in level or pavement type at side roads, driveways, and direct accesses to properties.

Cycle tracks can be continued with the same markings and no change of level across side roads. Alternatively, cycle tracks can be marked as advisory cycle lanes. Cycle lanes/tracks can be wider and coloured to increase visibility.

Crossovers for vehicles should be minimized in areas with high volumes of cyclists. For example, a single access point to several properties generates less conflicts than many individual accesses along a road.

The side roads should be as narrow as possible. Corners at the junction with the main road should have tight radii, to reduce vehicle speeds. Vehicles and cyclists should be visible to each other and parking/loading should not be allowed.

These designs are usually complemented with legal measures, giving cyclists priority over vehicles crossing the cycle track. However, there is often a problem with drivers not complying, forcing cyclists to wait.

EXAMPLES

In many countries vehicles turning into driveways, and properties are legally required to give priority to cyclists using cycle tracks.

There is a tendency for improving the design of accesses to driveways and properties, with smooth crossovers, ensuring the continuity of cycle tracks

The number of vehicle crossovers is subject to regulations, often in the framework of planning permissions. The 1980 Highways Act in the UK started to required approval for crossovers.

EVIDENCE

In a video survey of cycle tracks crossing minor roads, tracks where cyclists had no priority had fewer conflicts than those where cyclists had priority or where priority was unclear.

Pedler and Davies 2000 Cycle track crossings of minor roads. Transport Research Laboratory Report 462.

In a study in the UK, cyclists' rating of road conditions was negatively correlated with the frequency of side turnings but not with the frequency of driveways.

Guthrie et al 2001 Cyclists' assessments of road and traffic conditions: the development of a cyclability index. Transport Research Laboratory Report 490.

In a study in India, cyclists' ratings of road conditions were significantly associated with the frequency of driveways with high traffic volume, but not with the frequency of all driveways.

Beura et al 2017 Urban road segment level of service based on bicycle users' perception under mixed traffic conditions. Journal of Modern Transportation 25, 90-105.

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Shared or parallel pedestrian and cycle crossings



Temuco, Chile ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (at junctions)

DESCRIPTION

Crossing facilities that can be used by cyclists and pedestrians. The crossings can be unsignalised or signalised. They are usually located at junctions, but can be mid-block.

In shared crossings, the space for cyclists and pedestrians is completely unsegregated. However, pedestrians may have priority and cyclists may need to dismount.

In parallel crossings, cyclists and pedestrians have separate paths, defined by markings. The cycle crossing is sometimes marked with large squares (known as "elephant's feet"). Cyclists do not need to dismount.

For cyclists, the crossing is often the continuation of segregated cycle tracks running along the footway, which are deviated away from the carriageway before reaching the junction (known as bend-out designs).

Conflicts may arise because of different speeds and different types of movement of cyclists and pedestrians. This is particularly a problem for pedestrians with visual, hearing, or mobility impairments, and for older pedestrians.

EXAMPLES

In the UK, 'Toucan crossings ("two can") are signalised crossings shared by cyclists and pedestrians. They are wider than pedestrian-only crossings.

There are also shared and parallel signalised crossings in other countries (e.g. Australia, New Zealand), mainly used when they are along shared paths.

Christchurch City Council installed parallel crossings with two types of tactile pavement at the entrance of the pedestrian and cyclist crossing, to assist visually-impaired pedestrians.

EVIDENCE

Research on Toucan crossings in the UK showed that 80% of cyclists and 85% of pedestrians were happy sharing the crossing - but the sample of disabled pedestrians was small.

Taylor and Halliday 1997 Pedestrians' and cyclists' attitudes to Toucan Crossings. Transport Research Laboratory Report 277.

In a study of zebra crossings (unmarked crossings) illegally used by cyclists in London, 88% of cyclists did not dismount, but only 3% had conflicts with pedestrians.

Greenshields et al 2006 Shared zebra crossing study. Transport Research Laboratory. Report UPR/T/035/06

Simulation of solutions for roundabouts found that shared bicycle-pedestrian crossings decrease average vehicle and bicycle delay, but increase pedestrian delay, compared with separate crossings.

Al-Ghandour 2006 Bicycle/pedestrian crosswalk alternatives for a single-lane roundabout: experimental analysis of delay. International Conference on Transportation and Development 2016

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PART 6

Measures aimed at cyclists and micromobility vehicles (parking)

Cycle parking area



Copenhagen, Denmark ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Designated space with facilities to lock bicycles. They may include cycle stands (used to park 1-2 bicycles) or cycle racks (used to park 6+ bicycles). Other facilities may be provided (e.g. information boards with maps).

Areas with longer parking durations (>2 hours) (e.g. at stations or residential areas), require additional features for protection against theft/vandalism and weather. Underground facilities are a solution for securely parking many bicycles in busy areas.

Cycle parking areas should be along cycle lanes or tracks and near transport interchanges, rail stations, bus stops, trip attractors, and areas used by many cyclists. They increase the catchment area of these locations, compared with pedestrian access.

Cycle parking areas can be located on the footway, on the kerbside zone of the carriageway, or on the median strip. If on the footway or a walkable median, they should not obstruct the clear path for pedestrians.

Enough space must be provided to avoid cyclists parking outside the designated areas (e.g. against guard railings). Enough space is also required between stands for parking of non-standard cycles.

EXAMPLES

National Cycling Master Plans in the Netherlands, Denmark, and Germany in 1999-2002 included more and better cycle parking as a key strategy, leading to a growth of cycle parking availability.

London has published a cycle parking plan in 2009, with the aim at providing for a 100% increase in cycle trips by 2025. As of 2020, London had 150,00 parking spaces on streets and 20,000 at stations.

There are some moves to charge cyclists for parking spaces in more convenient locations: a pilot program was launched in Swiss cities in 2019. Cyclists can book a space via a mobile phone application.

EVIDENCE

A literature review concluded that bicycle parking supply and quality is a determinant of cycling for current and potential cyclists.

Heinen and Buehler 2019 Bicycle parking: a systematic review of scientific literature on parking behaviour, parking preferences, and their influence on cycling and travel behaviour. Transport Reviews 39, 630-656.

A study in Washington found that bicycle parking was related to higher levels of bicycle commuting, when controlling for other factors.

Buehler 2012 Determinants of bicycle commuting in the Washington, DC region: the role of bicycle parking, cyclist showers, and free car parking at work. Transportation Research D 17, 525-531.

In a stated/revealed preference study availability of outdoor and indoor cycle parking facilities was valued, respectively, as equivalent to a reduction of 2.5min and 4.3min of cycling time.

Wardman et al 2007 Factors influencing the propensity to cycle to work. Transportation Research A 41, 339-350.

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Bike corrals/hangars



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Series of cycle racks (facilities to park several bicycles), usually located on the kerbside zone of the carriageway, replacing one car parking space (which can accommodate up to 12 bicycles). The racks are either diagonal or perpendicular to the road.

Cycle racks can be separated from parked cars by barriers, to reduce the risk of vehicles using the space. They also need to be separated from the traffic lanes. Separation can be through marked lines, a buffer zone, low barriers, or bollards.

Cycle hangars are covered and lockable cycle racks. They help to protect bicycles against theft and the weather, allowing for overnight on-street parking in residential areas.

Bike corrals should be near cycling infrastructure and near transport interchanges, rail stations, bus stops, public areas, trip attractors, and areas used by many cyclists. Information boards with maps are sometimes installed next to the corral.

Enough space must be provided to avoid cyclists parking outside the corral (e.g. against guard railings). Enough space is also required between stands for parking of non-standard cycles.

EXAMPLES

Portland (USA) started a Bicycle Corral Program in 2004. As of April 2019, it had installed 158 corrals, with spaces for 6-12 bicycles, across the city.

As of July 2019, London had installed 1200 cycle hangars, with 7200 spaces. Citizens can apply for a hangar near their home.

New York launched its Bike Corrals program in 2011. Citizens can apply for one but a partner is required to be responsible for maintenance. 67 corrals had been installed as of September 2020.

EVIDENCE

Business owners in Portland agreed that bike corrals enhance street identity (84%), and increase transport options for employees (77%), foot/bike traffic (67%) and visibility of businesses from the street.

Meisel 2016 Bike corrals: local business impacts, benefits, and attitudes. Portland State University

The total number of parked bicycles increased and the number of illegally parked bicycles decreased after the installation of bike corrals in Denver.

Rijo 2015 Economic and traffic impacts following the installation of new bicycle facilities: a Denver case study. MA dissertation, University of Denver.

In Eugene (Oregon, USA), 89% of businesses with bike corrals in their blocks were happy with the street space, compared to 50% of businesses without bike corrals.

Peizer 2015 From perceptions to best practices: next steps for on-street bike parking. MA dissertation, University of Oregon. In Commercial Areas In Eugene, Oregon.

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Dock-based cycle share area



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Designated area to pick-up and drop-off bicycles from a shared bicycle scheme. The dock area is fixed and consists of cycle racks with locked bicycles, a structure with an interface to hire a bicycle, and sometimes a separate information with maps.

Dock-based systems allow users to unlock bicycles for a per-trip charge, with a paid membership, or for free. Bicycles can be used for a short time and can be returned to another dock in the same system.

Dock-based systems are a more efficient use of space, solving the problems of insufficient storage and parking of private bicycles. If near rail/metro stations, they enable one-way trips or cycling at both ends, increasing the catchment area of stations.

Dock areas should be located next to cycling infrastructure. They can be on the footway, on the kerbside zone (replacing parking spaces), or in nearby parks, squares, and other public spaces. If on the footway, they should not obstruct pedestrians.

The system should cover a large zone, and docks should be within short distances of each other and near trip attractors. The size of the area should be adjusted to demand, otherwise it requires redistribution of bicycles throughout the day.

EXAMPLES

The earliest bike share scheme was the White Bicycle Plan in Amsterdam in 1965, by Provos (a counterculture group). Like many early schemes, cycles were locked, not docked

Schemes based on information technology started in the early 2000s in Europe. The Velib scheme in Paris is one of the oldest and largest schemes.

There are thousands of schemes currently in operation, the largest ones in China, but they face competition from dockless schemes.

EVIDENCE

Analysis of the London cycle share system revealed positive health impacts overall. These benefits are clearer for men and older people.

Woodcock et al 2014 Health effects of the London bicycle sharing system: health impact modelling study. British Medical Journal 348:g425.

Modelling has shown that bus ridership in New York decreases 2.5% for every 1000 cycle share docks near bus routes

Campbell and Brakewood 2017 Sharing riders: how bikesharing impacts bus ridership in New York City. Transportation Research A 100, 264-282.

A study in China shows that extending the system, adding new docks, allows the original users' ability to reach new areas while also attracting new users.

Zhang et al 2016 Expanding bicycle-sharing systems: lessons learnt from an analysis of usage. Plos One, <https://doi.org/10.1371/journal.pone.0168604>

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Dockless shared cycle/scooter area



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Designated area on the pavement where shared bicycles and micro-mobility vehicles from a shared system can be picked up and dropped off. Unlike in dock-based systems these areas do not have any structures - they are empty unless occupied by a bicycle.

Dockless systems allow users to locate available bicycles from their mobile electronic devices and use them for a per-trip charge or with a paid membership. Bicycles can be used for a short time and can be returned in another place within a certain zone.

In the first years after the introduction of these systems, bicycles could be left in any public place within a large area, but this has led to the accumulation of bicycles in some streets, obstructing footways.

The use of designated areas would solve this problem, but enforcement is complex. It also requires the provider to gather bicycles left outside the designated areas. The areas could be on the footway, the kerbside zone, or the median strip.

Like dock-based systems, dockless systems are an efficient use of space, solving the problems of insufficient storage and parking of private bicycles. But unlike dock-based systems, they do not use space for structures (racks, interfaces, information).

EXAMPLES

The earliest dockless shared cycle scheme was Call a Bike, launched by Deutsche Bahn in Germany in 2000. It is still in operation.

These schemes have grown fast in China after 2014, helped by the use of mobile phone apps. 16 million bicycles (as of 2017) were placed on the streets, as companies competed for customers.

Chinese companies have since exported the model to other countries to various degrees of success. Insufficient demand, competition, and regulations have been challenges.

EVIDENCE

A review concluded that dockless systems improves cyclists' experiences at the end of their trips and facilitate public transport use.

Chen et al 2020 Dockless bike-sharing systems: what are the implications? Transport reviews 40, 333-353.

After dockless bicycle sharing became available in Shanghai, the cycling modal share increased from 22% to 31% (for commuting trips) and from 22% to 35% (for non-commuting trips).

Jia and Fu 2019 Association between innovative dockless bicycle sharing programs and adopting cycling in commuting and non-commuting trips. Transportation Research A 121, 12-21.

Even in a very large city (Shanghai), designation of only 7500 areas for parking dockless bikes (using "electric fencing") could cover 92% of parking demand and ensure 96% of bikes could be parked.

Zhang et al 2019 Electric fence planning for dockless bike-sharing services. Journal of Cleaner Production 206, 383-393.

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Bike & Ride



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Also known as bike station. Parking area for bicycles located next to train, light rail, or bus stations. It has many cycle racks (which can be lockable) and is located in large open spaces or in covered structures.

As bicycles are parked for long times, Bike & Ride areas require security to avoid theft and protection from weather. They may also have other services (e.g. repair and maintenance, showers, cycle rental services). A payment charge can be applied.

Using a Bike & Ride area is an alternative to carrying bicycles on board. Passengers then rely on walking or on a shared bicycle at the other end of the public transport trip to reach their final destination.

Bike & Ride areas increase the catchment area of stations, compared with pedestrian access, and provide an incentive for not driving to the station (or to the final destination).

In places with high cycle modal share, Bike & Ride facilities can occupy a large area and obstruct or force pedestrians to make detours. Underground or multi-storied facilities are sometimes provided.

EXAMPLES

There was a country-wide program in 1993-1998 in the Netherlands to provide secure cycle parking at train stations, and several other local programs since then.

The world largest cycle parking space is below Utrecht station. It opened in 2019 and can store 12,656 bicycles.

12 of the stations in the Bay Area Rapid Transit (BART) system in San Francisco have BART Bike Stations, offering valet parking, controlled-access parking, bike rentals and bike repairs.

EVIDENCE

Increases in bicycle parking spaces and other facilities for cyclists at stations in the Bay Area Rapid Transit system in San Francisco are related to increases in the share of cycling in trips to stations.

Cervero et al 2013 Bike-and-Ride: build it and they will come. Journal of Public Transportation 16, 83-105.

The increase in bike and ride facilities in the Netherlands increased number of bicycles parked at stations, and bicycle use, and bus use.

Martens 2007 Promoting bike-and-ride: the Dutch experience. Transportation Research A, 326-338.

Models of the likely impact of bike and ride improvements in Sao Paulo showed that they can increase job accessibility, but less so in poor peripheral areas.

Pritchard et al 2010 Potential impacts of bike-and-ride on job accessibility and spatial equity in São Paulo, Brazil. Transportation Research A 121, 386-400.

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Cycle parking/hire location: on footway



Tirana, Albania ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Location of cycle parking/hire areas on the footway, rather than the carriageway kerbside zone, middle strip, or side streets. It can use previously underused space, replace street furniture, or be on a new footway extension, narrowing the carriageway.

Cycle parking/hire areas should not be an obstruction for pedestrians or reduce space available for people-based place activities (e.g. sitting, outdoor dining) or green areas. Tactile paving can be added to alert visually-impaired pedestrians.

Enough space must be provided to avoid cyclists parking outside the designated areas (e.g. against guard railings). To reduce disruption, cycle parking can be aligned next to street furniture, close to the kerb.

This design is more suitable when cyclists use cycle tracks segregated from the carriageway, at an intermediate or at the footway level. If they use on-carriageway cycle lanes, access to the footway must be provided (e.g. with dropped kerbs).

If cyclists use cycle lanes, the cycle parking areas should be at locations with good visibility, to reduce conflicts when cyclists leave and re-enter traffic.

EXAMPLES

The introduction of the London cycle hire scheme in 2010 led to the creation of many docking stations on footways, in many cases on extensions created by removing car parking spaces.

New York City runs a CityRack program, maintaining 28,000 cycle racks, most on footways. The city also provides parking shelters in some locations, designed similarly to bus stop shelters.

The Los Angeles Department of transport also runs a Sidewalk Bicycle Parking Program, installing bike racks on footways on request from the public, aligned with street furniture.

EVIDENCE

In a survey to shop customers in Eugene (Oregon, USA), 52% of participants preferred cycle parking on the footway (not on kerbside, replacing car parking spaces).

Peizer 2015 From perceptions to best practices: next steps for on-street bike parking. MA dissertation, University of Oregon. In Commercial Areas In Eugene, Oregon.

In a study of four US cities, only 1 bicycle, out of 333 parked on the footway, were impeding pedestrian access.

Brown et al 2020 Impeding access: the frequency and characteristics of improper scooter, bike, and car parking. Transportation Research Interdisciplinary Perspectives 4:100099.

A study in Seattle found that the number of bicycle thefts increased in dense areas, with more cycle racks and kerbed footways.

Chen et al 2018 Bicycle parking security and built environments. Transportation Research D 62, 169-178.

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Cycle parking/hire location: on kerbside



Paris, France ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Location of cycle parking/hire areas on the kerbside zone of the carriageway, rather than on the footway, median strip, or side streets. It can be a bike corral with many cycle racks, replacing one or two car parking spaces or loading bays.

This solution does not take space for walking and place activities, and reduce clutter on the footway. It also reduces propensity of cyclists for riding on the footway, and provides a buffer between pedestrians and vehicles moving.

Enough space must be provided to avoid cyclists parking outside the designated areas (e.g. on the footway, or on nearby carriageway space), which may create conflicts with pedestrians and with cars parked nearby or moving along the carriageway.

This design requires physical structures (e.g. bollards, planters) to prevent vehicles from parking in bicycle-designated spaces. Separation from traffic lanes is also needed, using marked lines, a buffer zone, low barriers, bollards, or planters.

This design is suitable when cyclists use cycle lanes on the carriageway. It can also be used when cyclists use segregated cycle tracks. In this case, good access to the cycle parking areas must be provided

EXAMPLES

As a part of the redesign of Götgatan, a shopping/services street in Stockholm in 2013-14, some car parking spaces were reconverted as cycle parking areas

In Franklin Street, New York, a slip lane was removed replaced by cycle share area and a street mural.

Since 2015 Dublin has been operating an On-Street Cycle Parking Project, adding around 1,800 spaces in 2018 alone, often by reconverting car parking spaces.

EVIDENCE

A study in Australia found that reallocating space from car parking to cycle parking in a shopping street increase economic activity generated by square meter of parking from \$6 to \$31/hour.

Lee and March 2010 Recognising the economic role of bikes: sharing parking in Lygon Street, Carlton Australian Planner 47, 85-93.

The total number of parked bicycles increased and the number of illegally parked bicycles decreased after the installation of bike corrals in Denver.

Rijo 2015 Economic and traffic impacts following the installation of new bicycle facilities: a Denver case study. MA dissertation, University of Denver.

In Eugene (Oregon, USA), 89% of businesses with bike corrals in their blocks were happy with the street space, compared to 50% of businesses without bike corrals.

Peizer 2015 From perceptions to best practices: next steps for on-street bike parking. MA dissertation, University of Oregon. In Commercial Areas In Eugene, Oregon

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Cycle parking/hire location: on median strip

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Location of cycle parking/hire areas on the median strip of the road, rather than on the footway, kerbside zone of the carriageway, or side streets. It can use previously underused space, replace street furniture, or car parking spaces.

Cycle parking/hire facilities can also be an element on a newly built median strip, that contains other elements (e.g. space for walking, cycle lanes, greenery). The median strip can use space gained by narrowing the carriageway.

Enough space must be provided to avoid cyclists parking outside the designated areas (e.g. on the footway, or on nearby carriageway space), which may create conflicts with pedestrians and with cars parked nearby or moving along the carriageway.

This design also avoids conflicts with kerbside car parking and loading activities and buses stopping. If walking is possible on the median strip, cycle parking should not obstruct pedestrians or reduce sightlines, especially near crossing facilities.

This design is suitable when cyclists use segregated cycle tracks also on the median strip. However, it requires cyclists to cross the road to access the footway. Pedestrian crossings should be installed nearby.

EXAMPLES

Section 6 Civil Boulevard in Taipei has a wide median strip with a cycle lane, space for pedestrians, greenery, and cycle parking facilities.

As a part of the redesign of Blackfriars Road in London in 2015/2016, a kerbed platform was added to separate a cycle highway and the traffic lanes. This accommodates cycle share areas.

Also in London, the redesign of Kensington High Street in 2002 included the removal of guardrailling from the median strip, creating space for cycle parking.

EVIDENCE

There is no evidence on the effects of median cycle parking spaces, in comparison with other parking space locations, or with no parking spaces.

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Cycle parking/hire location: on side street



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Cyclists and micromobility vehicles (parking)

DESCRIPTION

Location of cycle parking/hire areas on side streets and space off main streets, including alleyways and non-residential service roads. This measure is accompanied by improved access to the side streets from the main road.

This may involve using space that was previously for parking and loading, for service vehicles (e.g. waste collection), or access to properties. The reversion involves banning car parking and loading or restrict the hours they are allowed.

This solution releases space from busy roads, minimizing conflicts with motorised vehicles parking on the kerbside and loading activities (except in the cases where this also happens on side streets).

The spaces may be on narrow streets, so a clear path should be kept for pedestrians and for the access of service and emergency vehicles. Access for bicycles from the main road to side streets should also not disrupt pedestrians and place activities.

This design may raise security concerns (theft and assaults to cyclists). The area should have good lighting and active and passive surveillance.

EXAMPLES

Cycle parking and cycle hire areas next to busy stations are often located in side streets, not on main roads.

This is also common in busy shopping streets, with cycle parking areas located in alleyways leading to main streets.

In residential areas, protected bike corrals (cycle hangars) are often provided in side streets, closer to properties.

EVIDENCE

There is little evidence on the effects of cycle parking spaces on side streets, but insights can be derived from cyclists' general preferences on cycle park location.

In a survey in the UK, the most important reason for choice of bicycle parking location was being near to destination (86%). The second reason was security (16%)

Taylor and Halliday 1997 Cycle parking supply and demand. Transport Research Laboratory Report 276.

A study in Seattle found that the number of bicycle thefts increased in dense areas, with more cycle racks, bus stops, and footways, and it was not significantly associated with street lighting.

Chen et al 2018 Bicycle parking security and built environments. Transportation Research D 62, 169-178.

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PART 7

Measures aimed at buses (moving)

Add bus lane



Shanghai, China ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Lane for the exclusive use of buses, marked but not physically segregated. It can operate permanently or at some times only. Cyclists, taxis, and rail-hailing, emergency, and high-occupancy vehicles may sometimes use bus lanes.

Bus lanes can run along complete road sections, or in some locations only. They may stop before junctions, to maximize the capacity. The lanes are delimited by marked lines or different pavement colours. Physical barriers may be added in some places.

Bus lanes are suitable in roads with high congestion and high frequency of bus services. The lane should not be shared with other modes, if that reduces bus speeds. Enforcement is required to avoid lanes being used by other vehicles.

Bus lanes are usually located on the kerbside of the carriageway, to facilitate boarding from bus stops. They can also be in the middle strip, if there is space for adding bus stops. Bus lanes can be reversible and contraflow.

The implement of bus lanes is often controversial. Car users complain of preferential treatment of bus users, if the bus lanes are underused. Rail-hailing companies complain if access to bus lanes is only granted to official taxis

EXAMPLES

The first bus lane was used in Chicago in 1940. Bus lanes now exist in many cities. In some large cities (e.g. London, New York, Paris, Seoul, Beijing), the network of bus lanes is very extensive.

The network of bus lanes in Beijing has 850km, having grown fast since bus lanes were introduced in 2007. Some lanes are busways, used by bus rapid transit services.

A large program to improve public transport in Santiago (Chile), launched in 2007, included 200km of bus lanes.

EVIDENCE

A review of bus priority measures in the UK found mixed results in terms of bus travel times, travel time reliability, and number of passengers - only some schemes achieved their aims

Daugherty et al 1999 A Comparative assessment of major bus priority schemes. Transport Research Laboratory Report 409

Bus lanes reduce collisions because they are a buffer to kerbside objects; reduce conflicts when buses stop; increase sight distances at junctions; and reduce speeds (by increasing traffic density).

Goh et al 2013 Road safety benefits from bus priority: an empirical study. Transportation Research Record 2352, 41-49.

In a study in South Korea, the presence of a bus lane was associated with a higher volume of pedestrians on the street

Jung et al 2017 Does improving the physical street environment create satisfactory and active streets? Evidence from Seoul's Design Street Project. Transportation Research D 50, 269-279.

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Remove bus lane



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Transformation of a bus lane into a lane for the general traffic or reassignment of the space for other uses (e.g. parking and loading areas, extended footways, cycle hire areas, green strips, or a kerbed median strip).

The removal of a bus lane involves the removal of signs, road markings, and physical barriers separating the lane from the rest of the carriageway. If the space is reassigned to pedestrians, kerbs need to be extended.

This measure may be a solution to narrow the road carriageway, providing more space for pedestrians (in wider footways) and cyclists (in new or wider cycling infrastructure). It also reduces the crossing width for pedestrians.

The removal of a bus lane can be compensated by measures to give priority to buses at junctions, for example bus advance areas with pre-signals for general traffic.

Removal of a bus lane may be motivated by the relocation or removal of bus routes, the reduction in the frequency of bus services, the reduction of overall traffic levels, or the implementation of traffic restriction measures.

EXAMPLES

In 2003, all bus lanes in Liverpool (UK) were suspended, as a trial to evaluate their benefits. 22 the 26 bus lanes in the city were permanently removed after the trial.

In Walworth Road (London), one of the schemes in the Mixed Priority Routes program, bus lanes were removed to extend footways. Bus advance facilities were provided to give bus priority at junctions

A bus lane was removed in 2019 to accommodate a new cycle highway in Deptford (London).

EVIDENCE

There was no change or an increase in bus travel times on 86% of bus lane sections that were removed in Liverpool. Non-bus travel times decreased in 68% of the sections.

Mott McDonald 2014 Liverpool Bus Lane Suspension - Monitoring Results Report. Report to Liverpool City Council.

The scheme in Walworth Road decreased collisions but increased serious ones. But evidence is scarce and cannot be attributed only to bus lane removal - other road design changes happened.

CIHT Manual for Streets 2 - Wider Application of the Principles. CIHT. Chapter 14.1 - Walworth Road, Southwark, London.

Some conclusions about bus removal can be derived from studies that evaluated the opposite (bus lane provision). A review found limited impacts on bus travel time, reliability, and patronage.

Daugherty et al 1999 A Comparative assessment of major bus priority schemes. Transport Research Laboratory Report 409

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Busway/Bus Rapid Transit



Bogotá, Colombia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Lanes for the exclusive use of buses, physically segregated from general traffic. They are sometimes grade-separated (elevated, in a tunnel, or sunken). Entrance is controlled through gates. A Bus Rapid Transit system (BRT) uses a network of busways.

Busways are usually in the road median strip. Interactions with other traffic are minimized, including cross-movements from other roads and driveways. Under or overpasses are sometime used, as well as bus priority at traffic signals.

Busways are used for frequent and fast bus service networks with long stop spacing. The stops are closed (i.e. physically separated from the rest of the road) and may be sunk or elevated. The lanes can be reversed according to demand throughout the day

Bus Rapid Systems are expensive, but cheaper and more flexible than trams/light rail systems. They require space for movement (including extra space for fast services), buffer areas, separation structures, and stops.

Guided busways are systems with dedicated space for buses that can be controlled by external means (e.g. by optical or radio guidance). The buses are also able to use the roads' general traffic lanes along some parts of the route.

EXAMPLES

An early version of a Bus Rapid Transit system (BRT) appeared in 1937 in Chicago and then in cities in the USA and Europe. The first modern BRT system opened in Curitiba (Brazil) in 1974.

The TransMilenio system in Bogota, Colombia, opened in 2000, was the first modern Bus Rapid Transit system in a large city and is currently the world's busiest.

The success of BRT systems in many Latin America has encouraged the creation of BRT in many cities in developing countries in Asia (e.g. Jakarta, the world's longest BRT) and Africa (e.g. Johannesburg)

EVIDENCE

A review of BRT systems found they attract development and increase land value around stations and along their corridor. This depends on land use policies. Costs depend on the busway and station design.

Wirasinghe et al 2013 Bus rapid transit - a review. International Journal of Urban Sciences 17, 1-31.

BRT systems in developing countries have benefited low-income groups in terms of travel time/cost savings, accessibility, safety, and health. But insufficient spatial coverage and high fares are a problem.

Venter et al 2018 The equity impacts of bus rapid transit: A review of the evidence and implications for sustainable transport. International Journal of Sustainable Transportation 12, 140-152.

A comparison of 41 systems did not show significant differences between effects on property values of BRT, Light Railways, and metro systems. But BRT has lower operational costs.

Ingvardson and Nielsen 2018 Effects of new bus and rail rapid transit systems – an international review. Transport Reviews 38, 96-116.

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Tramway



Prague, Czech Republic ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Space for the use of trams (also known as streetcars). Trams are public transport systems using fixed tracks along urban streets. Most tramways are at street level but can have sections on elevated platforms or using tunnels.

Tramways are often in the median strip of the road, with adjacent lanes for general traffic. The tracks can be shared with other modes or in dedicated lanes, but these are not usually physically segregated from general traffic.

Unlike buses, tram routes are fixed. Trams also stop always at the same places at platforms, facilitating passenger boarding. The same vehicle can also run in both directions. Trams may be given priority at signalised junctions.

Parked cars often obstruct tram tracks and tram stops. Tram tracks can also be damaged by heavy goods vehicles. Tracks can be dangerous for cyclists (as bicycle wheels can be caught in a tram track) and pedestrians (as they can trip over the tracks).

Tram services are often in city centres, along the same routes used for several decades. They are sometimes in transit streets, shared with non-motorised modes. New lines are often a part of regeneration of some areas or reconversion of heavy rail lines.

EXAMPLES

The first electric tram system was in Lichterfelde (Germany) in 1881. By the 1920s, trams were the main transport mode in many cities. Many lines were removed from the 1930s to give more space to cars.

Trams have remained in Eastern European cities even when lines were removed in other countries in the mid-20th Century. They became popular again in Western Europe and other regions from the 1990s.

As an example, Melbourne has an extensive tram network (250km). using many roads in the centre, including tram-only roads. Swanston Street is the world's busiest tram corridor in the world.

EVIDENCE

The Melbourne tram network has congestion benefits: it reduces total vehicle time travelled by 3.4% and the number of congested links by 16%.

Nguyen-Phuoc et al 2017 Net impacts of streetcar operations on traffic congestion in Melbourne, Australia. Transportation Research Record 2648, 1-9.

The replacement of a bus line with a modern tramway in Paris reduced roads space for other uses and did not contribute to a shift from car to public transport. The estimated net benefit was negative.

Prud'homme 2011 Substituting a tramway to a bus line in Paris: costs and benefits. Transport Policy 18, 563-572.

Tram priority lanes and higher tram speeds are associated with more tram-involved traffic fatalities in Melbourne. Higher traffic volumes decrease the likelihood of serious collisions.

Naznin et al 2016 Exploring the impacts of factors contributing to tram-involved serious injury crashes on Melbourne tram routes. Accident Analysis and Prevention 94, 238-244.

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Space for light railway



Melbourne, Australia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Light railways are public transport system using fixed tracks along urban streets. Unlike trams, they often use dedicated lanes, physically segregated from general traffic. They can run at street level, overground, or underground.

Light railways usually run in the median strip of the road, with adjacent lanes for general traffic. Unlike buses, routes are fixed. Vehicles always at the same places at platforms, facilitating boarding. The same vehicle can also run in both directions.

The junctions of light railway routes with other roads can be at-grade, or the line can be elevated or sunken. At-grade junctions require careful design, with traffic control, road markings, and measures to increase visibility.

Light railway systems have higher capacity than buses and bus rapid transit systems but are less flexible and more expensive to construct and operate. Construction requires moving underground utilities (e.g. water pipes).

Light railways are often in city centres, sometimes in transit streets shared only with non-motorised modes. New lines are often a part of regeneration of some areas or the reconversion of heavy rail lines.

EXAMPLES

Light railway systems became popular from the 1990s in Europe, Asia, and Australia, sometimes reconverting heavy rail or upgrading tram systems. Many new systems have opened in China since the 2010s.

The Docklands Light Railway in London opened in 1987 and has been extended since then, now covering 38km. Most of the line is elevated. It is integrated with the London Underground system.

The Bangkok Skytrain was one of the first modern light railways in Asia and is now one of the largest (53km, with 69km under construction) and busiest. It runs mostly on elevated tracks.

EVIDENCE

An international review found that urban light rail investment can help regenerate city centres and increase employment and property prices, but this depends on other types of investment.

Knowles and Ferbrache 2016 Evaluation of wider economic impacts of light rail investment on cities. Journal of Transport Geography 54, 430-439.

There is some evidence that light railways can control the tendency for the growth in car travel and congestion in some American cities.

Bhattacharjee and Goetz 2012 Impact of light rail on traffic congestion in Denver. Journal of Transport Geography 22, 262-270.

Evaluation of a series of investments in the UK found that passenger numbers were lower than expected and the systems had small impact on congestion, pollution, collisions, regeneration, and social inclusion.

National Audit Office 2004 Improving public transport in England through Light Rail. Report HC 518 Session 2003-2004.

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Lane for trolley buses



Tiraspol, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Space for the exclusive use of trolley buses (shared or not with other buses). Trolley buses are electric buses drawing power from cables suspended above and along the road. Wires can be suspended from poles or buildings.

Lanes for trolley buses are not usually physically segregated from the general traffic. If the buses are articulated into two parts, the road requires wide curves. Trolleybuses can only run in one direction, so a turning circle at terminals is needed.

Trolley buses do not have the same flexibility as other buses. But the fixed infrastructure is overhead (not tracks at surface level) so unlike trams, they can be steered to overtake parked cars. They also cause less problems for cyclists and pedestrians.

Trolley bus networks are less extensive and complex than other bus networks and have no express services. This is because overtaking of one trolleybus by another is not possible, unless the road has parallel trolley wires.

Trolley buses are often used in city centres because of they have a lower environmental impact than conventional buses. However, they require more investment, in cables and electricity substations. Trolley poles de-wire frequently, causing delays.

EXAMPLES

Trolley buses became popular in the 1930s, propelled by the development of pneumatic tyres. They were later replaced by buses in many cities, but remained in many Eastern European cities.

Shanghai has the oldest system of trolleybuses in operation (opened in 1914). The system has been reduced considerably since the 1990s but it still has 12 lines, some running on busways.

The Moscow trolley bus system was the largest in the world but it started to be phased out in 2017. Russia still has 85 trolley bus systems, including some of the longest and busiest.

EVIDENCE

A review found that trolley buses have technical, environmental and economic advantages over other road-based public transport modes.

Tica et al 2011 Development of trolleybus passenger transport subsystems in terms of sustainable development and quality of life in cities. International Journal for Traffic and Transport Engineering 1, 196-205.

A review of 5 trolley bus systems in the US found that they have environmental benefits and give more customer satisfaction than other buses, but are also more expensive to operate.

Rafter 1995 The electric trolley bus: a neglected mode in U.S. Transit Planning. Journal of the American Planning Association 61, 57-64.

A review comparing different forms of road public transport and an evaluation of a trolley bus system in Italy concluded that trolley buses can reduce noise/air pollution, while saving operating costs and energy

Falvo et al 2012 The electric trolley bus: a neglected mode in U.S. transit planning. International Symposium on Power Electronics, Electrical Drives, Automation and Motion.

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Lane for small collective transport

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Provision of dedicated road space for shared public transport services (in places where bus services do not exist) or permission for these services to use bus lanes (in places where bus services exist). Private cars are not allowed to use the space.

Shared transport services (also known as shared taxis) use medium/small vehicles (minibuses, vans, 3-wheeled vehicles) and can be formal (organised and regulated) or informal. In developing countries, they are often the only form of public transport.

In developed countries, shared transport includes shuttle buses (e.g. from airports to hotels), school and company buses, demand-responsive services ran as public services (e.g. for older or disabled people), and shared rail-hailing services.

The lane width depends on the vehicles used in each city. If the lanes are used by buses, they should be at least 3m wide. Minibuses and vans require slightly less space than buses. Two-wheeled vehicles require even less space, but more than a bicycle.

Allowing shared services on bus lanes is useful for services that run on fixed-routes but less for those that are demand-responsive. As shared services have more stops than regular bus services, they may disrupt bus movement.

EXAMPLES

Shared taxis started in 1914 in Los Angeles (jitneys). Currently, they are widespread in all developing countries. They rarely have dedicated road lanes or are allowed in bus lanes.

In 2019, New York City started to allow demand-responsive vehicles used by disabled people on bus lanes.

In Bristol (UK), shared taxis run by Slide, an app-based service, were allowed to use bus lanes. However, the service was discontinued in 2018.

EVIDENCE

Simulation of the effect of allocating a lane to shared taxis in Isfahan (Iran) found it would lead to a reduction in delays and increase in flows of shared taxis and other vehicles, due to less lane switching.

Zefreh and Török 2016 Improving traffic flow characteristics by suppressing shared taxis manoeuvres. Periodica Polytechnica Transportation Engineering 44, 69-74.

In contrast, a study in South Africa found that allowing minibuses on the bus lane would lead to overall delays due to increase in lane switching.

Fowkes et al 2014 The effect of allowing minibus taxis to use bus lanes on rapid transit routes. Presented at MISG 2014 conference.

Opening road shoulders to conventional buses and minibuses at peak-time in Tel-Aviv reduced bus travel time by 30% and increased bus occupancy by 10% - but the results were not split by type of bus.

Gitelman et al 2016 Bus operations on hard shoulders during congested morning hours – a pilot evaluation in Israel. Transport Research Procedia 1144-1153.

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Transit street



Brno, Czech Republic ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Also known as transit mall and bus-only street. Roads where only pedestrians, cyclists, and public transport (buses, trams, or light railway vehicles) are allowed. Private cars are not allowed at all times or at certain times.

Transit streets are suitable in city centres and commercial and leisure areas, used by many people, to encourage people to arrive by public transport. Cycling parking facilities should be provided along the street or at the entrances.

Deliveries have restricted hours (e.g. early morning). Local residents may be allowed to access the street. The limits of transit street may have physical barriers (known as bus gates) to prevent private cars from entering.

To improve pedestrian experience, the speed limits for public transport vehicles should be low. There is also a preference for cleaner, quieter public transport (e.g. electric buses). The design may include improved footways, greenery, and street art.

Transit streets can be shared spaces, with no formal demarcation between buses, cyclists, and pedestrians. As an alternative, public transport vehicles use dedicated space between footways, which are kerbed or simply marked.

EXAMPLES

Oxford Street, the busiest shopping street in London is a transit street, allowing only buses, taxis, and non-motorised modes. Plans for pedestrianizing part of the street, removing buses, have been cancelled.

Bourke Street and Swanston Street in Melbourne became a transit street in 2009. They allow trams and non-motorised modes.

Many cities in Eastern Europe have transit streets used by trams and light railway systems. In many medium sized towns, e.g. Brno (Czech Republic) and Kosice (Slovakia), the main shopping street is a transit street

EVIDENCE

A review of bus-only links in the UK found they have generally improved bus patronage or bus journey times.

UK Department for Transport (2004) Bus Priority- The Way Ahead. Resource Pack Edition 2.

A review of 8 projects across Europe, involving traffic restriction to cars but not to public transport, found reductions in car traffic and pollution and increase in bus passengers and pedestrian flows

European Commission 2004 Reclaiming city streets for people - Chaos or quality of life?

A study in Amsterdam found fewer conflicts than expected in a street shared by trams, pedestrians and cyclists, with pedestrians and cyclists spontaneously using different zones.

Zacharias 1999 The Amsterdam experiment in mixing pedestrians, trams and bicycles. ITE Journal 69, 22-28.

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Taxis on bus lane



Helsinki, Finland ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Allow taxis to use bus lanes for movement. This may include permission to stop to pick-up and drop off customers (if the road does not have kerbside area for this). Ride-hail services may or may not be allowed.

Allowing taxis on bus lane increase efficiency of road space where bus lanes are underused by buses. It releases space from other lanes, easing congestion. But at peak times taxis may slow down buses - so use of the lane may be restricted at those times.

As taxis have more stops than bus services, so they may disrupt bus movement. However, as bus lanes are usually on the nearside lane, taxis using bus lanes cause less disruption to general traffic when stopping and rejoining the traffic.

Allowing taxis on a bus lane that is also open to cyclists creates further conflicts, due to increase in demand for space in the bus lane and the mix of three types of vehicles with different sizes and moving at different speeds.

Allowing taxis on bus lanes can be controversial and can lead to protests not only from bus operators but also from ride-hail companies (if their services are barred from using those lanes).

EXAMPLES

In London, official taxis are allowed on bus lanes. This led to protests, disobedience, and legal action by a private taxi company in 2012. Ban of official taxis from some bus lanes has also led to protests in 2019.

A plan to allow private taxis on bus lanes in Belfast (Northern Ireland) was suspended following protests in 2018.

In Wellington (New Zealand) taxis are allowed on bus lanes when in-service (not when cruising for customers) - except for some lanes designated as bus-only lanes.

EVIDENCE

Allowing taxis on bus lanes reduces travel time for taxis (which have a higher value of time than other vehicles, on average) and removes traffic from other lanes, increasing the travel speed of other vehicles.

Oldfield et al 1977 With-flow bus lanes: economic justification using a theoretical model. Transport and Road Research Laboratory Report 809.

In New York, the presence of taxis on bus lanes was associated with delays to buses because they make more frequent kerbside pick-ups and drop-offs.

Safran et al 2014 Factors contributing to bus lane obstruction and usage in New York City: does design matter? Transportation Research Record 2418, 58-65.

In Athens, bus speeds in bus lanes where taxis were allowed were lower than speeds where taxis were not allowed. Each additional taxi reduced bus speeds by 0.4 km/hr.

Kepaptsoglou et al 2011 Bus lane violations: an exploration of causes. European Transport 48, 87-98.

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Change bus lane operating hours



Shanghai, China ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Change the times of day and days of the week bus lanes are closed to general traffic. Bus lanes rarely operate 24 hours. At other times, the lane can be used for movement by all vehicles, or for parking and loading or other uses.

The status of the space as a bus lane may be identified with signage and marks on the pavement. These can be fixed (indicating detailing hours of operation) or electronic (displaying the status of the lane in each moment).

The aim of changing operating hours is to increase road use efficiency, reserving the space to buses when demand for bus travel is higher, and reverting to general traffic when demand is lower. This reduces the amount of underutilised road space.

Taxis, ride-hail vehicles, and bicycles may be allowed to use the lane when it is active. Enforcement (with cameras) is needed to ensure the lane is not used by private vehicles (for movement or parking) when it is operating.

If displayed electronically, the transitions from/to bus lane can cause confusion for car drivers using the bus lane space and conflicts between them and car drivers in other lanes. A suitable time lag is required before enforcement starts.

EXAMPLES

Bus lanes in Edinburgh operate on weekday peak hours only. There is a plan (introduced in 2019, but not approved yet) to extend them to operate 12 hours a day seven days a week.

Operating times of bus lanes in the Seoul-Busan and Gyeongbu motorways in Seoul were extended from weekends to weekdays in 2008.

During the COVID-19 pandemic, 80km of bus lanes in London started to operate 24 hours a day, to allow bus service extended hours, reducing congestion on other lanes.

EVIDENCE

A model of the first bus lane in Seoul found that extending bus lane operating hours from 7:30-9:30 to 7:30-11:30 decreased overall travel costs

Black et al 1992 A traffic model for the optimal allocation of arterial road space: a case study of Seoul's first experimental bus lane, Transportation Planning and Technology 16, 195-207.

A part-time bus lane (6:30-9:30 only), using the road shoulder, in Tel-Aviv, reduced bus travel time by 30% and increased bus occupancy by 10%.

Gitelman et al 2016 Bus operations on hard shoulders during congested morning hours – a pilot evaluation in Israel. Transport Research Procedia 1144-1153.

A study in Athens found that car and taxi drivers believe lack of enforcement in bus lanes is higher in less-used times (afternoon) and places (suburbs). This leads to more illegal use of bus lanes.

Kepaptsoglou et al 2011 Bus lane violations: an exploration of causes. European Transport 48, 87-98.

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Dynamic bus lane

TYPE: Time allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Also known as intermittent bus lane. Bus lane that becomes active when the number of buses increase. At other times the lane may be used for general traffic. The lane can be activated based on data on volumes of buses in upstream traffic.

The lane can be identified with LED pavement lights and signs (indicating the lane for buses, and the need to move to other lanes, for other traffic). Enforcement is needed to ensure the lane is not used by private vehicles when active.

The transitions from/to bus lane can cause confusion for bus drivers and conflicts between them and the current users of the lane (e.g. cars, motorcyclists, cyclists). A suitable time lag is required before the lane is active.

The more dynamic the lane is, the fewer the uses it can have when it is not active. A fully dynamic lane can be a lane for general traffic or for cyclists, but not a car or bicycle parking space, or space for place activities.

Dynamic bus lanes may allow cyclists. They can also be static lanes at night-time, either inactive (if there is low demand for movement of buses) or active (if there is low demand for other uses).

EXAMPLES

There was a trial in Melbourne in 2001 for a dynamic lane for trams (Dynamic Fairway project) at a number of approaches to junctions. This became permanent after the trial.

There was a trial in Lisbon in 2005-2006 of an 800m dynamic bus lane on a two-lane one-way road, using variable message signs and pavement LED lights. It did not lead to a permanent dynamic bus lane.

There was a trial of a dynamic bus lane in Lyon (France) in 2017. The bus lane was identified with red LED lights, activated based on detection of buses on upstream traffic.

EVIDENCE

In the Lisbon trial, average speeds of bus services increased 15-25% and variability of bus travel times decreased. There were no significant negative impacts on other travel.

Viegas et al 2007 Intermittent bus lane system: demonstration in Lisbon, Portugal. Paper presented at 86th Transportation Research Board Annual Meeting.

The experience in Melbourne resulted in some improvement of average tram speeds (1-10%) and a good rate of driver compliance.

Currie and Lai 2008 Intermittent and dynamic transit lanes: Melbourne, Australia, Experience. Transportation Research Record 2072

The simulation of the effects of dynamic bus lanes tend to show positive effects for bus users and few delays for other road users.

Olstam et al 2015 Dynamic bus lanes in Sweden – a pre-study. PROVDYK – Final report

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Reversible bus lane

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Bus lane that changes direction during the day. The operating periods are usually the morning and evening peak, aligned with the direction of commuting flows. In the inter-peak period, the space may be a median turn lane or for movement in one direction.

In comparison with contraflow bus lanes, reversible lanes achieve a more efficient use of road space, as they serve only periods of higher demand for bus travel, releasing space in the other direction for general traffic.

A bidirectional lane is a variant of a reversible bus lane. In this case, buses run on a single lane in both directions in the same period. Buses wait in areas regularly spaced along the lane so that buses in the opposite direction can pass.

Reversible bus lanes should have a buffer to traffic lanes in the opposite direction or be separated by a kerbed median strip or movable barriers. Turning movements by cars should be banned or minimized.

Reversible bus lanes are usually located in the median strip of the road, to reduce conflicts with other traffic. The direction of travel is indicated with electronic signs. A time lag is needed to ensure the transition is safe.

EXAMPLES

The contraflow bus lane in Champlain Bridge in Montreal operates in different directions in the morning and evening peak periods. It opened in 1978 and has been suspended several times. It extends over 8km.

The Emerald Express, a bus rapid transit in Eugene (USA) uses a bidirectional bus lane, with buses scheduled by a signalling system to take turns using the lane. Buses pass each other at bus stops.

A section of the N-VI road in Spain has a bus-only reversible lane in the last 4km as it approaches Madrid. The lane is separated from the rest of the traffic by a physical barrier.

EVIDENCE

Simulation of a reversible bus lane in California showed that it could deliver benefits for bus rapid transit services without affecting general traffic.

Iswalt et al 2011 Innovative operating solutions for bus rapid transit through a congested segment of San Jose, California. Transportation Research Record. 2218, 27-38.

Modelling of the effects of the bidirectional bus lane in Eugene (USA) estimate a reduction of bus travel time by 40%.

Carey 2006 Bus rapid transit - the Eugene-Springfield, OR, USA, experience ITE Journal 76, 20-23.

Modelling showed that a bus service using single bi-directional bus lane yields a total travel time similar to one using double lanes, but only if the service is low-frequency (more than 20 minutes between services)

Li et al 2009 Planning for bus rapid transit in single dedicated bus lane. Transportation Research Record 2111, 76-82.

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Contraflow bus lane



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Bus lane in the opposite direction to the general traffic flow. It may be created by removing a lane in a one-way road and assigning it to contraflow bus traffic or by restricting movement to car traffic in one direction in a two-way road.

Contraflow lanes allows buses to take shorter and more direct routes, avoiding diversion. Bus routes also become more understandable for passengers, as they use the same roads in the outward and return trips. Walking distance to bus stops is also reduced.

A contraflow bus lane may be reversible. In this case, a with-flow bus lane changes direction during the day and becomes a contraflow bus lane. The direction is indicated with electronic signs. A time lag is needed to ensure the transition is safe.

Contraflow bus lanes should have a buffer to traffic lanes in the opposite direction or be separated by a kerbed median strip or movable barriers. Turning movements by cars across the contraflow bus lane should be banned or minimized.

Contraflow bus lanes may be shared with bicycles, or be adjacent to a contraflow cycle lane. They can create conflicts with pedestrians crossing the road, as pedestrians are not expecting vehicles from that direction.

EXAMPLES

The Exclusive Bus Lane is a 4km contraflow bus lane along New Jersey Route 495 (USA), opened in 1971. It operates from 6:00-10:00 and it carries 1,850 buses a day, run by more than 10 bus companies.

The contraflow bus lanes in Champlain Bridge in Montreal opened in 1978 and extends over 8km. The lane is reversible, operating in different directions in the morning and evening peak periods.

There are several contraflow bus lanes in central London. A contraflow in Bloomsbury, opened in 2006 to buses, and extending over several roads, was opened to cyclists in 2014.

EVIDENCE

Appraisal of contraflow bus lanes in Washington DC showed improvements in car and bus travel times and a benefit-cost ratio of 28 - higher than for with-flow bus lanes.

Cesme et al 2016 Application of bus-only lanes in Downtown Washington, D.C.: concurrent versus contraflow bus lanes. Transportation Research Record 2539, 119-129.

A contraflow bus lane in Rotherham (UK) slightly reduced bus distance (by 0.8km) and travel times (by 2 minutes) in some services.

UK Department for Transport (2004) Bus Priority- The Way Ahead. Resource Pack Edition 2.

Contraflow bus lanes in Chicago reduced bus and pedestrian accidents decreased by 52% and 19%, respectively

LaPlante and Harrington 1984 Contraflow bus lanes in Chicago: safety and traffic impacts. Transportation Research Record 957, 80-90.

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Median bus/tram lane



Budapest, Hungary ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Bus lane located in the middle section of the road carriageway, between lanes for general traffic. Median bus lanes usually include lanes in both directions. This design is common in segregated busways used for bus rapid transit service.

Bus stops need to be in the median strip too, between bus lanes in the two directions (so only one platform is needed) or between the bus lanes and the general lanes. Crossings are needed at each stop so pedestrians can access the stop from the footway.

Movements of other vehicles across median bus lanes should be banned or limited to junctions. At these junctions turn movements should be controlled by traffic signals, where buses can be given priority.

Median bus lanes are less likely to be obstructed by parked cars, taxis stopping, and goods vehicles loading. Conflicts with other moving vehicles are also reduced in comparison with kerbside lanes, which are crossed by vehicles to access the kerbside.

Median bus lanes reduce conflicts between buses stopping and cyclists using cycle lanes or vehicles stopped at the kerbside for parking and loading. They also reduce conflicts between bus passengers and pedestrians and cyclists using cycle tracks.

EXAMPLES

Bus Rapid Transit services, trams, and light railway systems around the world usually use the road median strip.

Since 1996, Seoul has implemented several Exclusive Median Bus Lanes. The Jongno Exclusive Median Bus Lane, a 2.8km lane in a busy corridor crossing the city centre opened in 2017.

The #98 B-Line rapid bus rapid transit service in Vancouver, opened in 2000, operated on a median lane along a 16km corridor. It was replaced by Canada Line, a light railway system.

EVIDENCE

In New York, kerbside bus lanes were 1.39 times more likely to be obstructed than offset bus lanes and were 1.97 times more likely to be used by buses.

Safran et al 2014 Factors contributing to bus lane obstruction and usage in New York City: does design matter? Transportation Research Record 2418, 58-65.

Median bus lanes in a corridor in Seoul could reduce fuel consumption by 19%, CO emissions by 23%, CO₂ by 19%, PM₁₀ and PM_{2.5} by 31%, and NO_x by 21%, compared with no bus lanes.

Kim et al 2019 Evaluating the environmental benefits of median bus lanes: microscopic simulation approach. Transportation Research Record 2673, 663-673.

In a study in South Korea, collisions in median bus lanes depend (negatively) on the widths of the bus lane, the traffic lanes, and the road shoulders, in that order.

Kim et al 2012 Determination of accident modification factors for the median bus lanes on urban arterials. International Journal of Urban Sciences 16, 99-113.

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Increase bus/tram lane width



Bordeaux, France ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Increase the width of the lanes for the dedicated use of buses or trams, reallocating space from other sections of the road. This can be achieved by removing car parking strips or removing or narrowing lanes for general traffic.

Bus/tram lanes should be wide enough to accommodate the type of vehicles using them and to reduce conflicts with traffic in other lanes. Bus lanes should be at least 3-3.25m wide and tram lanes should be 2.6-3.65 wide (depending on the type of vehicles).

A shared bus-cyclist lane should be wider than a non-shared bus lane. It should be either narrow enough to prevent buses overtaking cyclists or wide enough to allow for safe overtaking. Cyclists should only be allowed to pass buses at bus stops.

A buffer zone can be added between bus lanes and the adjacent traffic lanes, for extra safety when buses overtake and are overtaken. The buffer can be marked or unmarked. In wide roads, a double width lane allows express bus services to pass slower ones.

In general, kerbside bus lanes should be wider than median lanes, or include a wider buffer zone, to reduce the risk of conflicts with pedestrians on the footway or collisions with overhanging foliage from trees.

EXAMPLES

Wider bus lanes are usually provided in bus rapid transit systems, running on segregated busways, to increase bus speeds and to allow for overtaking of buses by other buses.

Changes in bus lane width are often justified with safety for cyclists sharing the lane. Design manuals in Belgium, Germany, Austria, UK, Sweden, and Denmark do not recommend wide lanes (>3.5m).

In Chinese cities, bus lanes have been narrowed to release space for more general traffic lanes and increase road capacity, in the context of increasing traffic levels.

EVIDENCE

A study with a review, interviews with agencies, and data analyses concluded that wider bus lanes have fewer collisions, but more serious ones (due to higher speeds)

Dai et al 2020 The Influence of lane width on bus crashes. Texas A&M Transportation Institute.

Collisions in bus lanes located on the median strip depend (negatively) on the widths of the bus lane, the traffic lanes, and the road shoulders, in that order.

Kim et al 2012 Determination of accident modification factors for the median bus lanes on urban arterials. International Journal of Urban Sciences 16, 99-113.

Although guidelines assume that wider shared bus lane are less safe for cyclists, a study in Belgium found no significant difference in close overtaking manoeuvres in a 3.1m lane and a 4.2 one.

De Ceunynck et al 2017 Sharing is (s)caring? Interactions between buses and bicyclists on bus lanes shared with bicyclists. Transportation Research F 46B, 301-315.

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Bus advance areas

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Area reserved for buses at junctions allowing buses to move to the head of the queue and to make all possible turning movements. If bus lanes exist, they end at the start of the advance area. General traffic stops at a pre-signal before the advance area.

The measure is useful where buses need to cross lanes to turn at junctions. To reduce unnecessary delays, technology can be used to detect if there are buses in the approaching traffic. If not, general traffic is not stopped at the pre-signals.

Bus advance areas are only effective if they are long enough to allow buses to safely approach them from the bus lane and then negotiate all turn movements. Driver compliance may also be a problem: cars may enter the advance area.

Bus advance areas can be either in kerbside or median lanes. They require space for the installation of the pre-signal. If this is placed in the middle of the carriageway, the space may be mistaken by pedestrians as a crossing facility.

This measure can be combined with turn restriction exemptions, i.e. turn movements at junctions that are only allowed to buses, not to the general traffic. This reduces the conflicts between buses and vehicles crossing their path from other lanes.

EXAMPLES

Bus advance areas with pre-signals were first introduced in Dusseldorf (Germany) in 1954. They now exist in the UK, Switzerland, and Denmark.

Bus advance areas were introduced in the UK in 1993, with an early successful case at Shepherd's Bush (London) in 1995. They are now common in London.

A bus advance area with a pre-signal for general traffic exists in Langstrasse, Zurich. Pre-signals turn red when a bus is detected approaching in the bus lane.

EVIDENCE

A review of bus advance areas in the UK found that they have generally improved bus journey times.

UK Department for Transport (2004) Bus Priority- The Way Ahead. Resource Pack Edition 2.

The use of pre-signals has been found to reduce overall travel times (for cars and buses), compared with mixed-use lanes or running bus lanes through a junction.

Guler and Menendez 2015 Pre-signals for bus priority: basic guidelines for implementation. Public Transport 7, 339-354.

Experiments of bus queue jump lanes in Kolkata (India) showed travel time savings. However, motorcycles often violated the restrictions, especially if there were no pre-signals.

Bhattacharyya et al 2019 Implementation of bus priority with queue jump lane and pre-signal at urban intersections with mixed traffic operations: lessons learned? Transportation Research Record 2673, 646-657.

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Tram/bus priority at junctions

TYPE: Time allocation

MAIN TARGET STREET USE: Buses (moving)

DESCRIPTION

Allow public transport vehicles to pass through signalised junctions ahead of general traffic. This reduces delays and facilitates turning movements across lanes. The measure can be applied only in some directions, at some times of day

One example is passive signal priority. This is a progression of signals that synchronize green signals for buses along bus lanes (green waves). The synchronization is based on estimated bus speed, including waiting time at bus stops.

Another example is active signal priority. This adjust signals to give priority to approaching buses. Buses are detected from roadside sensors and onboard devices. This delays other traffic and it is not efficient if buses are not full or behind schedule

Other forms of bus signal priority include special green phases for buses and longer green phases for buses running along bus-only roads, when they cross other roads (but this implies longer red phases for traffic on these roads, which may include buses).

This measure can be combined with turn restriction exemptions. For example, actuated transit phases (for turning) are only displayed when there is a bus at the junction. Phases can also be inserted or rotated within a cycle if there is a bus.

EXAMPLES

Signal priority for buses was first applied in 1985 in Charlotte, USA, followed by other US cities/regions (Arlington Heights in 1985; Portland in 1987, Los Angeles in 1990).

Helsinki launched HeLMi - Helsinki Public Transport Signal Priority and Passenger Information) in 1999 comprising bus/tram signal priority, schedule monitoring, and real time passenger information.

Geneva implemented traffic light priorities for buses in 2006, cover the large majority of bus lines. All buses are equipped with a system for traffic light priority.

EVIDENCE

A review of bus priority signals in 22 cities in 13 countries found the systems led to travel time reductions of 2-15% and patronage increases of 10-12% (after excluding outliers).

Gardner et al 2009 Review of bus priority at traffic signals around the world. UITP Working Group: Interaction of buses and signals at road crossings. Deliverable 1.

A review of previous studies on bus priority signals in the USA found that they tend to lead to reductions in bus travel time, delays, and waiting time.

Danaber 2010 Bus and rail transit preferential treatments in mixed traffic. Transit Cooperative Research Program Synthesis 83. National Academies Press, Washington.

Priority signals to trams in Melbourne and Toronto also reduced travel times and waiting times (e.g. 12-16 seconds per junction in Toronto).

Currie and Shalaby 2008 Active transit signal priority for streetcars: experience in Melbourne, Australia, and Toronto, Canada. Transportation Research Board 2042, 41-49.

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PART 8

Measures aimed at buses (stopping)

Add bus/tram stop



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Add a stop for an existing bus/tram service. This includes space for buses to stop for boarding areas, seating, shelter, ticket machines, and boards. This can be on the footway, median, or on an island between a cycle lane and the kerbside.

A length of the kerbside area of the carriageway, longer than the stop, needs to be cleared to facilitate the movement of buses approaching the stop area. Adequate footway space is also needed for access of passengers with mobility restrictions.

Bus stops are identified with markings and have restrictions (for parking and loading). Enforcement is required to prevent stops being obstructed by vehicles. The restrictions may not apply when bus service is not operating.

Bus stops can be clustered together in the same location, forming boarding lanes. This design facilitates passenger interchange between services, for example in roads where many bus routes intersect.

Increasing the number of bus stops reduces the distance walked to access buses, but reduce bus average speeds. It also takes space from pedestrians and blocks their movement. Pedestrian crossings need to be added, to reduce risky crossing behaviour.

EXAMPLES

Add a stop for an existing bus/tram service. This includes space for buses to stop for boarding areas, seating, shelter, ticket machines, and boards. This can be on the footway, median, or on an island between a cycle lane and the kerbside.

A length of the kerbside area of the carriageway, longer than the stop, needs to be cleared to facilitate the movement of buses approaching the stop area. Adequate footway space is also needed for access of passengers with mobility restrictions.

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Increasing the number of bus stops reduces the distance walked to access buses, but reduce bus average speeds. It also takes space from pedestrians and blocks their movement. Pedestrian crossings need to be added, to reduce risky crossing behaviour.

EVIDENCE

Proximity to bus stop and density of bus stops were positively associated with being an active commuter and with meeting recommendations of physical activity in Denmark.

Djurhuus et al 2014 The association between access to public transportation and self-reported active commuting. International Journal of Environmental Research and Public Health 11, 12632-12651.

Bus stop accessibility has a positive economic impact. The number of bus stops within walking distance has been positively associated with property prices, in a study in Wales (UK).

Wang et al 2015 Bus stop, property price and land value tax: A multilevel hedonic analysis with quantile calibration. Land Use Policy 42, 381-391.

More bus stops increase the environmental impacts of bus travel. It has been estimated that about 50 percent of bus trip emissions are generated near stops and intersections

Yu and Li 2014 Evaluation of bus emissions generated near bus stops. Atmospheric Environment 85, 195-203.

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Stop for small collective transport



Chisinau, Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Provision of dedicated space for the boarding/alighting of passengers of shared public transport services (in places where bus services do not exist) or permission for these services to use the stops of bus services (in places where these services exist).

Shared transport services (also known as shared taxis) use medium/small vehicles (minibuses, vans, 3-wheeled vehicles) and can be formal (organised and regulated) or informal. In developing countries, they are often the only form of public transport.

In developed countries, shared transport includes shuttle buses (e.g. from airports to hotels), school and company buses, demand-responsive services ran as public services (e.g. for older or disabled people), and shared rail-hailing services.

This measure is limited by the fact that it formalizes a system that relies on -demand stopping, i.e. at places where passengers need to board and alight, not in fixed locations. In many cases, the services do not even run along fixed routes.

This measure also requires space for vehicles to stop at the kerbside area of the carriageway, as well as space for boarding and seating and for shelters. This can be on the footway, median, or on an island between a cycle lane and the kerbside.

EXAMPLES

In Moldova, shared vans are the main (sometimes the only) form of public transport. They use central terminals and have fixed stops but outside city centres they often stop in other locations.

Seattle started an Employer Shared Transit Stop programme in 2017, with some bus stops shared with employer shuttle services.

Commuter shuttles run by Silicon Valley companies started to be allowed to use bus stops in San Francisco in 2014 - in exchange for a fee for each passenger.

EVIDENCE

Lack of bus bays or stopping places was identified as the number one challenge (out of 59) faced by shared taxi drivers in a region in Ghana.

Ageyeman et al 2019 Principal component analysis of driver challenges in the shared taxi market in Ghana. Case Studies on Transport Policy 7, 73-86.

A program for employer shuttle bus services sharing bus stops with city bus services in Seattle did not lead to delays to bus services.

Lewis et al 2018 Private shuttles and public transportation: effects of shared transit stops on travel time and reliability in Seattle. Transportation Research Record 2672, 210-219.

Company-run shuttle buses in developed countries can lead to gentrification in city centres, and protests, as they allow high-income workers to commute to suburban campuses.

Maharawa 2014 Protest of gentrification and eviction technologies in San Francisco. Progressive Planning 199, 20-24.

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Change bus/tram stop location along road



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Change the location of bus/tram routes or stops to reduce walking distances, increase the safety and convenience of bus passengers, or to reduce conflicts with other road users.

Bus stops should be near the passengers' final destinations (e.g. shops, public buildings, schools, parks, hospitals) and other public transport services. They can be clustered in same location, to facilitate the transfer between bus services.

Walking distance can also be reduced by aligning bus stops with those on the opposite side of the road and with pedestrian crossing facilities and pedestrian desire lines (e.g. where many pedestrians need to cross)

Bus stops should be where passengers can: cross the road safely after getting off the bus; are visible to bus drivers but protected from noise and air pollution; feel safe from crime; board the bus without obstacles (e.g. high kerbs).

Conflicts with car users may arise if bus stops are in places with high demand for vehicles stopping (e.g. convenience shops, ATM machines). Conflicts with pedestrians arise if the bus waiting area and shelter obstruct the pedestrians' clear path.

EXAMPLES

Bus stops are less spaced in US cities (average of 200-270m) than in European cities (300-450m).

Bus Rapid Transport Systems have long distances between stops (roughly double of conventional bus systems). In Hangzhou stops are an average of 1800m away.

There was an extensive change to the stops served by bus services in London in 2020 to serve the needs of school students, and reduce overcrowding, during the COVID-19 pandemics.

EVIDENCE

Walking distance to bus stops from metro stations was one of the main factors of metro passenger dissatisfaction in a survey in Bangkok.

Cherry and Townsend 2012 Assessment of potential improvements to metro-bus transfers in Bangkok, Thailand. Transportation Research Record 2276, 116-122.

In a study in Stockholm, bus passengers felt safer (from crime) in stops in areas with commercial land uses - but the number of passers-by (traffic and bus frequency) was not significant.

Abenoza et al 2018 Individual, travel, and bus stop characteristics influencing travellers' safety perceptions. Transportation Research Record 8, 19-28.

In a study in the USA, the presence of bus stops increased the odds of a junction to be a hotspot of collisions involving older pedestrians.

Kim 2019 The transportation safety of elderly pedestrians: modeling contributing factors to elderly pedestrian collisions. Accident Analysis and Prevention 131, 268-174.

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Bus/tram stop location: midblock



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Midblock bus/tram stops are located along a road segment, not near a junction. They can be located next to trip destinations, but are also along fewer walking routes and allow for fewer interchanges, compared with bus stops at junctions.

Midblock stops reduce the number of conflicting movements between buses and other traffic and increase the intervisibility of bus drivers and passengers, compared with bus stops at junctions.

Midblock bus stops require adjacent pedestrian crossing facilities to reduce risky crossing behaviour of passengers after getting off the bus. If the bus stop is inline, they also require space between parked cars for the bus to enter and exit the stop.

These stops usually lead to fewer conflicts between pedestrians and bus passengers, as there are fewer flows of pedestrians from different directions. There is also more scope for deviating cycle tracks behind bus stop, compared with junction stops.

This location is suitable when distance between the blocks is long, there is not enough space at a junction, there are important destinations midblock, bus services have a high volume of passengers, and the stop serves many services.

EXAMPLES

There are midblock bus stops in most cities, in front of major destinations (e.g. public buildings, stations, hospitals, schools, shopping centres).

However, midblock bus stops are considered as less desirable than junction stops in some road design guidance, and recommended only if junction stops are not possible.

Most bus stops in cities with grid street patterns (e.g. US cities) and tram stops in cities with big tram networks (e.g. Melbourne) are on junctions, not midblock, to facilitate interchange.

EVIDENCE

Mid-block stops cause less delay than bus stops on the nearside of a junction (except when the bus uses a bus lane) and the same or slightly more delay than bus stop on the far side of a junction.

Furth et al 2006 Near-side, far-side, uphill, downhill: impact of bus stop location on bus delay. Transportation Research Record 1971, 66-73.

A study of vehicle-pedestrian collisions in Lima (Peru) found an association between bus stops and vehicle-pedestrian collision risk at junctions but not in mid-block locations.

Quistberg et al 2015 Bus stops and pedestrian–motor vehicle collisions in Lima, Peru: a matched case–control study. Injury Prevention 21, 15-22.

A study in the USA found similar results for older pedestrians. The presence of bus stops increased the odds of a junction to be a hotspot of collisions involving older pedestrians.

Kim 2019 The transportation safety of elderly pedestrians: modeling contributing factors to elderly pedestrian collisions. Accident Analysis and Prevention 131, 268-174.

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Bus/tram stop on median strip



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Location of bus or tram stops in the median strip of the road, between lanes for general traffic. This design is usually combined with bus lanes and tram tracks also on the median strip or on the farside lanes.

A single platform, in the middle, can be used for boarding in both directions, with buses running on the sides. The alternative is two platforms, one on each side of the median, with buses running in the middle.

This design reduces conflicts between buses stopping with other road uses, including parking and loading activities at the kerbside, vehicles moving in the carriageway, cyclists using nearside cycle lanes, and pedestrians walking along the footway.

However, there are safety issues because pedestrians always need to cross the road to access the bus stop. Pedestrian crossing facilities are needed adjacent to the stop so that pedestrians can access the stop from the footway.

In roads with low traffic volumes and speeds, and in transit streets or shared spaces, bus passengers may be able to board directly from the traffic lanes.

EXAMPLES

Around the world, the stops of Bus Rapid Transit services, trams, and light railway systems usually use the road median strip.

Median bus lanes have median bus stops. As an example, Seoul has implemented several Exclusive Median Bus Lanes since 1996, with median bus stops.

After bus lanes were moved to the farside lanes in an arterial road in Manila (Philippines) in 2020, bus stops were moved to the median strip. The bus stops can only be accessed by footbridges.

EVIDENCE

In a study in China, median strip bus stops had shorter passenger boarding delays and shorter delays waiting for other buses to move than in-line kerbside stops and bus bays.

Wang et al 2016 Modelling bus dwell time and time lost serving stop in China. Journal of Public Transportation 19, 55-77.

A study of median bus stops in Seoul found a 38% rate of pedestrians crossing outside designated crossing facilities.

Lee et al 2015 Analysis on pedestrian crossing illegal behavior on exclusive median bus corridor: a case study of express bus terminal station. Journal of Korean Society of Transportation 33, 136-144.

Time losses to access median bus stops (due to increased walking distances and crossing delay) may offset the travel time savings of bus services on median bus lanes.

Gibson et al 2016 Estimating the bus user time benefits of implementing a median busway: methodology and case study. Transportation Research A 84, 72-82.

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Kerbside in-line bus stop



Hereford, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Also known as online bus stop. Design where buses stop in the same lane they use for movement. Bus passengers board from the footway. The bus waiting areas are on the footway, taking space from pedestrians. The design is also suitable for tram stops.

This design reduces delays for buses, as they do not need to leave and rejoin the traffic. If buses use a bus lane, there will only be delays to other buses. If buses use general traffic lanes, cars will be delayed or forced to overtake the bus.

This design generates conflicts between buses stopping and cyclists. Cyclists can be accommodated on a cycle track behind the bus stop waiting area or on a raised cycle lane between the waiting area and the lane used by buses

This design is suitable in roads with low/moderate traffic volumes and bus frequencies and with low pedestrian flows. It is also an inexpensive and flexible solution, compared with bus boarders and bulbs.

The footway kerbs should have a sufficient height to avoid steps and to allow for the use of access ramps. Enforcement is required to prevent parked cars from using the space of the bus stop

EXAMPLES

In-line kerbside bus stops are one of the two most common types of bus stops around the world (the other being bus bays)

The Bus Priority Programme in Wellington, launched in 2019, includes the creation of in-line bus stops as one of the key interventions.

The Liffey Cycle Route, a new cycle route in Dublin (Ireland) along the Liffey River opened in 2020 and has inline bus stops. This has led to protest from cyclists.

EVIDENCE

A study in Ottawa found that in-line kerbside stops caused 5-6 seconds less delay than bus bays.

City of Ottawa 2011 Operational impacts and policy implication of bus bay in the City of Ottawa. Report No. 101-16386.

In a study in Singapore, in/line kerbside stops were half as likely to encounter delays than bus bays. This was due to delays when buses rejoin traffic after stopping.

Liu et al 2017 Impact of different bus stop designs on bus operating time Components. Journal of Public Transportation 20, 104-118.

At higher traffic flow levels (above 2000 vehicles per hour), in-line kerbside stops cause considerable more reduction in the speed of general traffic than bus bays.

Koshy and Arasan 2005 Influence of bus stops on flow characteristics of mixed traffic. Journal of Transportation Engineering 131, 640-643.

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Kerbside off-line bus/tram stop (without bay)



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Design where buses stop in the kerbside lane (i.e. parking strips of cycle lanes). Bus passengers board from the footway. The bus waiting areas are on the footway, taking space from pedestrians. This design is also suitable for tram stops.

One variant involves buses entering the kerbside parking lane at designated areas, i.e. gaps in parking spaces. This requires enforcement to ensure cars are not parked illegally on the bus lane.

Another variant involves buses entering a cycle lane, in a marked area. This forces cyclists to cross to the traffic lanes. A solution is to deviate the cycle lane behind the bus stop waiting area.

The advantage of this design is that other vehicles can keep moving while bus stops. This design is suitable in roads with low/moderate bus frequencies, low demand for parking/loading, and low pedestrian flows.

To ensure the bus stop is accessible for all, the footway kerbs should have a sufficient height. This removes steps and allows for the use of access ramps.

EXAMPLES

Off-line kerbside stops without bay are common in small cities around the world. Buses stop in a gap between parked cars. The gap is marked as a no-parking area

Off-line stops are common in India. Sometimes the space is not marked and is occupied with cars, so buses stop on traffic lanes and passengers wait next to parked cars.

One of the main types of bus stop in China are kerbside stops where the buses stop on the cycle lane. This design also exists in Canada.

EVIDENCE

An observational study of an off-line bus stop in India revealed many conflicts: passengers waiting on the carriageway, vehicles on the bus stop area, buses stopping outside the stop area.

Chand and Chandra 2017 Improper stopping of buses at curbside bus stops: reasons and implications. Transportation in Developing Economies 3:5.

In a study in China, off-line stops on the bicycle lane had shorter passenger boarding delays and shorter delays waiting for other buses to move than in-line kerbside stops and bus bays.

Wang et al 2016 Modeling bus dwell time and time lost serving stop in China. Journal of Public Transportation 19, 55-77.

In another study in China, off-line stops on the bicycle lane reduced average bicycle speeds from 16-17km/h to 13-15km/h when a bus is present and overall traffic speeds from 22-25km/h to 18-19km/h.

Zhang et al 2014 Influences of various types of bus stops on traffic operations of bicycles, vehicles, and buses. Presented at the 94th Transportation Research Board Annual Meeting.

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Bus boarder



Santiago, Chile ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Also known as bus bulb and bus bump out. Design where buses stop in the same lane used for movement. Passengers board from an extension of the footway. The design can also be applied to tram stops.

The footway extension uses space from the kerbside area of the carriageway (taking space from parking/loading). Cycling can be accommodated in a raised cycle lane between the bus stop waiting area and the lane used by buses.

The boarder can be full width (the boarder includes the waiting area, leaving the footway clear for pedestrians) or reduced width or half-boarder (the waiting area is on footway, allowing other vehicles to overtake buses in narrow carriageways)

Bus boarders facilitate passenger boarding in roads that have parked vehicles and other obstructions. The design is suitable in places with high demand for parking/loading and high pedestrian flows

The width of the boarder should be the same as the width of parked cars or other obstructions along the carriageway. Kerbs should have sufficient height to avoid steps and to allow for the use of access ramps

EXAMPLES

Bus boarders started to be used in San Francisco in 1973, as part of the Transit Preferential Streets. Other North American cities (Portland, Seattle Vancouver) installed boarders from the 1990s.

Bus boarders have been used in London in 1994, when they were installed as a part of the London Bus Priority Network programme.

From 2019, New York City started to install new bus boarders in some streets (e.g. 14th Street), as part of the Better Buses Action Plan.

EVIDENCE

In San Francisco, bus boarders increased the space available per pedestrian and bus passenger by 132% and pedestrian flow rates by 11%. Queues were more frequent but generally short.

Fitzpatrick et al 2001 Evaluation of Bus Bulbs. Transit Cooperative Research Program Report 65.

Estimates of bus travel time savings after the installation of bus boarders in New Jersey ranged between 15 and 25 seconds per bus stop.

Daniel and Konon 2005 Effectiveness of bus bulbs for bus stops. New Jersey Institute of Technology. Report FHWA-NJ-2003-015

In a study in Croatia, bus boarders led to similar bus travel times and junction delays than in-line kerbside stops and to longer times and more delays than bays (but only for high traffic flows)

Cvitanić et al 2017 Joint impact of bus stop location and configuration on intersection performance. Promet - Traffic and Transportation 29, 443-54.

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Bus bay



Helsinki, Finland ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Also known as bus lay-by, bus pullout, and bus turnout. Design where buses stop in an extension of the carriageway. Passengers board from the footway. The design is not suitable for tram stops.

The carriageway extension uses space from the kerbside area of the carriageway (taking space from parking/loading) or from the footway (taking space from pedestrians and place activities). Waiting areas are in the footway, taking space from pedestrians.

This design facilitates the movement of private vehicles, which do not have to stop when buses stop. However, it may be difficult for buses to rejoin the traffic after stopping. Cycling can be accommodated in a cycle track behind the bus waiting area.

Bus bays are suitable in roads with high traffic volume, where buses are frequent and stop for long times, and where a kerbside stop or a bus boarder would reduce safety. In roads with bus lanes, a bus bay allows for express services to pass local ones.

This design requires enough length and width for buses to join and rejoin traffic - taking up more space than bus boarders and kerbside bus stops. It also requires enforcement to avoid vehicles from parking on the bay.

EXAMPLES

Bus bays are one of the two most common types of bus stops around the world (the other being in-line kerbside bus stops)

Bus bays are the main bus stop design in large Asian cities (e.g. Beijing, Singapore, Hong Kong, Tokyo).

Ottawa have a policy of not providing bus bays since the 1990s. This is due to concern with delays when buses rejoin traffic.

EVIDENCE

In a study in Singapore, bus bays were twice as likely to encounter delays than kerbside in-line stops. This was due to re-entry delays during departure from the bus bays.

Liu et al 2017 Impact of different bus stop designs on bus operating time Components. Journal of Public Transportation 20, 104-118.

An evaluation of bus bays in Ottawa found that they caused 5-6 seconds more delay than kerbside in-line stops.

City of Ottawa 2011 Operational impacts and policy implication of bus bay in the City of Ottawa. Report No. 101-16386.

At higher traffic flow levels (above 2000 vehicles per hour), bus bays cause considerable less reduction in the speed of general traffic than in-line kerbside stops.

Koshy and Arasan 2005 Influence of bus stops on flow characteristics of mixed traffic. Journal of Transportation Engineering 131, 640-643.

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Bus boarding island

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Design where buses run on the farside or middle lanes of the carriageway. Passengers cross from the footway and board the bus from a traffic island between the nearside lane and the lane where the bus runs.

The design can only be applied in multi-lane roads. The advantage is that buses moving in a lane away from the kerbside have fewer conflicts with cyclists and with parking and loading activities.

This design also reduces delays for buses, as they do not need to leave and rejoin the traffic. It can also reduce delays for other vehicles because when the buses stop they can use the nearside lane.

This design requires an adjacent pedestrian crossing facility. Pedestrians may also feel uncomfortable waiting between lanes of moving traffic because of exposure to pollution and noise, and intimidation from traffic.

A variant is a boarding island between a cycle track and the nearside traffic lane. Passengers cross the track to access the island from the footway. This reduces conflicts between buses and cyclists but creates conflicts between cyclists and passengers.

EXAMPLES

Boarding islands between traffic lanes are common in cities in the USA. In Europe, boarding islands are mainly between a cycle lane and a traffic lane.

The New York City Department of Transport has been installing bus boarding islands along many bus routes since 2014.

As part of the Spaces for People programme, Edinburgh has built new cycle lanes, moving bus stops to islands between those lanes and the traffic lanes. This has led to protests.

EVIDENCE

A study of a bus stop island in the median strip in a road in Seoul found a 38% rate of pedestrians crossing outside designated crossing facilities.

Lee et al 2015 Analysis on pedestrian crossing illegal behavior on exclusive median bus corridor: a case study of express bus terminal station. Journal of Korean Society of Transportation 33, 136-144.

In a study in Toronto, bus boarding islands were evaluated as a safer solution than a cycle bypass behind the bus stop, considering the conflicts between all users

Kamaras-Garland et al 2018 Design of cycle tracks at bus stops - case study and guidelines. Proceedings of the 2018 Canadian Society for Civil Engineering Annual Conference.

Pedestrians with disabilities have reported several issues with boarding islands: island too narrow, difficult wayfinding, clutter, cyclists not stopping, difficult to get on/off the bus.

Greenshields 2018 Bus stop bypasses accompanied visits of people with disabilities to bus stop bypasses. Transport Research Laboratory Report PPR853.

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Nearside bus stop



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Bus stop located just before a road junction. It is hoped that the signal cycle accommodates bus stopping, i.e. buses use the red signal waiting time for boarding and alighting, so they do not have to stop twice (at the stop and at the junction).

However, in roads with high traffic volumes, if there are queues and no bus lane, buses can miss the green signal, which can lead to delays, as buses will be idle even after passengers have boarded and alighted.

Buses need to rejoin the traffic just before the junction, which can cause conflicts with vehicles changing lanes and making turning movements. It can also cause conflicts with cyclists riding close to the kerb.

In nearside bus stops, passengers cross the road in front of the bus, and so are less visible to drivers, compared to farside stops, where passengers cross behind the bus.

This design is suitable in simple junctions with low traffic volumes, and in junctions where it is not possible for buses to stop at the farside, e.g. due to road geometry, or presence of some design elements.

EXAMPLES

Most bus stops in busy roads in the USA are located on the nearside of the junction, not the farside (or midblock)

There is an increased consensus in road design guidance documents in many countries that farside bus stops are more effective, decreasing interest in nearside stops.

The Washington Metropolitan Area Transit Authority relocated stops from the nearside to the farside of junctions in Washington DC in 2010, as part of its bus stop optimization program.

EVIDENCE

Nearside bus stops cause more delay than mid-block stops (away from a junction), except when the bus uses a bus lane.

Furth et al 2006 Near-side, far-side, uphill, downhill: impact of bus stop location on bus delay. Transportation Research Record 1971, 66-73.

In a study in Montreal, stop times (i.e. time from when a bus arrives and departs from the bus stop) at a nearside bus stops were 4.2-5 seconds longer than at farside bus stops.

Diab and El-Geneidy 2019 The farside story: measuring the benefits of bus stop location on transit performance. Transportation Research Record 2538, 1-10.

Relocation of a bus stop from the nearside to the farside of a junction with traffic signals in the USA decreased the proportion of pedestrians that crossed the road in front of a stopped bus.

Berger 1975 Urban Pedestrian Accident Countermeasures Experimental Evaluation: Volume 1—Behavioral Studies. US Department of Transportation Report HS-801-346.

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Farside bus stop



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Bus stop located just after a road junction. It can be combined with a priority traffic signal for buses, which allow buses to pass the junction before other traffic, decreasing the total time stopped (which will be only at the bus stop, not the signal)

Farside stops reduce the number of conflicts with other vehicles and bicycles (especially those making turning movements), as buses do not need to rejoin the traffic just before the junction.

However, if there is no bus bay on the far side, the bus can cause traffic to queue through the junction. Drivers may not expect the bus to stop again after clearing the signal, which may lead to rear-end collisions.

In farside bus stops, passengers cross the road behind the bus, and so are more visible to drivers, compared to nearside stops, where passengers cross in front of the bus.

This design is suitable in junctions with heavy traffic (especially on the near side), a complex layout (with many conflicting movements) and many traffic signal phases.

EXAMPLES

Road design guidance documents usually recommend locating bus stops on the farside of a junction, not the nearside (or mid-block)

The increased use of bus signal priority systems has increased the interest in farside stops even more, as the systems do not work if stops are on nearside, due to uncertainty in bus dwell time.

The Washington Metropolitan Area Transit Authority relocated stops from the nearside to the farside of junctions in Washington DC in 2010, as part of its bus stop optimization program.

EVIDENCE

Farside bus stops cause the same delay or slightly less delay as mid-block stops (away from a junction)

Furth et al 2006 Near-side, far-side, uphill, downhill: impact of bus stop location on bus delay. Transportation Research Record 1971, 66-73.

In a study in Montreal, stop times (i.e. time from when a bus arrives and departs from the bus stop) at a farside bus stops were 4.2-5 seconds shorter than at farside bus stops.

Diab and El-Geneidy 2019 The farside story: measuring the benefits of bus stop location on transit performance. Transportation Research Record 2538, 1-10.

Relocation of a bus stop from the nearside to the farside of a junction with traffic signals in the USA decreased the proportion of pedestrians that crossed the road in front of a stopped bus.

Berger 1975 Urban Pedestrian Accident Countermeasures Experimental Evaluation: Volume 1—Behavioral Studies. US Department of Transportation Report HS-801-346.

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Angled/sawtooth bus stop



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Bus boarder or bus bay at an angle to the kerbside. This design is mainly used when more than one bus stop is required in the same location, e.g. in off-street bus stations or public spaces with a large area available for bus stops.

Angular bus stops use much space, to accommodate the bus and the manoeuvres to park the bus and reverse out. Enough space is required to ensure intervisibility between the bus and other buses or other vehicles using the area.

This design allows buses to be stopped close to the kerb, to facilitate boarding. However, overhanging buses can be an obstruction to passengers waiting and moving along the platforms, or pedestrians moving on that space.

Bus passengers should not be allowed to walk behind the bus or on the space used by buses to move in and out of the bus stop. Restrictions may also need to be applied to the movement of cyclists and motorised vehicles.

A variant of angled bus stops is sawtooth stops. In this design, buses stop at a shallower angle to the kerb and a gap is left between stops so that buses can leave the stop without backing out.

EXAMPLES

Angular bus stops are the most common design used in bus stations. Some authorities (e.g. Washington Metropolitan Area Transit Authority) recommend the use of sawtooth stops.

There are a few examples of angled bus stops in public squares that have many bus stops, acting as a bus interchange point.

Angled bus stops are rarely used for on-street bus stops

EVIDENCE

A study of designs for BRT stops found that, for high flows of buses and pedestrians, angled sawtooth stops were the best solution, considering bus/pedestrian movement and space used.

Seriani and Fernandez 2014 Bus and pedestrian traffic management at BRT stations: a case study in Santiago de Chile. Association for European Transport Papers Repository.

Angled bus stops reduce capacity of bus stops (number of departing buses/hour)

Al-Mudhaffar et al 2016 Bus stop and bus terminal capacity. Transportation Research Procedia 14, 1762-1771.

Angular bus stops may cause collisions between buses and waiting passengers or pedestrians.

National Transportation Safety Board 1998 Highway Accident Summary Report: Bus Collision with Pedestrians, Normandy, Missouri June 11, 1997. Report PB98-916201.

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Part-time bus stop

TYPE: Time allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Space that is a designated bus stop only at some times of day or days of the week. At other times, the space can be used for parking and loading, vehicles stopping, bicycle parking, or for place activities (e.g. an evening outdoor café).

The status of the space as a bus stop may be identified with signage and marks on the pavement. These can be fixed (indicating detailing hours of operation) or electronic (displaying the status of the space in each moment).

The aim of changing operating hours is to increase road use efficiency, allowing other uses when there is no demand for buses stopping. This reduces the amount of underutilised road space.

The times can be the same as the bus service operating hours, or other. Even when bus stop is only operating at certain hours, other uses may still be restricted outside those areas to reduce the risk of uses beyond the permitted time.

The bus stop space can work in a similar manner as a bus stop when it is not operating, by other modes of public transport (waiting or stopping), including taxis, small collective transport, and ride-hail services.

EXAMPLES

In many places, bus stops are only in operation for certain hours or days (when bus services are running). Vehicles are allowed to stop/park on bus stop space outside those hours.

In the UK, vehicles are not prohibited from stopping at all bus stops. But when they are, the restriction usually applies at all times.

There are few examples of bus stops used for other than car parking outside operating hours.

EVIDENCE

There is no evidence on the effects of part-time bus stops. Insights can be derived from studies on flexible roadscape designs, which generally showed reductions in travel times.

Simulation of flexible kerbside space in a street in London, with space allocated to different uses at different times, showed it would reduce traffic delay. However, bus stops were considered as fixed elements, not flexible.

ARUP 2018 FlexKerbs - Evolving Streets for a Driverless Future

Multifunctional lanes in Barcelona (with space allocated to general traffic, deliveries, and parking, at different times) reduced travel time by 12-15%. But part-time bus stops were not included.

Hayes et al 2006 MIRACLES (Multi Initiative for Rationalised Accessibility and Clean Liveable Environments) Deliverable 4.2 Annex 3 – 2nd Implementation Report for Barcelona.

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Bus stop waiting area



Tiraspol, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Buses (stopping)

DESCRIPTION

Provision of space for passengers waiting for buses. The space can include various facilities (e.g. shelter, seating, lighting, information boards, and ticket machines). At a minimum, it includes only signs on a pole.

The presence of the waiting area should not create conflicts with pedestrians walking along the road. The waiting area should be wide enough for the number of passengers, i.e. a width of 1.5-3 m.

Provision needs to be made for all users, eliminating obstructions and slopes and providing space for persons in a wheelchair to turn around.

Stops with high volume of passengers and serving several bus services may be designated as stations, inside a building, including ticket machines, shops, information displays, seating areas, and bicycle storage.

If the materials used in the shelter do not provide clear and unobstructed views, they increase opportunities for concealment and reduce indirect surveillance, impacting bus passengers' security.

EXAMPLES

The Landmark London programme replaced the shelters in London's bus stops with new shelter with a bespoke design, including improved roofs and clearer information boards.

Bus stops in market economies have gained functions other than bus transport, e.g. generate revenue from advertising. Shelters are often installed based on their potential to display adverts.

Bus shelters now display real-time information on bus arrivals and are starting to include more facilities. For example, Bangkok is planning to install shelters with Wi-Fi and phone chargers.

EVIDENCE

Bus stop shelters mitigate the bus ridership losses in days with extreme weather, especially in stops with lower service frequencies and fewer transfers

Miao et al 2019 Extreme weather, public transport ridership and moderating effect of bus stop shelters. Journal of Transport Geography 74, 125-133.

A review found that the presence of shelters, benches, lighting, and the maintenance and cleanliness of the bus stop increase passengers' perceived personal security (from crime)

Tucker 2003 Safer Stops for Vulnerable Customers. Center for Urban Transportation Research at the University of South Florida. Report NCTR-473-13.

Shelters may increase exposure to pollution. Those open towards the carriageway have higher concentrations inside the shelter than outside. Those open away have lower concentrations inside the shelter.

Moore et al 2012 Air quality at bus stops: empirical analysis of exposure to particulate matter at bus stop shelters. Transportation Research Record 2270, 76-86.

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PART 9

Measures aimed at motorised vehicles (moving)

Narrow the road carriageway



Lima, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Reduce the width of the road carriageway, releasing space for cycle tracks, a wider footway, or car parking. The reduction may be achieved by reducing the number of traffic lanes, narrowing the lanes, or both.

One of the aims of this measure is to reduce traffic speed. Central lines may be removed to further reduce speed. Buffer areas need to be retained to separate directions of travel and to separate the road carriageway from the footway.

There is a risk that vehicles enter cycle lanes or even footways while overtaking. In busy junctions, the reduction also implies less space for slip lanes for vehicles turning, increasing conflicting movements.

This measure is suitable in built-up areas and roads with low traffic volume, low proportion of large vehicles in the traffic, less need for car parking space, and high pedestrian and cyclist flows.

The reduction can occur only in some sections of the road, where traffic speed reduction and ease to cross the road are more crucial aspects. Footway extensions can be used in these sections.

EXAMPLES

The carriageway space of the Avenida 9 de Julio in Buenos Aires was narrowed in 2013, to add a wide median strip with BRT stations, greenery, and pedestrian paths.

The redesign of the Boulevard de Magenta in Paris in 2001-2006 involved narrowing the carriageway, by removing and narrowing traffic lanes, to widen footways, a new cycle track, and trees.

The carriageway of Blackfriars Road in London was narrowed in 2015/2016 to add a kerbed platform separating a cycle highway from the rest of the traffic

EVIDENCE

The redesign of a road in New Jersey, narrowing traffic lanes reduced pedestrian exposure risk and increased driver predictability, had a slight effect on speeds and a negligible effect on traffic volume.

King et al 2003 Pedestrian safety through a raised median and redesigned intersections. Transportation Research Record 1828, p56-66.

Each 3m of road width increase the vehicle-pedestrian collision rate in 9%, when controlling for other road characteristics.

Quistberg et al 2015 Multilevel models for evaluating the risk of pedestrian–motor vehicle collisions at intersections and mid-blocks. Accident Analysis and Prevention 84, 99-111.

Narrow carriageways have been reported as one of the main things people dislike in their neighbourhoods because it makes circulation and car parking more difficult.

York et al 2007 The Manual for Streets - Evidence and Research. Transport Research Laboratory Report 661.

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Reduce number of traffic lanes



Arequipa, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Also known as road diet. Removal of one or more lanes for general traffic, in one or both travel directions. This reduces the space for the movement of private motorised vehicles - bus lanes are not usually affected.

The space released is assigned to other uses, e.g. a median turn lane, cycling infrastructure, a walkable/green median strip, a wider footway, and parking space. It also reduces crossing distance for pedestrians.

This requires complimentary measures to reduce conflicts at junctions and to ensure that buses (moving or approaching stops) and cyclists are not negatively affected, in terms of delays and safety.

The reduction of lanes is suitable in built-up areas and roads with moderate traffic volumes and high volumes of pedestrians (including pedestrians crossing the road).

One of the aims of this measure is to reduce traffic speed. Central lines may be removed to further reduce speed. The measure should ensure that there is a separation between the road carriageway and footway.

EXAMPLES

In 2013, four traffic lanes were removed from Avenida 9 de Julio in Buenos Aires, replaced with a wide median strip, with BRT stations, greenery, and pedestrian paths.

The transformation of Second Avenue in New York in 2010 involved removing one traffic lane (and narrowing the others), to accommodate a new bus lane and cycle track (with buffer)

The redesign of Götgatan in Stockholm in 2013/14 involved removing two traffic lanes, gaining space for wider footways and wider cycling infrastructure.

EVIDENCE

A review of 70 cases in 11 countries found that reducing space for private motorised traffic reduced overall traffic levels (considering the altered road and alternative roads)

Cairns et al 2002 Disappearing traffic? The story so far. Municipal Engineer 151, 13-22.

Comparison of several interventions in roads in Australia and New Zealand found that removing traffic lanes reduced speed in 5km/h and collisions with injuries by 35%

Turner et al 2017 Safe system infrastructure on mixed use arterials. Austroads Technical Report AP-T330-17.

Reducing the number of lanes from 3 to 2 (in each direction) has an estimated benefit (for pedestrians crossing the road) of £1.28 per trip. Reducing from 2 to 1 has a benefit of £1.00 per trip.

Anciaes and Jones 2018 A stated preference model to value reductions in community severance caused by roads. Transport Policy 64, 10-19.

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Decrease width of traffic lanes



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Reduction of the width of general traffic lanes, reallocating space to footway, kerb extensions, median strips, or road shoulders. Bus lanes may not be affected. The narrowing can be visual, using textures/colours to separate lanes from other uses.

This releases space for other uses without a large reduction on capacity for motorised vehicles. But may be difficult to accommodate buses and commercial vehicles. And it may contribute to collisions if speeds are high.

This measure also reduces crossing distance for pedestrians. It also encourages lower speeds and discourages vehicles from overtaking cyclists. But with widths between 2.7-3.25m, drivers may try to do it.

The measure is suitable in built-up areas and roads with low traffic volumes (especially of large vehicles) are high flows of pedestrians and cyclists. It is less suitable in curved roads or in busy junctions.

One of the aims is to encourage slower speeds and more careful driving. The central lines separating directions of travel may be removed after the width reduction, to further reduce traffic speed.

EXAMPLES

The transformation of Second Avenue in New York in 2010 involved narrowing all traffic lanes (and removing one), to accommodate a new bus lane and cycle track (with buffer)

The redesign of the Boulevard de Magenta in Paris in 2001-2006 involved narrowing traffic lanes, to widen footways, a new cycle track, and trees.

Traffic lanes were narrowed to build wider footways in the Strand in London in 2010. Cyclists have protested. A plan was announced in 2019 to remove all motorised traffic from a part of the street.

EVIDENCE

Narrower lanes tend to decrease traffic speed. Drivers also drive further away from the road edge.

Lewis-Evans and Charlton 2006 Explicit and implicit processes in behavioural adaptation to road width. Accident Analysis and Prevention 38, 610-617.

Comparison of sites in Australia and New Zealand found that narrower lanes reduce speed in 7km/h in 85th percentile and collisions with injuries in 30%

Turner et al 2017 Safe system infrastructure on mixed use arterials. Austroads Technical Report AP-T330-17.

Vehicles overtake cyclists at lower speeds in narrower lanes (<3,75m), but only in roads with 30mph (48km/h) speed limit, not in roads with 20mph (32km/h) limit.

Shackel and Parkin 2014 Influence of road markings, lane widths and driver behaviour on proximity and speed of vehicles overtaking cyclists Accident Analysis and Prevention 7, 100-108.

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Increase number of traffic lanes



Dubai, UAE ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Add one or more general traffic lanes to an existing road, in one or both travel directions. The new lanes may be added along the whole length of the road or just in some parts (e.g. approaching junctions).

Adding new lanes requires space that is currently assigned to other uses (e.g. marked or raised median strips, road shoulder, footways, car parking strips). In some cases, space is created by demolishing buildings.

The increase in the number of lanes reduces the need for overtaking and can increase traffic speeds. However, it increases the number of encounters with traffic for pedestrians crossing the road. It also increases number of conflicts at junctions.

The number of traffic lanes can be increased by reducing the width of existing lanes. However, this reduces the potential of the measure for increasing traffic speeds, as vehicles need to drive more carefully.

This measure is only suitable in low-density areas and roads with high traffic volumes and low volumes of pedestrians (including pedestrians crossing the road) and cyclists.

EXAMPLES

Planned capital cities (e.g. Brasilia, Astana) are usually structured around roads with many lanes. Naypyidaw (Myanmar) has roads with up to 20 lanes, all used by little traffic.

Adding lanes is usually the solution found to accommodate increased car use in developing countries. The Kathmandu ring road was widened in 2018 from 2 to 8 lanes, by removing trees.

Many urban streets were converted into multi-lane roads in Chinese cities since the 1990s, by demolishing buildings and removing footways.

EVIDENCE

A cross-sectional and time-series analysis of roads in US states found that fatalities/injuries increase with the number of lanes, when controlling for road type and demographics.

Noland 2003 Traffic fatalities and injuries: the effect of changes in infrastructure and other trends. Accident Analysis and Prevention 35, 599-611.

Another study in the USA found that red-light running was more likely at road junctions with more lanes.

Porte and England 2000 Predicting red-light running behaviour: a traffic study in three urban settings. Journal of Safety Research 31, 1-8.

A study in 24 medium-size cities in California found that more road lanes are associated with a higher car share and a lower share of public transport, walking, and cycling.

Marshall and Garrick 2010 Effect of street network design on walking and biking. Transportation Research Record 2198, 103-115.

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Increase width of traffic lanes



Arequipa, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Increase of the width of lanes for general traffic. This is achieved by reassigning some of the space currently used as median strips, road shoulders, footway, or car parking spaces. In some cases, space is created by demolishing buildings.

This increases the capacity of the road to accommodate large vehicles, including buses and Heavy Goods Vehicles. The recommended lane width is 3.3.5m, but may be 2.75m in residential roads and roads with low speeds (30km-h speed).

Increasing lane width increases the crossing distance for pedestrians. It also encourages higher traffic speeds and overtaking of cyclists. There is also increased potential for double parking.

Lane width can also be increased by reducing the number of existing lanes. However, this reduces the potential of the measure for increasing traffic speeds, as the number of vehicles per lane increases.

This measure is more suitable outside built-up areas and roads with high traffic volumes, with a high proportion of large vehicles, and with low pedestrian and cyclist flows. It is useful in suitable in curved roads.

EXAMPLES

In the USA, traffic lanes in new urban roads are often wide because city governments apply national-level standards, which suggest wide lanes.

In the 1990s, Beijing had a road-widening scheme stipulating that new roads should be 25-80m wide. Many roads have been widened in China since the 1990s, usually with several, and wide, lanes.

The tendency in European countries is to reduce lane width in urban roads, not to increase, to release space for other uses.

EVIDENCE

Lane width tend to increase traffic speed. Drivers also drive closer to the road edge.

Lewis-Evans and Charlton 2006 Explicit and implicit processes in behavioural adaptation to road width. Accident Analysis and Prevention 38, 610-617.

A cross-sectional and time-series analysis of roads in US states found that road widths above 3.35m increase fatalities and injuries.

Noland 2003 Traffic fatalities and injuries: the effect of changes in infrastructure and other trends. Accident Analysis and Prevention 35, 599-611.

Vehicles overtake cyclists at higher speeds in wider lanes (>3,75m), but only in roads with 30mph (48km/h) speed limit, not in roads with 20mph (32km/h) limit.

Shackel and Parkin 2014 Influence of road markings, lane widths and driver behaviour on proximity and speed of vehicles overtaking cyclists Accident Analysis and Prevention 7, 100-108.

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Remove centre lines



Blois, France ©Paulo Anciaes

TYPE: Design

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Removal of the marked lines that separate traffic lanes for different travel directions. In most cases, the measure is not reinstating the lines after surface work, rather than removing them on an existing surface (to avoid damage to the surface).

The aim is to reduce traffic speed. Drivers are more cautious when moving and overtaking as it is more difficult to negotiate oncoming traffic. There is also less propensity from passing cyclists too closely.

This measure is often applied in conjunction with narrowing the carriageway, releasing space for cycle lanes. Its application may require restrictions to some types of vehicles, especially heavy goods vehicles.

Removing centre lines reduces drivers' visibility of the road, especially at night or on rainy days. It may also be confusing for pedestrians crossing the road, who are unsure about the safest place to stop, if needed.

This measure is more suitable in roads with low traffic volume and with low speed limits (below 50km/h), and in sections where other traffic calming measures would not be feasible.

EXAMPLES

Around the world, many rural roads and narrow urban roads and streets do not have centre lines

In 2014, there was a trial project in London for not reinstating centre lines on three roads (Seven Sisters Road, Wickham Road, Brighton Road). They were not reinstated after the trial.

There were other trials in England and Scotland, in roads outside urban areas. For example, Wiltshire County Council removed centrelines from 12 roads in 2002.

EVIDENCE

A review found that roads with no centre lines can have up to 36 times more collisions. Centrelines are particularly effective at night-time and in low visibility situations.

Carlson et al 2009 Benefits of pavement markings - a renewed perspective based on recent and ongoing research. Transportation Research Record. 2107, 59-68.

In a driving simulator study, removing centre lines caused drivers to drive slightly slower and to move closer to the centre of the road. Drivers' heart rates increased.

De Waard et al 2004 How much visual road information is needed to drive safely and comfortably? Safety Science 42, 639-655.

Removal of centre-lines leads to drivers passing cyclists at lower speeds, but only in roads with 30ph (48km/h) speed limit, not roads with 20mph (32km/h) limit.

Shackel and Parkin 2014 Influence of road markings, lane widths and driver behaviour on proximity and speed of vehicles overtaking cyclists Accident Analysis and Prevention 7, 100-108.

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Add or widen median strip



Valparaíso, Chile ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Also known as central reservation. Space between traffic lanes in different directions. It can be painted, raised with kerbs, or planted. Physical barriers (e.g. guardrailing) may be added, or kept, if already existent, to separate vehicles.

If the median has no physical barriers, it allows vehicles to pass cyclists or slower vehicles; emergency vehicles to cross over into the opposite lane; and pedestrians to stop and cross in two stages (at crossing facilities or informal crossings)

If the median is raised, wide enough, and has few gaps, it also allows pedestrians to walk along the road. Alternatively, it can provide space for place activities (e.g. seating areas), car parking, bicycle parking, or street furniture (e.g. lighting).

Median strips can be green spaces (e.g. trees, swales, grassed strips). If wide, they can be used as a cycle track or as a corridor for trams, light railway systems, or buses. Underground rivers can also be restored to run at-surface along the median.

The presence of a median strip, especially if kerbed, may reduce travel speeds, as gives drivers less flexibility. Kerbed medians without ramps also become a barrier to pedestrians with impairments at informal crossings.

EXAMPLES

Restricted-access roads (e.g. motorways) and multilane roads usually have wide medians, with barriers at the carriageway edges, and sometimes a grassed strip in the middle.

In 2013, a long and wide median strip was added to Avenida 9 de Julio in Buenos Aires (one of the widest urban streets in the world), with a busway, greenery, and pedestrian paths.

The space between Carretera 7 and Calle 32 in central Bogota is a wide median accommodating a cycle lane, several clear paths for pedestrians, benches, a planted strip, and a station entrance.

EVIDENCE

The redesign of a 4-lane road in New Jersey, adding a raised median, reduced pedestrian exposure risk and increased driver predictability, and little effect on traffic speed and volume.

King et al 2003 Pedestrian safety through a raised median and redesigned intersections. Transportation Research Record 1828, p56-66.

A study in 24 cities in California found that the proportion of streets with (raised or painted) medians is associated with only small changes in the walking and cycling modal share.

Marshall and Garrick 2010 Effect of street network design on walking and biking. Transportation Research Record 2198, 103-115.

Adding a median strip to a road has an estimated monetary benefit for pedestrians crossing the road of £1.08 for each walking trip.

Anciaes and Jones 2018 A stated preference model to value reductions in community severance caused by roads. Transport Policy 64, 10-19.

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Median turn lane

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Also known as two-way centre turn lane or centre left/right turn lane. Two-way lane in the centre of the road for vehicles in each direction to wait for a gap in the traffic before turning.

This lane can be created by readapting the median strip, reconverting one traffic lane, or by a more radical design of the road, with space taken from the footway, parking strips, or the road shoulders.

This lane reduces turning movement conflicts and disruption to moving traffic caused by vehicles turning. The lane is usually discontinuous, i.e. only available near junctions, with the other sections having a marked or raised median

The median turn lane can be used by emergency vehicles to avoid delays. Enforcement is needed to prevent vehicles from using this lane as a lane for movement or parking. Pedestrians may be able to use these lanes to stop when crossing the road.

Median turn lanes are more suitable in roads with low traffic volume and speed, in low-density areas with few pedestrians. It is not suitable in complex junctions with many turn movements or in multilane roads.

EXAMPLES

Median turn lanes are often created as a part of "road diet" measures, which reduce the lanes for general traffic. This has been common in the USA since the 1970s.

In New Zealand, median turn lanes are known as flush medians. They are wide continuous medians marked with white diagonal lines (not kerbed).

Median turn lanes are common in other countries (e.g. Germany, Gulf countries). In Japan, most signalised junctions have one (known as "right turn lane markings")

EVIDENCE

A review of projects that converted 4-lane urban roads to 3 lanes with a median turn lane showed an average reduction of 19% in collisions - but many projects added cycle lanes, a confounder.

Thomas 2013 Road Diet Conversions: A Synthesis of Safety Research. Report to Federal Highway Administration, DTFH61-11-H-00024.

Analysis of data for 8 sites in the US found that conversions of 4-lane roads to 5-lane, including a new median turn lane, reduce collisions by 16-65% and have a benefit-cost ratio of 97-379.

Das et al 2018 Safety effectiveness of roadway conversion with a two way left turn lane. Journal of Traffic and Transportation Engineering 5, 309-317.

Roads with median turn lanes have a vehicle-pedestrian collision rate 34% higher than roads without one, when controlling for other road characteristics.

Quistberg et al 2015 Multilevel models for evaluating the risk of pedestrian–motor vehicle collisions at intersections and mid-blocks. Accident Analysis and Prevention 84, 99-111.

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One-way traffic



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Streets where movement is only possible in one direction. They can be isolated or integrated into a network of one-way streets over an area (known as a gyratory). They may have a contraflow cycle or bus lane.

One-way traffic increases driving distances and tends to increase traffic speeds. It reduces the legibility of the network for vehicles and pedestrians (who often fail to look in the correct direction before crossing the road).

At the same time, one-way traffic simplifies movements at junctions and facilitates crossing (as pedestrians only have to look one side). It also releases space that can be used to widen footways, car parking, bus lanes, cycle lanes, or greenery.

Systematic application of one-way traffic can be a measure to discourage drivers from using residential streets for through movement. This measure can be applied in conjunction with turn restrictions, lower speed limits, and traffic calming.

One-way streets are more suitable in narrow roads, in busy junctions (as it reduces the number of conflicts), and in grid networks, when there are alternative routes in the opposite direction.

EXAMPLES

One-way traffic started to be used in several countries from the 1930s, to cope with increased traffic in streets that had not been designed for the movement of motorised vehicles.

Gyratories (systems of one-way streets) are common in the UK. Hanger Lane (London) is one of the most complex, with a square shape, many slip lanes, and four sets of traffic signals.

In many countries, one-way streets are being re-converted, often with accompanying restrictions. Tottenham Court Road (London) was reverted to two-way traffic in 2020 but private cars are banned.

EVIDENCE

A study in Jerusalem found that, outside the city centre, collision rates at junctions were 3.6-3.8 higher in one-way streets and 1.1-1.7 higher in mid/block locations in all street types, compared with two-way streets.

Hochrman et al 1990 Safety of one-way urban streets. Transportation Research Record 1270, 22-27.

In contrast, a study in Seattle found that one-way roads had a vehicle-pedestrian collision rate 35% lower than two-way roads, when controlling for other road characteristics.

Quistberg et al 2015 Multilevel models for evaluating the risk of pedestrian–motor vehicle collisions at intersections and mid-blocks. Accident Analysis and Prevention 84, 99-111.

A study of a conversion from one-way to two-way traffic found that traffic flow increased but collisions decreased. Property values increase and crime decreased.

Riggs and Gilderbloom 2015 Two-way street conversion: evidence of increased livability in Louisville. Journal of Planning Education and Research 36, 105-118.

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Yield street (bidirectional single lane street)



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Also known as single lane two-way streets. Street where movement is possible in both directions but there is only space for a vehicle to pass at a time. When two vehicles meet from opposite directions, one needs to yield to the other.

In narrow streets, this design may be the only solution, if there are no alternative links for traffic in both directions. Clear signage must be installed at transitions (when the road narrows) and at all junctions leading to the yield street.

In wider streets, this design can still be applied, to release space for on-street car parking or for wider footways. A chicane design can be applied, with parking spaces or footway extensions distributed along the road.

This design is suitable in low/traffic, low-speed streets, to reduce delays and the risk of head-on collisions. Physical barriers may be needed, to prevent encroachment from vehicles onto the footway.

Yield streets may be problematic for cyclists because of the risk of being squeezed between moving and parked vehicles. Access to emergency vehicles is also more difficult, as they need to slow down or stop for approaching vehicles.

EXAMPLES

Yield streets are common in rural areas (due to low traffic) and dense urban roads (due to space constraints). There is increased interest in designing new yield streets (converting 2-lane 1-way or 2-way streets)

As an example, the city of Columbus (Ohio, USA) conducted a Slow Streets study to identify streets that can be converted from one-way to two-way yield streets. A pilot started in four streets in 2019.

The Emerald Express, a bus rapid transit in Eugene (USA) uses a bidirectional bus lane, with buses scheduled by a signalling system to take turns using the lane. Buses pass each other at bus stops.

EVIDENCE

In an experimental study in the USA, 1-lane 2-way streets were judged as safer by cyclists than 1-lane 1-way, multi-lane 1-way and multilane 2-way streets

Riggs 2019 Perception of safety and cycling behaviour on varying street typologies: opportunities for behavioural economics and design. Transportation Research Procedia 41, 204-218.

Modelling showed that a bus service using single bi-directional bus lane yields a total travel time similar to one using double lanes, but only if the service is low-frequency (more than 20 minutes between services)

Li et al 2009 Planning for bus rapid transit in single dedicated bus lane. Transportation Research Record 2111, 76-82.

There is little further evidence on yield streets. But insights can be derived from the literature on carriageway narrowing and lane removal. A review in Australia found this reduces safety and collisions.

Turner et al 2017 Safe system infrastructure on mixed use arterials. Austroads Technical Report AP-T330-17.

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Reversible traffic lane

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Lane that changes direction according to time of day. The direction is usually aligned with the main commuting flows. In the inter-peak period, the space may be empty (e.g. median strip), a median turn lane or for movement in one of the directions.

One or more lanes, or the whole road can be reversed. The aim is to improve the efficient use of road space, serving the periods of higher demand. This allows for the removal of one lane, releasing space for other uses (e.g. wider footways, car parking).

Reversible lanes should have a buffer to traffic lanes in the opposite direction or be separated by a kerbed median strip or movable barriers. Turning movements should be banned or minimized.

These lanes are usually located in the median strip, to reduce conflicts with traffic in other lanes. The direction of travel is indicated with electronic signs. A time lag is needed to ensure the transition is safe.

Reversible lanes make more crossing the road more difficult for pedestrians, as they occupy the median strip, reducing space for refuges. Pedestrians may also be confused and look in the wrong direction, when crossing the reversible lane.

EXAMPLES

Reversible lanes are common in bridges, where space is limited. Examples include the Sydney Harbour Bridge, Panmure Bridge (Auckland), and Lions Gate Bridge (Vancouver).

One section of Connecticut Avenue NW in Washington, which crosses an area with mixed land uses, has a pair of reversible lanes in the median strip.

Jarvis Street in Toronto, which also crosses a busy area in the city centre, has a reversible lane. It was removed in 2010 but reinstated in 2012.

EVIDENCE

Evaluation of reversible lanes in arterial roads in Washington found some evidence that collisions were higher in sections of the road with reversible lanes than in other sections.

Dey et al 2011 Reversible lane operation for arterial roadways: the Washington, DC, USA Experience. ITE Journal 81, 26-28, 33-35.

In a survey in Phoenix, around 65% of drivers agreed congestion would increase if a reversible lane was removed. 45% thought the reversible lane was safe and 55% thought it reduced travel time.

Golub 2002 Perceived costs and benefits of reversible lanes in Phoenix, Arizona. ITE Journal 82, 38-42.

A study in China found that reversible lanes can help reduce concentrations of PM2.5 and its harm to pedestrians, via its effects on reduced congestion.

Wang et al 2020 Effect of reversible lanes on the concentration field of road-traffic-generated fine particulate matter (PM2.5). Sustainable Cities and Society 62: 102389.

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Part-time traffic lane

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Lane for the movement of general traffic that becomes active only at certain times or days. At other times the lane may be empty (e.g. the road's hard shoulder or median strip) or for other uses (bus lane, parking spaces, or a pedestrianised street).

Static signs and pavement markings indicate the times the lane is open to traffic. Traffic signals and electronic signs can also be used. Enforcement (with cameras) is needed to ensure that the lane is not used for movement during the times it is not active.

The aim is to increase road use efficiency, allowing movement when demand for movement of cars or commercial vehicles is higher, or simply when demand for other uses is low. This reduces the amount of underutilised road space.

The transitions from/to traffic lane can cause confusion for drivers, unexpected movements by vehicles in other lanes, and conflicts between drivers moving into the new lane and its current users (e.g. buses, parked cars).

The use of empty space (e.g. shoulders) may disrupt emergency and service vehicles, and reduce flexibility of vehicles moving in adjacent lanes. Pedestrians may also not expect vehicles in lanes (or whole streets) empty of traffic at other times.

EXAMPLES

Hard shoulders have been used as part-time traffic lanes in motorways in the USA since the 1970s (the I-66 in Virginia). Later, some lanes became dynamic (operating when needed).

In one section of Connecticut Avenue NW in Washington, the outside lanes are used as traffic lanes in the peak period. In the off-peak period, they become spaces for parking and loading.

Traffic is allowed across some parks at some times. As an example, traffic can cross Prospect Park (New York) for limited hours on some routes, but these have been restricted over the years.

EVIDENCE

A study of part-time traffic lanes in road shoulders in Washington showed they led to conflicting movements at the merge/diverge areas and an increase of 38% in collisions in those areas.

Lee et al 2012 Safety impacts of freeway managed-lane strategy inside lane for high-occupancy vehicle use and right shoulder lane as travel lane during peak periods. Transportation Research Record 2012, 113-120.

Simulation of the effects of a morning part-time shoulder lane shows that increases speed, increasing collision risk during unsafe situations, but also reduces the number of unsafe situations.

Coffrey and Park 2020 Part-time shoulder use operational impact on the safety performance of interstate 476. Traffic Injury Prevention 21 470-475.

A part-time bus lane (6:30-9:30 only), using the road shoulder, in Tel-Aviv, reduced bus travel time by 30% and increased bus occupancy by 10%.

Gitelman et al 2016 Bus operations on hard shoulders during congested morning hours – a pilot evaluation in Israel. Transport Research Procedia 1144-1153.

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Dynamic traffic lane

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Lane for the movement of general traffic that becomes active when demand for roadspace increases or in case of unexpected events (e.g. collisions). At other times the lane may be empty (e.g. the road's hard shoulder) or for other uses.

Electronic signs indicate if the lane is open to traffic. The speed limit may vary according to traffic conditions. Enforcement (with cameras) is needed to ensure the lane is not used for movement during the times it is not open.

The transitions from/to traffic lane can cause confusion for drivers, unexpected movements by vehicles in other lanes, and conflicts between drivers moving into the new lane and its current users (e.g. buses). A lag is required before the lane is active.

The more dynamic the lane is, the fewer the uses it can have when it is not active. A fully dynamic lane can be a bus or cycle lane when it is not active for movement, but not a car or bicycle parking space.

Dynamic traffic lanes can be static lanes at night-time, either inactive (if there is low demand for movement of general traffic) or active (if there is low demand for other uses).

EXAMPLES

Dynamic hard shoulders have been used in motorways in Germany since 1996, and also exist in France, Italy, Netherlands, USA and South Korea.

Some motorways in England (known as Smart Motorways) had dynamic hard shoulders (becoming traffic lanes when needed). As of 2020, there was a plan to remove this feature, due to safety issues.

There are no examples of dynamic traffic lanes in urban streets. Dynamic bus lanes (which are general traffic lanes when not active) have been trialled in Lisbon, Melbourne, and Lyon.

EVIDENCE

An evaluation study of Smart Motorways in the UK found that dynamic hard shoulders tended to be underutilized.

Ogawa 2017 Monitoring and evaluation of smart motorway schemes. PhD Dissertation, University of Southampton.

A study in South Korea found that dynamic lanes on motorway hard shoulders reduced travel time by 19-26%.

Jang et al 2014 Effectiveness of managed lanes on south Korean expressways. Presented at the 93rd Transportation Research Board Annual Meeting.

A test in a motorway in Spain, for a European research project (INFRAMIX), found that dynamic lanes for autonomous vehicles improve flows for those vehicles, but not for conventional ones.

Lytrivis et al 2020 Evaluation, impact analysis and new safety performance criteria. INFRAMIX – Road INFRAsstructure ready for MIXed vehicle traffic flows, Deliverable 5.3.

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Flexible design

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Road design where space is reallocated among different uses at different times or in response to demand and conditions. Space can be reallocated among a section of the street (footway, kerbside zone, carriageway) or the whole street.

One possibility is to allocate space for movement at peak-time, with some space being for other uses at other times, such as markets at lunch time, seating areas and taxi bays in the evening, parking space at night, and loading bays in early morning

Some design elements can be active at some times only; including part-time or dynamic bus lanes, cycle lanes, pedestrian crossings, and street furniture (e.g. pop-up parklets and seating areas). The design can also include dynamic pricing of parking.

The changes in space allocation can respond to data captured from sensors and be implemented with LED lights on pavements (with a different colour for each allocation) and digital signs, synced with navigation systems on vehicles and on smartphone apps

Two challenges of flexible designs are how to manage transitions and how to enforce restrictions. The latter is relevant for vehicle-based place activities: vehicles may remain in the space after it has been reallocated to movement.

EXAMPLES

In the late 1990s, Barcelona has introduced multifunctional lanes in the centre, used for general traffic (8:00-10:00, 17:00-21:00), deliveries (10:00-17:00) and car parking (21:00-8:00).

There is a plan for a flexible design in Oxford Street, the main shopping street in London, with car traffic restriction in the afternoon, access for loading in the morning, and for taxis and ride-hail in the evening.

In China and Southeast Asia, footways have different uses throughout the day, with users informally claiming different parts of the space at each time.

EVIDENCE

Multifunctional lanes in Barcelona (with space allocated to general traffic, deliveries, and parking, at different times) reduced travel time by 12-15%.

Hayes et al 2006 MIRACLES (Multi Initiative for Rationalised Accessibility and Clean Liveable Environments) Deliverable 4.2 Annex 3 – 2nd Implementation Report for Barcelona.

Simulation of flexible kerbside space (allocating space to pedestrians, cyclists, taxis, and deliveries at different times), showed it would reduce average delay in the morning peak (192 to 51 seconds) and lunch time (67 to 54 seconds).

ARUP 2018 FlexKerbs - Evolving Streets for a Driverless Future

Analysis of a footway in Ho Chi Minh showed a mix of different uses, with users cooperating to reassign space throughout the day. Place activities used 10-40% of available space.

Kim 2012 The mixed-use sidewalk. Journal of the American Planning Association 78, 225-238.

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Motorcycle lane

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Provision of dedicated lanes for the exclusive use of motorcycles. The lanes can operate permanently or at some times only and can be bidirectional, allowing for two-way traffic on the same side of the road.

There are few design guidelines for motorcycle lanes. Where they exist, they are wider than cycle lanes (3-4m), allowing for overtaking. General guidelines for motorcycle travel emphasize smooth surfaces, good visibility, and no obstructions.

The aim of dedicated motorcycle lanes is to reduce conflicts with larger vehicles. The exclusive lane can be marked or physically segregated, and can have some of the safety design features used in cycle lanes, such as two-stage turns at crossings.

Motorcycle lanes are suitable in roads with high volumes both of motorcyclists and of other vehicles, especially large vehicles. Enforcement (with cameras, or barriers) is required to avoid the lanes being used by other vehicles.

An alternative is to allow motorcycles on cycle lanes or bus lanes. This may cause conflicts with cyclists and buses, who travel at different speeds. Pedestrians may also feel confused when encountering two types of vehicles.

EXAMPLES

Dedicated lanes for motorcycles exist in several Asian countries. They were introduced in the 1970s in Malaysia and in the 1980s in Taiwan. In Taiwan, they have waiting zones at junctions, for two-stage turns.

In Chinese cities there are shared lanes, used by motorcycles, electric bicycles, and conventional bicycles.

Motorcycles can use some bus lanes in London and in other cities in the UK.

EVIDENCE

The introduction of a motorcycle lane in Malaysia led to a 39% reduction in motorcycle collisions.

Sobadi et al 2000 Multivariate analysis of motorcycle accidents and the effects of exclusive motorcycle lanes in Malaysia. Journal of Crash Prevention and Injury Control, 1, 11-17.

Another study in Malaysia found a high frequency of collisions with objects on motorcycle lanes, especially with guard railings.

Ibrahim et al 2017 Evaluating the effect of lane width and roadside configurations on speed, lateral position and likelihood of comfortable overtaking in exclusive motorcycle lane. Accident Analysis and Prevention 111, 63-70.

Most motorcyclists thought a new motorcycle lane in Colombia was safe and reduced travel time. But half of car drivers protested because of delays and half of cyclists protested because of reduced safety.

Osorio-Cuéllar 2015 First motorcycle-exclusive lane (Motovia) in Colombia: perceptions of users in Cali, 2012–2013. International Journal of Injury Control and Safety Promotion 24, 145-151.

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Lane for electric vehicles

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Traffic lane for the exclusive use of electric vehicles. It can be for cars only, or for all electric vehicles (including goods vehicles). Electric bicycles and micromobility vehicles may have a separate lane, or use cycle lanes.

In roads with space restrictions, the lane would be shared with public transport and high-occupancy vehicles. Electric vehicles can also be allowed in transit streets, cycle streets, or even pedestrianised areas (with a low speed limit).

Regular charging points are also required along the lane. They should have easy access (e.g. from a nearside lane for electric vehicles). There are also experiments for automatic recharging while travelling along special road lanes.

Underuse would be a problem. One solution would be to open the lane to other vehicles in off-peak times (for free) and peak-times (for a charge). Another solution is to allow electric vehicles to use bus lanes, but this could cause delays for buses.

Enforcement is required to avoid conventional vehicles using the lane for electric vehicles. Pedestrians may also feel confused while crossing the road, not expecting quiet vehicles using a dedicated lane.

EXAMPLES

There are no examples of exclusive lanes for electric vehicles. For a time, they are allowed on bus lanes in Norway. In the USA, they can use high occupancy lanes for free or reduced charge.

There is a plan to add an exclusive lane for electric vehicles (cars, buses, and trucks) in the 710 Freeway in Los Angeles. This would be a part of the road widening; it would not replace other lanes.

There are some examples of "electric roads". A road section that allows for the recharging of commercial electric vehicles was opened in Stockholm in 2018. There were tests in other countries.

EVIDENCE

Access to high-occupancy vehicle lanes was significantly related with the probability of buying an electric vehicle in California.

Fowler et al 2018 2015–2017 California vehicle survey. Report to California Energy Commission.

In contrast, access to bus lanes was negatively related with the probability of buying an electric vehicle in Norway - possibly due to the individuals' concern regarding bus lane congestion.

Zhang et al 2016 The impact of car specifications, prices and incentives for battery electric vehicles in Norway: choices of heterogeneous consumers. Transportation Research C 69, 386-401.

Another study in California estimated that the willingness-to-pay of owners of hybrid vehicles to use high-occupancy lanes is high, but the air pollution reduction benefits are low.

Shenmake and Jarvis 2014 Hybrid cars and HOV lanes. Transportation Research A 67, 304-319.

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Lane for autonomous vehicles

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Traffic lane for the exclusive use of autonomous vehicles. This lane may coexist with lanes for conventional vehicles or may replace those lanes. Lanes for autonomous vehicles may be used for movement and for in-lane passenger pick-up/drop-off.

Coexistence of lanes for autonomous and other vehicles causes problems because cross-lane movement is required to access the kerbside. Conflicts may also arise at junctions. The lane for autonomous vehicles may also be blocked by parked vehicles.

Lanes for autonomous vehicles can be dynamic, activated only when demand for movement exists. At other times, the lane may be for parking. Elements of the lane can also be dynamic, including direction and speed limit.

Fewer and narrower lanes are required for the circulation of autonomous vehicles, because these vehicles are narrower, require less space between vehicles, and can share lanes with vehicles in the opposite direction.

The use of autonomous vehicles also reduces the need for parking space, as private vehicles can be parked remotely and shared ones can circulate to pick-up/drop-off passengers where needed. This releases space that can be reallocated to other uses.

EXAMPLES

A European project (Inframix) tested dedicated (permanent and dynamic) lanes for autonomous vehicles in two motorway sections, in Spain and Austria, in 2017-2020.

Another European project (InSmart) trialled the use of autonomous minibuses on a bus lane in Trikala (Greece) in 2013-2016.

There was a trial of an autonomous shuttle in London in 2017 (GATEway project). The shuttle ran on a dedicated lane alongside a separate shared pedestrian and cycle lane.

EVIDENCE

A simulation has shown that dedicated lanes for autonomous vehicles coexisting with other lanes do not improve traffic flows, especially in roads with low traffic density.

Ye and Yamamoto 2018 Impact of dedicated lanes for connected and autonomous vehicle on traffic flow throughput. Physica A: Statistical Mechanics and its Applications 512, 588-597.

In a trial in a shared area, pedestrians considered autonomous vehicles as low risk. The majority crossed in front of an approaching vehicle, rather than behind or waiting for the vehicle to fully pass first.

Hulse et al 2018 Perceptions of, and behaviours around, driverless vehicles. Report for Innovate UK. Transport Research Laboratory.

In a trial of autonomous minibuses on a bus lane in Greece, survey respondents preferred autonomous to other buses. Opinions were not affected by autonomous buses being often obstructed by parked cars

Portouli et al 2017 Public attitudes towards autonomous mini buses operating in real conditions in a Hellenic city. Proceedings of 2017 IEEE Intelligent Vehicles Symposium.

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Lane for goods vehicles

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Dedicated lane for the movement of goods vehicles (light or/and heavy vehicles). The lanes can be part-time only, when more deliveries are made (e.g. early morning), reverting to general traffic at other times. Roads can also be truck-only (truckways).

New, dedicated lanes for goods vehicles, can better accommodate these vehicles, compared with general lanes, as they can be wider, next to road shoulders, and have wider corner radii and more resistant pavement.

Lanes for goods vehicles may follow a route across several roads (known as truck routes). They can increase the reliability of travel times, avoiding delays in busy roads shared with private cars.

If the lanes for goods vehicles are on the nearside, the presence of many large vehicles restricts the visibility of the road for vehicles entering the road at junctions. If on the farside, there is a risk of side-swipe collisions.

These lanes are useful in wide roads (especially motorways) and in access roads to ports and industrial areas. They are not suitable in narrow roads and in central or residential areas, used by pedestrians and cyclists.

EXAMPLES

A truck lane was implemented in Waller Street, an arterial road in Ottawa (Canada) in the 1980s. The lane has a 300m truck-only lane, used as a bypass to divert trucks from congested roads.

Truck lanes started to be built in July 2019 on the State Route 60 in California, which links several industrial areas. The lanes are built from widened roads, not reallocation of road space from general traffic.

There is a project for truck lanes in the Interstate 75 motorway near Atlanta. Work will start in 2024. The lanes will also be built by widening the road, not by reallocating existing road space.

EVIDENCE

A study in Seattle found that exclusive truck lanes would lead to the same travel time savings (8%) than allowing truck on shared lanes with buses and high-occupancy vehicles.

Trowbridge et al 1996 The potential for freight productivity improvements along urban corridors. Washington State Transportation Center. Report T9903-36.

An appraisal study in California found that, compared doing nothing, adding truck lanes to a motorway reduces congestion (more than general lanes) and collisions/injuries/fatalities (less than general lanes)

Fischer et al 2003 Planning truck-only lanes - emerging lessons from the Southern California experience. Transportation Research Record 1833, 73-78.

A modelling study in Toronto found that converting a general lane to a truck lane would increase truck demand and reduce truck travel times - but would increase car travel times.

Roorda et al 2010 Exclusive truck facilities in Toronto, Ontario, Canada: analysis of truck and automobile demand. Transportation Research Record 2168, 114-128.

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Goods vehicles allowed on bus lane

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Allow goods vehicles (light or/and heavy vehicles) to use bus lanes. This can at all times or only at some times, when more deliveries are made (e.g. early morning), with the lane reverting to bus-only at other times.

This arrangement increases the efficiency of road space, as it allows for the use of space that can be underused when buses are infrequent. It also allows goods vehicles to use wide lanes, compared with lanes for general traffic.

The shared bus lanes may be a part of a larger route for goods vehicles, across several roads (known as truck routes). These routes can increase the reliability of travel times, avoiding delays in busy roads shared with private cars.

Sharing bus lanes with goods vehicles would lead to faster deterioration of the road pavement. It can also increase delays and increase conflicts with buses. It restricts the visibility and increases exposure to noise and air pollution for bus users.

These lanes are useful in wide roads (especially motorways) and in access roads to ports and industrial areas. They are not suitable in roads with high-frequency buses and in central or residential areas, used by pedestrians and cyclists.

EXAMPLES

Newcastle (UK) has an extensive network of "no car lanes", open to goods vehicles, buses, taxis, motorcycles, and bicycles. Some lanes open to cars from 7pm to 7am.

New Jersey Turnpike has car-only lanes and other lanes shared by trucks, buses, and cars. The two sets of lanes are grade-separated.

There is a trial (2019-21) in New York to allow through movement on a section of 14th Street to buses and trucks only, using Transit-Truck Priority lanes. This applies from 5am to 10pm.

EVIDENCE

Models show that allowing goods vehicles on a bus and taxi lane is unlikely to be beneficial in terms of overall travel times for different modes.

Oldfield et al 1977 With-flow bus lanes: economic justification using a theoretical model. Transport and Road Research Laboratory Report 809.

A model of the first bus lane in Seoul found that a bus lane with trucks was linked with higher overall travel costs (for all users) than either mixed traffic (i.e. no bus lane) or a bus-only lane.

Black et al 1992 A traffic model for the optimal allocation of arterial road space: a case study of Seoul's first experimental bus lane, Transportation Planning and Technology 16, 195-207.

A study in Seattle found that exclusive truck lanes would lead to the same travel time savings (8%) than allowing truck on shared lanes with buses and high-occupancy vehicles.

Trowbridge et al 1996 The potential for freight productivity improvements along urban corridors. Washington State Transportation Center. Report T9903-36.

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High-Occupancy Vehicle lanes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Also known as car pool lanes and HOV lanes. Lanes for the exclusive use of vehicles with more than one occupant (at least 2 or 3 occupants). In quiet periods, single-occupancy vehicles may be allowed, or the minimum number of occupants may be lower.

HOV lanes may be located in the nearside or offside of the road carriageway, or in the median strip. They may be reversible, changing direction during the day (following commuting patterns), and contraflow (in an otherwise one-way road).

Buses, taxis, two-seater vehicles, motorcycles, and electric vehicle may be able to use these lanes. However, taxis may need to have a minimum of occupants. Heavy Goods Vehicles are always banned. bicycles may be allowed, depending on road type.

HOV lanes may be physically segregated from other lanes (with permanent or temporary structures, or grade-separation), or simply marked, and identified with signs. Vehicles using HOV lanes may have priority at traffic signals.

Compliance is a problem. Enforcement (e.g. with cameras) is required to avoid single-occupancy vehicles using the lanes. Underuse is another problem. The lane may then be converted to high-occupancy toll lane, allowing single-occupancy vehicles for a fee.

EXAMPLES

HOV lanes were first introduced in the Shirley Highway near Washington DC in 1973, when a bus lane was open to car pools with at least 4 occupants.

Most HOV lanes are in North America, but there are several examples in Australia and some Asian countries. Some HOV lane schemes in Europe have failed, and the lanes were reassigned to general traffic.

In some US cities (e.g. Washington), HOV lanes have encouraged casual carpooling (known as slugging), with drivers collecting passengers at road entrances/car parks.

EVIDENCE

A model of the effect of HOV on congestion found that, assuming no change in carpooling behaviour, HOV lanes add less than 2% to vehicular delay but reduce people delay by more than 10%.

Daganzo and Cassidy 2008 Effects of high occupancy vehicle lanes on freeway congestion. Transportation Research B 42, 861-872.

However, HOV lanes tend to be underutilized, which represents an inefficient use of road space, and that travel time savings do not provide a significant incentive to use them

Krona and Varaiya 2008 Effectiveness of California's High Occupancy Vehicle (HOV) system. Transportation Research C 16, 98-115.

The evidence of the effect of HOV lines on total distance travelled and emissions is mixed: it can be positive or negative, depending on effects on commuters' route choice and on congestion.

Shenmake 2012 Can carpooling clear the road and clean the air? Evidence from the literature on the Impact of HOV lanes on VMT and air pollution. Journal of Planning Literature 27, 363-374.

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Improved access roads and footway crossovers



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Facilitate vehicle access to properties and parking lots. If demand is high, this involves adding/improving access roads and driveways. If demand is low, it involves footway crossovers (also known as kerb cuts), with a ramp for vehicles.

The design should minimize conflicts with vehicles moving along road. The corners in the junction between the main road and side roads or footway crossovers should have a small radius to reduce the speeds of vehicles entering.

Side roads and footway crossovers should be minimized in areas with high pedestrian volumes and used by older pedestrians. A single access point to several properties generates fewer conflicts than many individual accesses.

The ramps in footway crossovers should not extend across the full width of footway to avoid changes in level for pedestrians. The ramps can also be mistaken by pedestrians as crossings to the other side of the road, leading to unsafe crossing behaviour.

Accesses need to provide some distance between the property boundary and the carriageway to ensure visibility. Cycle tracks also need to be visible (e.g. wider, or coloured), to reduce conflicts with vehicles coming into/from properties.

EXAMPLES

Driveways, side roads, and footway crossovers have been added liberally to road designs around the world as car use increased during the 20th Century.

Adding new vehicle crossovers is now subject to regulations in some countries. The 1980 Highways Act in the UK started to required approval for new footway crossovers.

Many city authorities in the USA encourage and offer grants to businesses to improve driveways and access roads

EVIDENCE

Research for the Manual for Streets in the UK shown that few collisions happened involving vehicles in and out of driveways, even in roads with high traffic volumes

UK Department for Transport 2007 Manual for Streets, Part 7.9

Driveways and kerb cuts for vehicles lead to the accumulation of water and snow in Winter. This has been reported by older pedestrians as a barrier to walking.

Li et al 2012 Aging and the use of pedestrian facilities in Winter - the need for improved design and better technology. Journal of Urban Health 90, 602-617.

There is also much evidence that cross slopes in footway crossovers contribute to wheelchair users avoiding of feeling insecure using streets

Cooper et al 2012 Effects of cross slopes and varying surface characteristics on the mobility of manual wheelchair users. Assistive Technology 24, 102-109.

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Speed humps



London, UK ©Paulo Anciaes

TYPE: Design

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Raised area extending across the carriageway to force drivers to reduce speed. They can be placed mid-block or at junctions (raising the entire junction or its approach). Speed humps may be identified with a different colour or texture.

To be effective in reducing speeds, speed humps are required at regular intervals (<70m) and be consistent with the road geometry. They are usually implemented in residential roads or near sensitive areas (hospitals, schools, parks).

Speed humps can reduce the drivers' visibility of the road. Drivers may also not expect speed humps, so warning signs are needed. Pedestrians can also confuse the deflections for crossing facilities, and cross in dangerous locations.

The humps should be less steep in roads with bus and cycle lanes. Cycle lanes can be re-routed. Speed cushions (covering only part of the road width and allowing larger vehicles to straddle them) also facilitate the movement of buses

Speed humps are often subject to protest by some residents and businesses because they increase noise and because drivers may avoid speed humps by using adjacent roads. Humps also slow down emergency vehicles and affects drainage and clearing of snow.

EXAMPLES

Speed humps have been applied in the USA since the 1950s. They were introduced in the Netherlands in 1970 and in the late 1970s and 1980s in other Western European countries.

They are common in most cities around the world, but in different variants. For example, speeds cushions are common in European cities.

Speed humps are common in Australia, where they often serve as raised pedestrian crossings (known as wombat crossings)

EVIDENCE

A literature review found that traffic calming measures, including speed humps, tend to reduce traffic injuries and fatalities.

Bunn et al 2003 Traffic calming for the prevention of road traffic injuries: systematic review and meta-analysis. Injury Prevention 9, 200-204

Speed humps may increase vehicle fuel consumption and pollutant emission rates due to the change on speeds.

Abn and Hesham 2009 A field evaluation case study of the environmental and energy impacts of traffic calming. Transportation Research D 14, 411-424.

A study in an American city found no statistical relationship between the presence of speed humps and the value of nearby properties.

Bretherton Jr et al 2002 The economic impact of speed humps on housing values. ITE Journal 70, 50-54.

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Speed table



London, UK ©Paulo Anciaes

TYPE: Design

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Raised section of the road, with a flat top, and ramps on both sides, to force drivers to reduce speed. They are usually placed at road junctions and are known as raised junction or platform junction. The entire junction, or its approach can be raised.

Unlike speed humps, speed tables extend along some length of the road - usually around 7m, with a height of 1m. They can be identified with signs alerting driver and with a change in the colour or textured of the carriageway surface.

Speed tables can reduce visibility. Pedestrians can also confuse the deflections for crossing facilities, and cross in dangerous locations. However, pedestrian crossings can be integrated in the design, forming a raised pedestrian crossing.

Speed tables may be applied in combination with other speed reduction measures (e.g. footway extensions) and in gateway treatments at the entrances to low-speed zones. They are usually applied in relatively narrow roads.

Speed tables are less disruptive to buses and emergency vehicles than speed humps. However, they achieve a smaller reduction in traffic speeds than speed humps. They can also disrupt the management of surface water run-off.

EXAMPLES

Speed tables are common in Europe, North America, Eastern Asia, Australia and New Zealand. In all these areas, they are less common than speed humps.

In some places, when there is a radical redesign of a road, speed tables are replaced with chicanes or with point-closures to through traffic.

Speed tables are sometimes removed, if they do not achieve the intended results, cause other problems, or are subject to protest from car users or residents.

EVIDENCE

Comparison of sites in Australia and New Zealand found that raised intersections reduce speed in 3km/h and collisions with injuries in 40%

Turner et al 2017 Safe system infrastructure on mixed use arterials. Austroads Technical Report AP-T330-17.

Speed tables may not achieve a high speed reduction. It depends on the ramp slope, the speed table length, and the distance from the previous traffic control device.

Moreno et al 2011 Speed table evaluation and speed modelling for low-volume crosstown roads. Transportation Research Board 2203, 85-93.

However, a study of traffic calming solutions in South Korea found that speed tables outperform speed humps in terms of speed reduction and noise - but not in terms of emissions.

Lee et al 2013 An evaluation framework for traffic calming measures in residential areas. Transportation Research D 25, 68-76.

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Chicanes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (moving)

DESCRIPTION

Extensions of the footway that form an S-shaped carriageway path, forcing or encouraging drivers to reduce speeds. They also have the effect of narrowing the road carriageway reducing crossing distance.

The footway extensions can be filled with street furniture, benches, trees, planted areas, bus stops, and facilities for vendors and street activities. Kerbs are needed to prevent cars from using the extension to travel straight.

The objective of chicanes is to reduce speeds and vehicle-vehicle and vehicle-pedestrian collision risk. The reduction of speed can also reduce noise. The design is suitable in residential areas with low traffic volumes.

Chicanes can squeeze cyclists, if the remaining space allows cars to overtake them. Chicanes should be wide enough for cars to pass cyclists safely or so narrow that overtaking is impossible. They should allow the access of emergency vehicles.

The road design can be changed so that cycle lanes/tracks allow cyclists to travel straight. However, cycle lanes/tracks should not be as wide as to allow cars to use them. Barriers may be needed to prevent cars from encroaching on cycling infrastructure.

EXAMPLES

Chicanes have been used in Sweden since the 1980s and are common in Western Europe, but much less common than other traffic calming measures (e.g. speed humps and tables)

As an example, chicanes are common in suburban areas in the UK, where they have been introduced in the 1990s.

When there is a radical redesign of a road, chicanes sometimes replace speed humps or speed tables.

EVIDENCE

A literature review found that traffic calming measures, including chicanes, tend to reduce traffic injuries and fatalities.

Bunn et al 2003 Traffic calming for the prevention of road traffic injuries: systematic review and meta-analysis. Injury Prevention 9, 200-204

A study of 142 chicanes in the UK found that they reduce speed in 12mph (19km/h), on average, at each chicane, and 7-8 mph (11-13km/h) between chicanes

Sayer et al 1998 Traffic calming - an assessment of selected on-road chicane schemes. Transport Research Laboratory Report 313.

A comparative study of traffic calming solutions in South Korea found that chicanes are better than speed humps/tables in terms of speed reduction and noise, but worse in terms of emissions

Lee et al 2013 An evaluation framework for traffic calming measures in residential areas. Transportation Research D 25, 68-76.

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PART 10

Measures aimed at motorised vehicles (restrictions)

Point closures/traffic cells



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Closure of a road to through-movement of motorised vehicles. This can be achieved by turning restrictions (forcing drivers to turn or preventing them to do so) or by using fixed barriers (bollards, gates, kerbs), or movable ones (diverters, planters)

The closures can be at a junction or between junctions. The measure is usually applied in residential areas, to prevent motorised vehicles from using quiet roads as shortcuts to avoid congestion in major roads. It may be applied in city centres

Point closures can be applied systematically within an area to create traffic cells, i.e. sub-areas bounded by traffic restrictions. This prevents the movement of vehicles through cells. Residents can still access the road in both directions.

Cyclists are often exempt (a practice known as filtered permeability) and can pass through the gaps between barriers, wide enough for cyclists to pass. Distribution vehicles may be exempt but can only pass through if barriers are movable or depressible.

Point closures often attract opposition from car users and some residents and businesses because of trip delays and the need to use busier roads. However, in some cases, residents/businesses may pass through by deactivating depressible bollards.

EXAMPLES

Some parts of Barcelona are being reorganised as 'superilles' (superblocks), with a size of around 400m². Motorised traffic is only allowed around, not inside, the superblocks.

Point closures are also common in many cities in the Netherlands, in some cases covering a large part of the city centres, but also in residential areas.

Point closures are becoming more common in the USA (e.g. Seattle, Portland), as part of Neighbourhood Greenways initiative. Speed humps and traffic diverters discourage/prevent through-movement.

EVIDENCE

A program to close many roads to through traffic of private cars in Cambridge (UK) reduced traffic levels (8.4% in the first 4 years, a further 16% in the next 6 years). The share of cycle trips increased.

Melia S. (2015) Urban Transport Without the Hot Air Volume 1. UIT Cambridge. Chapter 14.

Point-closures in Vitoria-Gasteiz (Spain) led to reductions in traffic and air pollution (7% less PM10). Public acceptance of the scheme rose after implementation.

Civitas Modern (2013) Superblocks concept for access restriction - final evaluation

The Barcelona Superblock scheme could prevent an estimated 700 premature deaths each year, through reduction of air pollution, noise, and heat, and increase of green space and physical activity.

Mueller et al 2020 Changing the urban design of cities for health: the superblock model. Environment International 134: 105132.

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Area-wide traffic restriction



Lisbon, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Access to all streets in an area restricted to all vehicles (including bicycles) or to all motorised vehicles. The restriction can be enforced with physical structures (e.g. bollards) or simply with signs

The restriction may apply only at some times of day, some days of the week, or in special occasions. Movable or depressible bollards can be used to allow the access of vehicles when restrictions do not apply.

This policy is usually applied in shopping/leisure areas in city centres. But it can also be applied in new residential areas (known as car-free developments). These areas have limited car parking areas at their edges.

Traffic restrictions do not usually apply to local residents, service and emergency vehicles, construction vehicles, and (at some hours) to delivery vehicles. Buses and taxis may also be exempted. Tram lines may pass through the restricted area.

There is usually some opposition from residents or businesses complaining about restricted car access. Those in surrounding areas also complain of increased congestion, pollution, noise, and parked cars.

EXAMPLES

Several cities in Europe have restricted car traffic in central areas. In most cases, these areas are commercial/leisure. However, in Groningen (Netherlands) the traffic-free city centre has a large resident population

In Pontevedra (Spain) car traffic was banned from a large area, comprising almost half of the city's streets.

Car traffic was restricted in a few new residential developments in Amsterdam and Copenhagen. The provision for residents' car parking is limited and at the edges of the neighbourhood.

EVIDENCE

A study in Berlin found that 60% of respondents are willing to accept a car-free city centre without any further changes. The proportion increases if there were improvements in bus and cycling infrastructure

Gundlach et al 2018 Investigating people's preferences for car-free city centers: a discrete choice experiment. Transportation Research D 63, 677-688

Area-wide traffic restriction may lead to a redistribution of car traffic across the whole city, also re-distributing levels of exposure to the negative environmental effects of car travel

Anciaes 2015 Area-wide traffic restriction in Lisbon City Center: opportunity lost or mistake avoided? Transportation Research Procedia 8, 237-246.

An evaluation of car-free residential areas in Vienna found a positive environmental effect: residents are responsible for fewer transport emissions

Ornetzeder 2008 The environmental effect of car-free housing: a case in Vienna. Ecological Economics 65, 516-530.

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Regular road closure



Santiago, Chile ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Access to a road or to all roads in an area restricted on a regular basis (certain days of week or seasons). The restrictions usually apply to all motorised vehicles, but can also apply to cyclists or micromobility vehicles.

One example (known as open streets, car-free days, or *ciclovias*) is the restriction of traffic in major roads on weekend days. The roads can be used by cyclists, pedestrians, other non-motorised modes, and for street activities.

Another example is play streets, i.e. restriction of traffic after school hours or on weekends or holidays. Equipment for play and exercise may be provided. The restriction is usually applied in quiet residential streets or near schools.

Some roads may also be closed one day of the week for markets, sport events, performances, extensions of on-street business areas (e.g. outdoor cafes) or other regular street activities.

The restrictions are enforced with movable barriers. The restriction can be a pilot for regular closures. Restrictions may not apply to local residents and emergency vehicles, and (at some hours) to service/delivery vehicles.

EXAMPLES

Ciclovias were introduced in Bogota in the 1980s and are popular in many Latin American cities. As of 2015, there were ciclovias in 496 cities in 27 countries.

Play Streets have been implemented in Belgium cities since 1998, during summer school holidays. They have also become popular in some cities in the UK and USA.

London has many street markets, usually in quiet roads. Some are held daily, others weekly. Motorised traffic is restricted during market days/hours.

EVIDENCE

Participants in Ciclovias in Bogota have higher likelihood of meeting physical activity requirements and feel safer from traffic and crime than non-participants.

Torres et al 2013 The Ciclovía and Cicloruta programs: promising interventions to promote physical activity and social capital in Bogotá. Am. Public Health 103, e23-30

Another study of Ciclovias in North and Latin American cities found that the physical activity benefits far outweigh the costs of the initiatives

Montes et al 2012 Do health benefits outweigh the costs of mass recreational programs? An economic analysis of four Ciclovía programs. Journal of Urban Health 89, 153-170.

A literature review of 6 studies on the effects of play streets found that the initiative increases sense of community and increase physical activity.

Meyer et al 2019 Systematic review of how Play Streets impact opportunities for active play, physical activity, neighborhoods, and communities. BMC Public Health 19: 335.

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Vehicle-based restrictions



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Restriction of access to a road or area to vehicles with certain weight, height, width, age, or emissions. Restricted vehicles are not completely barred but are fined if entering the restricted roads/areas. Access may be permitted for a few.

Large or wide vehicles are often banned from roads or road sections deemed too fragile because of the type of pavement, level (bridges or tunnels), or land use (near hospitals or schools, inside residential areas, old towns).

Environmental zones (also known as low emissions zones) ban vehicles that do not meet emission standards. This excludes many heavy goods vehicles and older cars, although some may be exempted. The regulation may not apply to public transport vehicles.

Zero-emission zones have stricter restrictions regarding the allowed vehicles. They may allow only non-motorised vehicles, electric and hydrogen fuel vehicles. The restriction may also apply to public transport vehicles.

Environmental zones can cover a few streets only, some neighbourhoods, or larger areas (e.g. city centres). Whole cities can ban more pollutant vehicles, or allow them at some times or days only.

EXAMPLES

There are more than 250 low-emission zones in Europe. As an example, the Berlin Environmental Zone, implemented in 2008, allows only certified vehicles, that meet minimum emission standards

There are few example of low-emission zones outside Europe. Beijing implemented one in 2017, banning heavy goods vehicles that fall below emission standards from entering the city.

Restrictions to trucks in some types of road are widespread. For example, trucks have been banned from all elevated roads in Shanghai. In 2020, the restriction was for smaller trucks at night-time.

EVIDENCE

The low-emission zone in Amsterdam reduced concentrations of NO₂, NO_x, PM₁₀ and other pollutants.

Panteliadis et al 2014 Implementation of a low emission zone and evaluation of effects on air quality by long-term monitoring. Atmospheric Environment, 86, 113-119.

However, a review of the environmental impact of low-emission zones in 17 German cities found a significant but small reduction of NO₂, NO, and NO_x concentrations.

Morfeld et al 2014 Effectiveness of low emission zones: large scale analysis of changes in environmental NO₂, NO and NO_x concentrations in 17 German Cities. PLoS ONE 9: e102999

Low emission zones reduce the number of firms making urban deliveries - but this has compelled the industry to improve their efficiency (e.g. using new vehicles)

Dablanc and Montanon 2015 Impacts of environmental access restrictions on freight delivery activities: example of low emissions zones in Europe. Transportation Research Record 2478, 12-18.

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License plate number traffic restrictions

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Also known as road space rationing, Restriction to the use of roads by vehicles with license plates numbers with certain numbers on certain days of the week. The measure can apply for whole cities, or some areas.

The restriction is based on the last digit of the license plate number. Vehicles can be banned one or more days a week. The system is enforced by cameras that recognize license plates. Fines are applied to drivers circulating on banned days.

The measure only applies on weekdays and during the day (or only at peak times). The measure may not apply to buses, taxis, delivery vehicles, electric vehicles, motorcycles, and vehicles driven by drivers with disabilities.

The measure can be applied seasonally (when pollution is worse) or temporarily, when pollution levels become critical. The restricted vehicles, days, and hours, can also be altered depending on the evolution of car ownership and use.

To reduce the impact on the economy and on one-car households, the measure requires complementary measures to improve car alternatives, for example free, cheaper, or more available public transport.

EXAMPLES

License plate number restrictions have been applied in many capital cities (Athens, Rome, Paris, Mexico City, San Jose, Bogota, Quito, Santiago, Beijing, Jakarta)

The first example of was the Daktylios scheme in Athens (Greece). It started in 1982 and applies in the city centre. Vehicles with odd/even plate number are only allowed on odd/even days of the month.

The Beijing scheme was introduced in 2008. Vehicles cannot use the roads one day a week, during day time, based on the end number of the license plate. The banned days rotate every three months.

EVIDENCE

In Mexico City, there was no evidence of improvement in air quality. Furthermore, there was an increase in number of vehicles in circulating and in proportion of high-emissions vehicles.

Davis 2008 The effect of driving restrictions on air quality in Mexico City. Journal of Political Economy 116, 38-81.

In Tianjing, half of previous car users shift to public transport on restricted days, but 37% of previous public transport users shift to car on restricted days.

Jia et al 2017 Commuters' acceptance of and behavior reactions to license plate restriction policy: a case study of Tianjin, China. Transportation Research D 52, 428-440.

Beijing's license plate restrictions increased demand for housing near stations and the city centre. These areas become wealthier, so public transport accessibility decreased for lower-income households.

Jerch et al 2019 Road rationing policies and housing markets. DETU Working Papers 2004.

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Dynamic traffic restriction

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Restriction to the movement of vehicles in some roads or areas when demand for roadspace increases, or in case of events, both regular (e.g. schools close) or unexpected (collisions, storms). At other times, vehicles are allowed to use the road/areas.

The restriction can be activated dynamically based on data on the number of vehicles in downstream traffic (in the case of a road) or on the total number of vehicles that have entered the restricted area.

Electronic signs indicate if the road/area is open to traffic. Enforcement (with cameras) is needed to ensure compliance. This can be achieved with movable physical barriers (e.g. depressible bollards) or with cameras.

The transitions from/to the restricted period can cause confusion for drivers, unexpected turning movements, and conflicts with other vehicles. A time lag is required before the restriction starts to be enforced.

The restriction process may not operate at night-time, when access is always allowed. It may also apply only to some types of vehicles (e.g. maximum number of heavy vehicles). Buses and cyclists are exempted.

EXAMPLES

Some motorways in the UK (known as Smart Motorways) have dynamic lane closure systems, redirecting drivers away from some lanes affected by congestion or collisions.

Other common examples are road closure in response to weather events (e.g. in mountainous areas, or prone to flooding) and to the number of vehicles entering a zone (e.g. in roads crossing natural parks).

There are no examples of dynamic traffic restriction on an urban road or area responding to traffic levels.

EVIDENCE

There is no evidence on dynamic traffic restriction responding to traffic levels. Insights can be derived from studies on variable message signs alerting drivers of congestion or closed routes (not as a result of a traffic restriction measure)

A review found that signs alerting drivers of congestion or road closures are generally effective in influencing drivers' route choice decisions.

Hagani et al 2013 Evaluation of dynamic message signs and their potential impact on traffic flow. Maryland Department of Transportation, Report SP109B4C

A test of drivers' reaction to signs displayed road closure and recommendations for alternative routes found they reduced speed and caused braking manoeuvres.

Erke et al 2007 Effects of route guidance variable message signs (VMS) on driver behaviour. Transportation Research F, 447-457.

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Road pricing



Portugal ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Also known as toll road, tollway, or turnpike. Charge for motorised vehicles using a road section. The charges can be fixed or variable, applying at certain times or days only; to the whole road or to some lanes only; to all vehicles or only some types.

In urban areas, toll roads are mainly restricted-access (e.g. motorways). However, charges also apply to crossing bridges and tunnels. In some cases, a toll is collected only on one direction.

The charge can be fixed for defined road sections or vary with the distance travelled. It varies with vehicle type. Goods vehicles are charged more than private cars. Public transport vehicles are usually exempted. Taxis may also be exempted.

The objective is to manage demand, redirecting trips to off-peak times, less congested roads, car-pooling, or other modes, reducing congestion and environmental impacts. The system generates revenue but the implementation can be expensive.

Many systems are automated: drivers do not stop and charges are collected electronically. This method saves space for payment booths and prevents bottlenecks and can be used to vary prices according to demand. However, it has privacy issues.

EXAMPLES

Toll roads have existed since Ancient times, applied to different types of vehicles. The first modern toll road, charging cars, opened in 1924 in Milan.

Singapore (in 1975) and several European cities (since the 1990s) adopted a system where charges apply to the use of all roads within an area (cordon/area-wide charging)

Charges to use bridges are common. A well-known example is the George Washington Bridge in New York. Toll bridges are often used to recover the investment. After some time, tolls may be removed.

EVIDENCE

Road charging can increase inequalities, if they impact low-income households dependent on car use, but this depends on how the revenue of the system is used.

Levinson 2010 Equity effects of road pricing: a review. Transport Reviews 30, 33-57.

A review of studies of environmental impacts of road pricing schemes found a consistent positive impact in terms of reduced CO2 emissions.

Cavallaro et al 2018 The potential of road pricing schemes to reduce carbon emissions. Transport Policy 67, 85-92.

Road pricing can lead to changes in travel behaviour, increasing trips in unpriced times and in priced roads. The net effect on traffic volume depends on the availability of public transport.

Gibson and Carnovale 2015 The effects of road pricing on driver behavior and air pollution. Journal of Urban Economics 89, 62-73.

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Cordon and area-wide charges

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Cordon charges are charges for motorised vehicles entering an area, usually the city centre. The charges can be fixed or variable, applying at certain times of day, or some days only, to all vehicles or only to some types.

Area-wide charges are applied on a per-distance basis within an area, and not just to enter the area. Buses, taxis, motorcycles, emergency or alternative fuel vehicles, residents, and disabled drivers may be exempted.

The objective is to manage demand, redirecting trips to off-peak times, less congested roads, car-pooling, or other modes, reducing congestion and environmental impacts. The system generates revenue but the implementation can be expensive.

Many systems are automated: drivers do not stop and charges are collected electronically. This method saves space for payment booths and prevents bottlenecks and can be used to vary prices according to demand. However, it has privacy issues.

The system may be based on concentric circles. There have been advances in GPS-based systems that allow drivers to pay according to the distance travelled, bringing the charge in line with road use.

EXAMPLES

The first example was the Singapore Area Licensing Scheme, in 1975. A paid license was required to use roads in a part of the city.

Later examples include several Norwegian cities (Bergen 1986, Oslo 1990, Trondheim 1991), Rome (2001), London (2003), Stockholm (2006), Milan (2008), Gothenburg (2013).

Cordon charging often fails to gain political and public acceptance. It has been rejected in Hong Kong, New York, Manchester, Birmingham (UK) and Edinburgh.

EVIDENCE

Cordon/area-wide charging leads to immediate decreases in traffic and congestion but these may rebound. They may not lead to permanent changes in car use.

Metz 2018 Tackling urban traffic congestion: The experience of London, Stockholm and Singapore. Case Studies on Transport Policy 6, 494-498.

Evaluation of the Stockholm system found it has a net benefit, comparing the benefits of the travel time and cost reduction and the investment and operating costs.

Eliasson 2009 A cost benefit analysis of the Stockholm congestion charging system. Transportation Research Part A: Policy and Practice 43, 468-480.

Evaluation of the Milan system also found a net benefit, comparing reduced congestion and pollution benefits, and implementation costs.

Rotaris et al 2010 The urban road pricing scheme to curb pollution in Milan, Italy: description, impacts and preliminary cost benefit analysis assessment. Transportation Research A 44, 359-375.

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Dynamic road pricing

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Charge for using a road or entering an area, with the rate varying according to demand (i.e. the number of vehicles using the road). The rate is updated every few minutes or less regularly. Some periods may be free (by design or because of low demand).

Dynamic road pricing is more effective in the management of demand for road space than fixed pricing because it has the potential to shift some trips to off-peak times, less congested roads, car-pooling, or to other modes.

Many systems are automated: drivers do not stop and charges are collected electronically. This method saves space for payment booths and prevents bottlenecks and can be used to vary prices according to demand. However, it has privacy issues.

There have been advances in GPS-based systems that allow drivers to pay according to the distance travelled, bringing the charge in line with road use.

Dynamic road charging can increase social inequalities, if it impacts low-income households who lack alternatives to travelling in the more expensive periods (if they lack reliable public transport and have fixed work schedules).

EXAMPLES

The San Diego I-15 high-occupancy toll lanes scheme opened in 1998 was the first dynamic pricing scheme. The toll varies every 6 minutes, depending on demand.

The tolls in the 91 Express Lanes in California vary per hour and day of the week, with the values set every 3 months.

There are few examples outside the USA. The Jerusalem-Tel Aviv Highway 1 in Israel has Fast Lanes. The toll value is shown at the entrances. If the average speed is below 70km/h, the fee is not charged.

EVIDENCE

A study of the San Diego I-15 toll lanes scheme found that considerable travel time savings, and travel time reliability can be achieved by drivers who use those lanes

Supernak et al 2003 Dynamic value pricing on I-15 in San Diego: impact on travel time and its reliability. Transportation Research Record 1839, 45-54.

A study in Texas (USA) found that the benefits of dynamic pricing (reduction of travel time, vehicle operating and ownership cost, and emissions) exceed the costs of implementation

Burris and Sullivan 2006 Benefit-cost analysis of variable pricing projects: QuickRide HOT Lanes. Journal of Transportation Engineering 132, 183-190.

Dynamic road pricing has a moderate impact on demand. A study in Seattle found that a 10% increase in the toll decreases demand by 1.6%

Brent and Gross 2017 Dynamic road pricing and the value of time and reliability. Journal of Regional Science 58, 330-349.

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High-Occupancy Toll lanes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Usually known as HOT lanes. Lanes for the exclusive use of vehicles with more than one occupant (at least 2 or 3 occupants). Single-occupancy vehicles can use the lanes but have to pay a toll. In quiet periods, single-occupancy vehicles may be allowed.

The toll is collected through electronic collection systems and can vary by time of day or the level of demand at each moment. HOT lanes may be free for all vehicles in off-peak periods. In some cases, vans and truck are not allowed to use HOT lanes.

HOT lanes may be located in the nearside or offside of the road carriageway, on in the median strip. They may be reversible, changing direction during the day (following commuting patterns), and contraflow (in an otherwise one-way road).

HOT lanes are usually in cities and aim at reducing peak-time congestion for commuters. They mitigate two problems of High-Occupancy Vehicle (HOV) Lanes: underuse and lack of public support. Unlike standard toll roads, they offer drivers a choice.

As with other forms of road charging, HOT lanes have equity issues because they benefit car users who have greater ability to pay. HOT lanes are also more expensive to construct and operate than HOV lanes.

EXAMPLES

The first High-Occupancy Toll lane scheme was the 91 Express Lanes in California, opening in 1995, extending over 18km in the median strip of a longer motorway.

Similar schemes have followed in other US cities, especially in California and Texas. There are some examples in Canada. The schemes are usually limited to a few roads or road sections.

The Bay Area Express Lanes in San Francisco is a network of High-Occupancy Toll lanes. The network is planned to cover 600 miles of roads by 2035.

EVIDENCE

A review of HOT lane schemes in the USA found that the majority led to a reduction in carpooling.

Burris et al 2014 The impact of HOT lanes on carpools. Research in Transportation Economics 44, 43-51.

A study in Toronto found that users are willing to pay for the travel time savings provided by using HOT lanes, with the value depending on the urgency of the trip.

Finkleman et al 2011 Empirical evidence from the Greater Toronto Area on the acceptability and impacts of HOT lanes. Transport Policy 18, 814-824.

A study of a conversion of a High-Occupancy Vehicle (HOV) lane to a HOT lane in the USA found that it led to a reduction of 5.3% in the number of traffic collisions.

Cao et al 2012 Safety benefits of converting HOV lanes to HOT lanes: case study of the I-394 MnPass. ITE Journal 82, 32-37.

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Prohibition of overtaking



Portugal ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Ban of vehicles passing others travelling in the same direction. The ban may apply to some vehicles only (e.g. overtaking by or of trucks). It may apply to overtaking of small vehicles (e.g. motorcycles, bicycles) travelling in the same lane.

The measure applies to roads with a single lane per direction. It may also apply in roads with more than one lane, as a restriction to the lane that can be used for overtaking, or to movements across lanes to overtake.

In single-lane roads, overtaking bans reduce the conflicts with oncoming traffic, reducing collision risk and delays. This measure reduces the unpredictability of traffic movements in each lane, helping pedestrians to cross the road.

This measure may be achieved by changes to the road design, narrowing the road carriageway, reducing the number of lanes (removing passing lanes) or narrowing lanes so that overtaking is difficult. Kerbed median strips also achieve the same effect.

This measure is required in narrow roads, and roads with poor sightlines (e.g. with curves or gradients). It is also useful in roads with many cyclists and pedestrians. In roads with heavy vehicles it can lead to car driver frustration.

EXAMPLES

Netherlands has banned overtaking in most single-lane primary roads in the country, as a part of the Sustainable Safety programme in the early 1990s.

Several countries (France, Spain, Germany, Belgium, Portugal, UK, Ireland) have introduced regulations stipulating that drivers need to keep a minimum distance (1.5m) when overtaking cyclists.

Overtaking cyclists is usually banned in cycle streets (road designated for cyclists but where cars are allowed), common in the Netherlands.

EVIDENCE

In a study in the US, no passing zones were found not to be significantly related with injury severity of traffic collisions in urban areas and positively related in rural areas (due to non-compliance)

Wu et al 2016 Analysis of driver injury severity in single-vehicle crashes on rural and urban roadways. Accident Analysis and Prevention 94, 35-45.

Overtaking manoeuvres were identified in a literature review as one of the main causes of collisions between bicycles and motorised vehicles (both cars and buses).

Prati et al 2017 Factors contributing to bicycle-motorised vehicle collisions: a systematic literature review. Transport reviews 38, 184-208.

Analysis of car-bicycle collision data in New Zealand found that collisions caused by cars overtaking bicycles were infrequent but "extraordinarily severe" - accounting for 40% of fatalities.

Atkinson and Hurst 1983 Collisions between cyclists and motorists in New Zealand. Accident Analysis and Prevention 15, 137-151.

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Reduce speed limit



Sydney, Australia ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Reduction of the speed limit for motorised vehicles in specific roads or all roads of the same category in a given area. The reduction can apply to some times of the day only and may differ by type of vehicle.

Guidance of suitable speed limits varies with country and city. In built-up areas, speed limits should be 40km/h or lower, but even lower in lanes shared with cyclists (30 km/h or lower) or with pedestrians (15 km/h or lower).

The speed limit should consider the volumes of vehicles and pedestrians and the frequency of junctions and pedestrian crossings. The aim is not only to reduce collision risk but also air pollution and noise.

The measure may not reduce actual speeds if drivers do not comply. It requires effective enforcement (with cameras) and some changes to road design (lane narrowing, speed humps, footway extensions, pavements with different colours or textures).

Speed limits are displayed with signs. If using electronic displays, the speed limit can change regularly according to time of day or automatically with road conditions).

EXAMPLES

Speed limits were reduced in Barcelona's motorways in 2008, from 120km/h and 100 km/h to 80 km/h. The measure was reverted in 2010.

Speed limits were reduced from 90km/h to 70km/h on the main arterial roads in Sao Paulo and from 60km/h to 50km/h in other arterial roads. However, this measure was later reverted.

There is a plan to reduce speed limits in most streets in Paris to 30km/h, with only a few roads with a 50km/h limit.

EVIDENCE

A review showed that the reduction in average speeds that follows a reduction of urban speed limits has a low impact on travel time, which is affected by road conditions and design and delays at intersections.

Archer et al 2008 The impact of lowered speed limits in urban and metropolitan areas. Monash University Accident Research Centre Technical Report.

The reduction of the speed limit in Sao Paulo reduced collisions by 21.7%. Estimated benefits were 1.32 higher than costs and accrued mostly to low-income pedestrians and motorcyclists.

Ang et al 2020 Should congested cities reduce their speed limits? Evidence from São Paulo, Brazil. Journal of Public Economics 184: 104155.

Reducing traffic speed decreases the barrier effect of the road for pedestrians (even when traffic volumes are high) and its effects on walking behaviour and wellbeing.

Anciaes et al 2019 Perceptions of road traffic conditions along with their reported impacts on walking are associated with wellbeing. Travel Behaviour and Society. 15, 88-101.

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Differentiated speed limit per lane

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Different minimum or maximum speed limits in different lanes of a road, in the same direction. One lane may be designated as passing lane, with a higher speed limit. Speed limits may change dynamically according to demand for space in each lane.

Speed limits per lane allows for the road to be shared between motorised vehicles and cyclists, without the need to build segregated lanes for cyclists. A low maximum speed limit can be set for the lane used by cyclists.

Differentiated speed limits per lane also allow for the creation of lanes for slower vehicles (e.g. Heavy Goods Vehicles), decreasing delays for other vehicles, and risky overtaking manoeuvres.

Drivers may be confused and do not keep to the required speed in their lanes. They may also be more prone to change lanes. This may increase or decrease conflicts and delays, depending on traffic conditions.

This measure would involve either increasing speed limit in some lanes or decreasing it in others, compared with the current situation. Enforcement of this system is a challenge - it may require multiple cameras.

EXAMPLES

In Italy, some motorways have minimum speed limits per lane, with higher speed limit lanes restricted to heavy vehicles. In the USA, high-occupancy lanes have higher maximum speed limits.

Around the world, multi-lane roads with designated passing lanes already have a minimum implicit speed (speed higher than in other lanes, at each moment).

Differentiated speed limits have not been used on non-restricted access roads and streets in urban areas.

EVIDENCE

A study in California found that differentiated speed limits per lane reduced average speed and traffic flow and increased lane change manoeuvres.

Wingerd 1967 The feasibility of minimum speed limits by lane on multiple lane highways. California Division of Highways HPR, C-3-10

A driving simulator experiment of differentiated maximum and minimum speed limits per lane found this reduced the drivers' propensity for change lanes and the duration of those changes.

Shia and Liu 2019 Impacts of differentiated per-lane speed limit on lane changing behaviour: a driving simulator-based study. Transportation Research F 60, 93-104.

In a survey study in the USA, truck drivers disagreed with differentiated maximum speed limits (lower in a lane for trucks) and did not find that it increased safety.

Wolshon et al 2009 Trucker perceptions of lane restriction and differential speed limit policies on freeways. Journal of Transportation Safety and Security 1, 101-120.

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Dynamic speed limit

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Also known as variable speed limit. Speed limit for motorised vehicles that varies, on the same road, according to road conditions. The limit is displayed on electronic signs and is updated based on information from cameras and sensors.

Dynamic speed limits reduce speed limits from the default maximum to account for conditions that make the road more dangerous, including collisions, roadworks, surface damage, and weather (fog, rain, snow, ice)

Dynamic speed limits can also adjust speed limits to the number of vehicles using the road or the type of vehicles (for example, reducing the limit if there are many slower vehicles in the traffic, e.g. goods vehicles, buses).

Enforcement requires further monitoring and data collection. The transitions can cause conflicts with vehicles ahead, behind, and in other lanes. A lag is required before enforcement of the new speed limit starts.

This measure is usually applied in motorways and other roads dominated by motorised vehicles, but can apply to streets in city centres, and consider the number of pedestrians and bicycles using the road, and special times of day (e.g. when schools close).

EXAMPLES

Variable speed limits were introduced in the early 2000s in motorways in the UK, Germany, and the Netherlands.

Several motorways in the UK (known as Smart Motorways) have variable speed limits (in some cases, combined with dynamic lanes) - but they do not cross built-up areas.

A variable speed limit was introduced in Barcelona's motorways in 2009.

EVIDENCE

Variable speed limits in Barcelona's motorways reduced NOx and PM10 levels. In comparison, the reduction of speed limits from 120 or 100km/h to 80km/h had no impact.

Bel et al 2015 The environmental effects of changing speed limits: a quantile regression approach. Transportation Research D 36, 76-85.

An appraisal of a proposed variable speed limit in a section of a motorway in the USA estimated a benefit (in terms of reduced collision costs) 3.25 higher than implementation costs.

Wilkie 1998 Variable speed limit systems on urban freeways: review and recommendations. Proceedings of the 8th ITS Annual Meeting and Exposition.

Driver compliance is positively related to the safety impacts of variable speed limits and negatively related to travel time.

Hellinga and Mandelzys 2011 Impact of driver compliance on the safety and operational impacts of freeway variable speed limit systems. Journal of Transportation Engineering 137, 260-268.

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Low speed zones



London, UK ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (restrictions)

DESCRIPTION

Also known as slow zones or home zones. Areas with low traffic speed limits (15-30km/h) and designs to reduce speeds. In some cases, drivers are legally required to yield to cyclists and pedestrians throughout the area. Car parking may be banned.

They are usually in residential areas, but can be in areas with high volumes of pedestrians and cyclists, such as shopping streets, university campuses, and near schools, markets, and parks. Traffic is usually two-way, with no priorities at junctions.

These zones should provide space/facilities for walking, social activities and children playing (e.g., seating, play equipment), as well as cycle parking and green areas. The surface is usually level, with no kerbs, so adequate drainage is required.

The transition to low speed zones can be identified simply with signs or with gateway treatments, including a narrowed or raised carriageway, and changes in the pavement material, texture, or colour.

Low-speed zones include measures to induce drivers to drive slowly, including horizontal and vertical deflection at regular intervals. Enforcement is sometimes required to prevent high speeds.

EXAMPLES

Low speeds were introduced in the Netherlands in the 1960s (Woonerf - Home zones) and are very common nowadays. They are shared spaces with a low speed limit of 15km/h

Other European examples exist. Home Zones were introduced in the UK in 2006 with a 20mph (32km/h) limit. Encounter Zones were introduced in Switzerland in 2002 with a 20km/h limit.

Some Asian countries (Japan, South Korea, Singapore) have created Silver Zones in areas used by elderly pedestrians, with 30km/h speed limits.

EVIDENCE

The introduction of 20 mph zones in London led to a 42% reduction in road casualties, with a greater reduction among children, and no evidence of increases in the areas adjacent to 20 mph zones.

Grundy et al 2009 Effect of 20 mph traffic speed zones on road injuries in London, 1986-2006: controlled interrupted time series analysis. British Medical Journal 339:b4469

A review of seven home zones in the UK found that they were used by children intensively. However, adults only spent time on the streets when accompanying children

Biddulph 2012 Radical streets? The impact of innovative street designs on liveability and activity in residential areas. Urban Design International 17, 178-205.

Residents use streets in home zones for longer periods and engage in more activities, compared with streets that only have traffic calming measures

Biddulph 2012 Street design and street use: comparing traffic calmed and home zone streets. Journal of Urban Design 17, 213-232.

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PART 11

Measures aimed at motorised vehicles (at junctions)

Remove slip lanes



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Removal of lanes that are used by vehicles turning at junctions without entering the junction. This reduces conflicts between pedestrians crossing and vehicles turning, while also reducing the junction radius, reducing the speed of turning vehicles.

The space released can be used for traffic lanes or to extend the footway, providing space for pedestrians waiting to cross, street furniture, or green areas. In this case, barriers can be used to prevent encroachment from vehicles turning.

This measure reduces the crossing distance for pedestrians and allows for the alignment of crossing facilities with footways, reducing detours. It also increases mutual visibility between drivers and pedestrians.

The removal of slip lanes also reduces the risks associated with conflicting movements of cyclists moving forward and vehicles turning, especially when cyclists are less visible when using segregated facilities.

However, the measure increases delays at junctions. It also impacts on the swept paths of vehicles. Larger vehicles may not be able to turn. A solution is to widen the carriageway or to accept large vehicles occasionally crossing into the opposing lane.

EXAMPLES

Slip lanes are often removed due to pedestrian safety concerns. Over a quarter of slip lanes have been removed in the central part of Auckland (New Zealand) in 2012-2015.

Slip lanes have been removed in large US cities, often assigning space to pedestrians. In the junction between 23rd Street and South Street in Philadelphia, a slip lane was turned into a pedestrian plaza in 2014.

In Capitol Hill, Seattle, a slip lane was removed to create a new plaza, with a design chosen by the public, with an artistic design.

EVIDENCE

In a study of pedestrian collisions in Melbourne, slip lanes accounted for a less than proportional number of collisions with turning vehicles, compared with other designs.

O'Brien et al 2012 Pedestrian safety at slip lanes and alternative turn lane treatments. Transportation Research Record 2299, 110-120.

A grid street network with smaller intersections would increase road capacity both for pedestrians and motorised vehicles, compared with slip lanes combined with pedestrian refuges.

Bern and Marshall 2013 Capacity analysis of pedestrian treatments at large arterial intersections and comparison with a lane-equivalent, small intersection gridded network. Journal of Urban Planning and Development 139, 241-249.

A literature review found that slip lanes tend to reduce delays for vehicles and collisions between vehicles and have little effect in vehicle-pedestrian collisions.

Potts et al 2006 Synthesis on right-turn deceleration lanes on urban and suburban arterials. NCHRP Project 3-72.

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Corner extensions of footway



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Also known as neckdowns and narrowed junctions. Extensions of footways to reduce the radii of junctions for vehicles turning, reducing speeds. Space is taken from the carriageway by removing lanes (including slip lanes) or reducing lane widths.

The space released can be used for pedestrians waiting to cross (reducing conflicts with pedestrians walking), or to install street furniture or green areas. Kerbs, bollards, or movable structures can be used to prevent encroachment from vehicles turning.

This measure reduces crossing distance for pedestrians and allows for the alignment of crossings with footways, reducing detours. It also increases mutual visibility between drivers and pedestrians and discourages illegal car parking on junctions.

Corner extensions are also useful to reduce the risks associated with conflicting movements of cyclists moving forward and vehicles turning, especially when cyclists are less visible when using segregated facilities

However, this measure impacts on the swept paths of motorised vehicles. Larger vehicles may not be able to turn. A solution is to widen the carriageway or to accept large vehicles occasionally crossing into the opposing lane.

EXAMPLES

New York has a policy of building corner extensions since 1968, to improve safety and encourage people to use shopping streets.

Some Asian countries (Japan, South Korea, Singapore) have created Silver Zones in areas used by elderly pedestrians. Corner extensions are one of the main design features of streets in these zones.

Octavia Boulevard, a street created from a reconverted urban motorway in 2002 in San Francisco, was enhanced in 2015 with treatments at junctions, including corner footway extensions.

EVIDENCE

A study in the US found that footway extensions at junctions increase the probability that drivers stop for pedestrians - explained by increased visibility of pedestrians.

Johnson 2005 Pedestrian safety impacts of curb extensions: a case study. Report for Oregon Department of Transportation SPR304-321.

Evaluation of footway extensions at corners in New York found some reduction of add collisions and vehicle-pedestrian collisions, and their severity. But in some places there was an increase.

King 2000 Calming New York City Intersections. Proceedings of the Urban Street Symposium 1999.

Experiments show that most trucks have problems turning in roads with corner radii less than 18m.

Firestine et al 1989 Operating large trucks on roads with restrictive geometry. Federal Highway Administration Report FHWA-IP-89-025.

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Turning restrictions



Dordrecht, The Netherlands ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Prohibit vehicles to turn in some directions at junctions. This measure can be applied to all motorised vehicles or some types of vehicles only (e.g. heavy goods vehicles). Buses and cyclists may be exempted.

The measure can be applied using traffic signs and signals or with physical barriers (raised median strips, diverters). If buses and cyclists are exempted, turning lanes may be required on the approach to the junction.

Turning restrictions reduce the number of conflicting movement at junctions, especially in complex junctions with many lanes. This is particularly important for the safety of cyclists. U-turns at junctions or mid-block may also be banned.

Turning restrictions are useful in areas with many cyclists and pedestrians. They are also a way to prevent traffic from busy roads from entering minor roads and to enforce one-way traffic or traffic restriction in side roads.

This measure can be complemented with the removal of turn or slip lanes, releasing space for other uses (e.g. small plazas). It also allows for the alignment of pedestrian crossing with the footway.

EXAMPLES

The redesign of Elephant and Castle, a major roundabout in London, in 2015, included several new turning restrictions to reduce the complexity of the traffic circulation.

The Downtown Flushing Mobility and Safety Improvement Project, in New York, in 2012, reorganised junctions (a hotspot of collisions in the area), restricting turning movements.

In most roads in North America and China, vehicles are allowed to turn at junctions on red signals, stopping for pedestrians (the Turn on Red rule). This is banned in the rest of the world.

EVIDENCE

The more complex a junction is, the higher the likelihood of a vehicle-pedestrian collision, when controlling for other road characteristics.

Quistberg et al 2015 Multilevel models for evaluating the risk of pedestrian–motor vehicle collisions at intersections and mid-blocks. Accident Analysis and Prevention 84, 99-111.

Three-way junctions are safer for older pedestrians than 4-way ones. They have been linked with fewer collision risk in a study in the USA.

Kim 2019 The transportation safety of elderly pedestrians: modeling contributing factors to elderly pedestrian collisions. Accident Analysis and Prevention 131, 268-174.

Banning turning on red signals improves safety. the Right Turn on Red rule in the USA is consistently associated with more risk: increase in collisions with pedestrians (60%) and bicycles (100%).

Zador 1984 Right-turn-on-red laws and motor vehicle crashes: a review of the literature. Accident Analysis and Prevention 16, 241-245.

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Uncontrolled junction



USA ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Junction without a traffic light, sign, or roundabout. In three-way junctions, priority is assigned to the vehicle on the main road. In four-way junctions, priority is assigned to the vehicle on right/left side (depending on country regulations).

Uncontrolled junctions are an alternative to traffic signals and roundabouts, in locations with low traffic volumes and speeds. The installation and operation cost is low, compared with signalised junctions.

Uncontrolled junctions are different from all-way stops as priority is assigned to one arm. This can be indicated with signs (a priority sign on the road with priority and a stop or yield sign on the other roads).

These junctions are only suitable where visibility is good, i.e. it is easy to see vehicles on other roads and pedestrians crossing. They are not suitable in complex junctions with many possible movements.

Collision risk at uncontrolled junctions can be reduced by improving visibility at all approaches to the junction, reducing speeds with traffic calming devices or lower speed limits, and enforcement of traffic regulations with cameras.

EXAMPLES

Uncontrolled junctions are a common design in suburban and rural roads with low traffic volumes. But in countries with increased car use (e.g. India), signals are sometimes removed to increase flows

In Europe there is increased interest in removing traffic controls from roads with low traffic in city centres and creating low-speed shared spaces, with uncontrolled junctions.

In Coventry (UK) a signalised junction (Jordan Well/Gosford Street) was removed creating a diagonal-shaped red-coloured shared space. The scheme won the 2014 Urban Transport Design Award.

EVIDENCE

If traffic levels are low, removing signals has benefits. A study in a depopulating area found that 30% of signals could be removed without reducing level of service, while making cost savings.

Schrader and Hummer 2015 As estimate of potential savings from removing traffic signals in a depopulating urban area. Transportation Research Record 20, 286-297.

A study in Philadelphia found that replacing signals by multiway stop signs on one-way streets led to a 24% reduction in the number of vehicle-pedestrian collisions.

Persaud et al 1997 Crash reductions related to traffic signal removal in Philadelphia. Accident Analysis and Prevention 29, 803-810.

Vehicle-pedestrian collision rates at uncontrolled junctions, with yield or stop signs, or no signs, are lower than those of signalised junctions.

Quistberg et al 2015 Multilevel models for evaluating the risk of pedestrian–motor vehicle collisions at intersections and mid-blocks. Accident Analysis and Prevention 84, 99-111.

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All-way stop

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Unsignalised junction where priority is not assigned with signs or markings. All vehicles arriving at the junction have to stop. Priority is assigned to the first vehicle arriving. All-way stops are usually in four-way junctions.

All-way stops are an alternative to traffic signals and roundabouts, in locations with low traffic volumes and speeds. The installation and operation cost is low, compared with signalised junctions.

This design increases driver uncertainty, leading to reduced speed. It can be applied in conjunction with a road geometry and design that encourages low speed, for example a speed table or speed humps at the approach to the junction.

These junctions are preferred where visibility is poor and is safer if traffic from all arms stops. Cyclists may be exempted from stopping if the junction is clear. Pedestrians be assigned priority, even if there are no marked crossing facilities.

They are not suitable for some layouts. For example, drivers tend to perceive the straightest road as the major one, and regard it as the one with priority, processing across the junction without stopping.

EXAMPLES

All-way stops are common in the USA and Canada, in suburban and rural roads with low-traffic. In other countries, all-way stops are mainly used in junctions with a bad collision record.

In 1978, Philadelphia removed 462 traffic signals (mostly converted to all-way stops) after a state ruling banning signals at low-traffic junctions.

In some places, all-way stops can be designed in signalised junctions, with lights blinking red continuously, together with stop signs. Seattle installed 3 of these junctions in 2017.

EVIDENCE

A study of conversions of junctions to all-way stops in the USA found they reduced total collisions (68%), injury collisions (77%) frontal-impact collisions (75%) and “ran-stop-sign” collisions (15%).

Lovell and Haner 1986 The safety effect of conversion to all-way stop control. Transportation Research Record 1068, 103-107.

A study in Canada found installing stop signs in junctions in residential areas reduced injury collisions by 61%-72% and total collisions by 45%-55%.

Sayed et al 2006 Safety evaluation of stop sign in-fill program. Transportation Research Record 1953, 201-210.

All-way stops reduce capacity and increase delay, queue lengths, and emissions, compared to roundabouts.

Vlabos et al 2008 Evaluating the conversion of all-way stop-controlled intersections into roundabouts. Transportation Research Record 2078, 80-89.

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Roundabout



London, UK ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Junctions with a circular central islands around which traffic circulates. Drivers give way to vehicles already circulating. In some cases, or at some times, roundabouts are signalised. Traffic signs are not usually used.

Roundabouts reduce conflict points and give drivers more time to react. However, they require measures to reduce speed at entrances. They are cheaper but occupy more space than signalised junctions. The space can be used with greenery or public art.

Pedestrian crossings are offset from the entrances to the roundabout, deviating pedestrians from desire lines. However, pedestrians have problems perceiving the movement of vehicles when crossing.

Cyclists may not be noticed by drivers entering and leaving the roundabout, especially if not driving slowly. Cyclists can also unexpectedly leave the roundabout in the outside lane of dual carriageway.

Mini-roundabouts are road markings defining a small circle around which drivers circulate. They are suitable in narrower roads with lower speeds, and occupy less space but can still be inconvenient for cyclists and pedestrians

EXAMPLES

Traffic circles, an early version of roundabouts, were introduced in the early 20th century. Entering vehicles had the priority, which lead to congestion and collisions.

Modern roundabouts have been introduced in the 1960s and are currently a feature of cities around the world. There are variants: e.g. British roundabouts differ in design from European ones.

In some places, large roundabouts have been removed. For example, since 2010, the majority of roundabouts in Qatar have been converted to signalised junctions.

EVIDENCE

There is international evidence that roundabouts have lower serious/fatal collisions than other types of junctions. This is due to lower speeds and fewer conflicting movements.

Elvik 2003 Effect on road safety of converting intersections to roundabouts. Transportation Research Record 1847, 1-10.

A study of 91 roundabouts in Belgium found that the conversion of junctions to roundabouts led to a 27% increase in injury collisions and a 41-46% increase in collisions with fatal or serious injuries.

Daniels et al 2008 The effects of roundabouts on traffic safety for bicyclists: an observational study. Accident Analysis and Prevention 40, 518-526.

Roundabouts reduce traffic speeds but also reduce delays, as they facilitate a continuous flow of traffic. As a result, emissions of pollutants are lower.

Mandavilli et al 2008 Environmental impact of modern roundabouts. International Journal of Industrial Ergonomics 38, 135-142.

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Signalised junction



Pristina, Kosovo ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Junction where movements from different directions are controlled by an automated system. Some users (e.g. buses, pedestrians, cyclists) can be prioritised, using advance signal timings, or advance stop areas.

Signalised junctions are more expensive than uncontrolled junctions. They may or may not reduce delays, depending on conditions. Outside peak hours, the signals can be deactivated or the cycle timing can be changed, to reduce delays and costs.

These junctions are more suitable in roads with high traffic volumes, because sightlines can be respected less comprehensively than in other junctions. They are also suitable in roads with many children and older pedestrians and many HGVs in turning flows.

The coordination of traffic signals along a corridor (using signal progression/green waves) can be a strategy to give priority to buses and cyclists and to reduce traffic speeds, if the assumed speeds in the progression are low.

Traffic signals should be located where they are not an obstruction to the movement of pedestrians. Car parking and stopping should be banned near signalised junctions to enhance visibility of all users.

EXAMPLES

Signalization is a widespread measure when traffic volumes start to increase at a junction, or when a junction is identified as a hotspot of collisions.

In many cities, signalised junctions are now centrally controlled using adaptive systems, operating based on information about traffic flows.

Signalised junctions sometimes replace other traffic controls. Since 2010, the majority of roundabouts in Qatar have been converted to signalised junctions

EVIDENCE

In a systematic cost-benefit analysis study, signalization has a benefit-cost ratio of 1.1 (€ 8731 per unit). But depending on the costs of installation/operation, they may become cost-ineffective.

Daniels et al 2019 A systematic cost-benefit analysis of 29 road safety measures. Accident Analysis and Prevention 133: 105292.

A before-after study in Denmark found that conversions from uncontrolled to signalised junctions reduced collisions and injuries (21% and 17%) at 3-leg junctions and 4-leg ones (39% and 33%).

Jensen 2009 Safety effects of intersection signalization: a before-after study. Presented at the 89th Transportation Research Record Annual Meeting.

Vehicle-pedestrian collision rates at signalised junctions are higher than at roundabouts and uncontrolled junctions (with sign or not)

Quistberg et al 2015 Multilevel models for evaluating the risk of pedestrian–motor vehicle collisions at intersections and mid-blocks. Accident Analysis and Prevention 84, 99-111.

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Actuated or adaptive signal control

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (at junctions)

DESCRIPTION

Traffic signals operating based on information from sensors, rather than on a regular sequence of lights. Sensors detect movements in all arms of the junction. The length of green signal depends on traffic volume.

Actuated signal control systems change traffic signals in response to the presence/absence of vehicles approaching a junction leg. Adapted signal control systems change traffic signals in response to number of vehicles.

In adaptive systems, signal timings can be optimized based on a library of options, pre-developed based on historical traffic data. This library needs to be regularly updated. The phases also cannot respond to unexpected conditions.

An alternative is to continuously optimize signal timings, based on traffic conditions at each moment. However, these systems are still based on the number of vehicles, regardless of the number of occupants.

Actuated and adapted signal controls reduce the predictability of the time needed to pass the junction, both for vehicles and pedestrians - the time might be different in each occasion.

EXAMPLES

SCOOT (Split Cycle Offset Optimisation Technique) is an adaptive traffic control used in 350 cities worldwide (as of 2020). It responds to changes in traffic but not as rapidly as to create large fluctuations.

Sydney Coordinated Adaptive Traffic System a system developed in Australia and, as of 2020, used in 1800 cities worldwide (with different names). It combines coordinated actuation and fixed time plans.

UTOPIA (Urban Traffic Optimization by Integrated Automation) is an adaptive system that prioritises public transport. As of 2020, it is used in 50 cities.

EVIDENCE

A study in Muenster (Germany) found that adaptive signal controls could increase traffic flow by 30%, compared with actuated signal control.

Brilon and Wietbolt 2013 Experiences with adaptive signal control in Germany. Transportation Research Record 2356, 9-16.

Simulations showed that an adaptive traffic control system reduces delay under-saturated flow conditions and helps postpone the onset of congestion, but operates like a fixed system once saturation is reached.

Jhaveri et al 2003 SCOOT Adaptive signal control: an evaluation of its effectiveness over a range of congestion intensities. Presented at the 82nd Transportation Research Record Annual Meeting.

A study in Oakland County (Michigan, USA) found that an adaptive traffic control system reduces angle collisions by up to 19%.

Fink et al 2016 Quantifying the impact of adaptive traffic control systems on crash frequency and severity. Journal of Safety Research 57, 1-7.

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PART 12

Measures aimed at motorised vehicles (parking and loading)

Increase number of parking spaces



Chisinau, Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Provision of more on-street car parking spaces, reallocating space from other uses. This can be achieved by narrowing the footway, removing road shoulders or the median strip, removing traffic lanes, or converting the road to one-way traffic.

Adding more parking spaces can contribute to reduce instances of footway parking and double parking. It also reduces cruising for parking, (driving around an area searching for a free parking space), reducing delays and emissions.

Parked cars can act as a buffer between moving vehicles and pedestrians walking along road, but are also a physical and visual obstruction to pedestrians crossing the road.

Parked cars reduce space for installation of cycling infrastructure and can generate accidents with open doors. At the same time, they can also protect cyclists from moving traffic, if the parking strip is between the footway and the traffic lanes.

Parking spaces can be discontinuous, alternated with footway extensions, green areas, cycle parking/share docks, or parklets. This also creates gaps and increases visibility of pedestrians crossing the road.

EXAMPLES

The tendency in Western European cities has been to provide less, rather than more on-street parking.

At the same time, new land developments tend to have growing proportions of on-street parking, as authorities changed from minimum to maximum requirements for the number of off-street parking spaces.

In US cities, on-street parking has been added in many roads as a part of road diet measures that removed traffic lanes. The aim was to attract more people to the road, improving businesses and liveability.

EVIDENCE

A literature review concluded that on-street parking has a positive effect on local businesses and negative effect on road capacity. The effect on traffic safety is mixed.

Biswas et al 2017 Ejects of on-street parking in urban context: a critical review. Transportation in Developing Economies 3:10.

In a study in New York, more on-street parking was related to higher car ownership - even for households that have access to off-street parking.

Guo 2013 Does residential parking supply affect household car ownership? The case of New York City. Journal of Transport Geography 26, 18-28.

A study of 250 road segments in Connecticut (US) found that streets with on-street parking had lower traffic speeds and fewer proportions of severe collisions than streets with off-street parking

Marshall et al 2008 Reassessing on-street parking. Transportation Research Record 2046, 45-52.

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Decrease number of parking spaces



Arequipa, Peru ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Removal of on-street car parking spaces, reallocating space to other uses (wider footway, new general/bus/cycle lanes, green areas, street furniture, cycle parking/hiring, parklets, or footway extensions). The road can be converted to one-way traffic.

Parking spaces can be removed from a whole road section (or one of both sides) or a whole area. They can be removed piecewise, alternated with other uses. Individual spaces can be reconverted to parklets or cycle corrals.

Removing parking spaces may reduce car use. But it may also lead to more illegal parking (double parking or on footways) and to cruising for parking (driving around searching for a parking space), increasing delays, congestion, and emissions.

This measure should be applied alongside the improvement of public transport access and provision on cycle parking. On-street parking can be replaced with off-street parking (on underground or multi-level structures or parking lots further away).

Removal of on-street car parking spaces tends to lead to protest from businesses and protest from residents who do not have access to private parking. Alternatives include keeping parking spaces but restricting use to residents.

EXAMPLES

Champs-Elysees (Paris) was renovated, removing parking lanes in order to widen the footways from 12 to 24 metres. The road now has a pedestrian area of 47,300 m².

In 2016, 136 parking spaces were removed to install a cycle lane in a stretch of Bloor Street, a shopping street in Toronto.

In 2019, more than 100 parking spaces were removed from Wick Street in London to install a new cycle track, trees, and a grassed strip.

EVIDENCE

In a study in New York, less on-street parking was related to lower car ownership - even for households that have access to off-street parking.

Guo 2013 Does residential parking supply affect household car ownership? The case of New York City. Journal of Transport Geography 26, 18-28.

Decreasing on-street parking spaces in residential areas without private parking decreases demand for housing, due to inconvenience and insecurity of parking vehicles far from home.

Borgers et al 2008 Preferences for car-restrained residential areas. Journal of Urban Design 13, 257-267.

The removal of 136 on-street parking spaces to installed a cycle lane in a shopping street in Toronto increased number of customers and customer spending.

Arancibia 2019 Measuring the local economic impacts of replacing on-street parking with bike lanes. Journal of the American Planning Association 85, 463-481.

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Parallel parking spaces



Kuopio, Finland ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Also known as longitudinal parking. Parking spaces parallel to the kerb. Vehicles park aligned along a continuous or discontinuous area, either at the kerbside zone of the carriageway or in the middle strip of the road.

Each space should be 5-6m long and 1.8-2.5m wide, to reduce encroachment on the adjacent footway or carriageway space. Barriers may be installed needed to avoid encroachment.

Parallel parking accommodates fewer vehicles per length of road, but also uses less space than perpendicular or angled parking. It causes less disruption and conflicts with moving vehicles, as drivers' visibility is less restricted when moving out.

Parallel parking spaces may cause conflicts with cyclists and pedestrians, and with moving traffic, when doors are open. A buffer should be added to separate the parking spaces from the traffic lanes, cycle lanes, and the footway.

Parallel parking spaces are suitable in roads with space constraints, road with low parking demand or with many competing demands for roadspace, and roads with high traffic volumes and speeds.

EXAMPLES

Parallel parking is the most common type of on-street parking in central areas of most cities.

Car parking in front of Arsenal Stadium in London was changed from angular to parallel parking in 2012. The space was reallocated as an advisory cycle lane.

There are several examples of conversions from angle to parallel parking in small US towns. In 2018, Franklin (North Carolina) changed parking in the main street after complaints of parked cars disrupting traffic flows.

EVIDENCE

A study in Manchester found that parallel parking causes longer delays than angled parking when drivers enter parking spaces, but shorter delays when vehicles are leaving.

Yousif and Purnawan 1999 On-street parking: effects on traffic congestion. Traffic Engineering and Control 40, 424-427.

A review of North American studies shows that “dooring” incidents next to parallel parking spaces account for 12%-27% of bicycle-vehicle collisions in urban areas, one of the most common types.

Schimek 2018 Bike lanes next to on-street parallel parking. Accident Analysis and Prevention 120, 74-82.

Parallel parking can act as a buffer protecting pedestrians from vehicle pollution, with reductions of 33%-49% in exposure.

Gallagher and McNabola 2011 Optimizing the use of on-street car parking system as a passive control of air pollution exposure in street canyons by large eddy simulation. Atmospheric Environment 45, 1684-1694.

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Perpendicular parking spaces



Oulu, Finland ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Also known as bay parking. Parking spaces perpendicular to the kerb. Vehicle park side to side along an area, usually in the kerbside zone of the carriageway.

Each space should be 4.5-5m long and 2.3-2.5m wide, and be marked on the pavement. Overhanging vehicles can be an obstruction to pedestrians walking along the footway and to cyclists moving along nearside lanes.

Perpendicular parking accommodates more vehicles per length of road, but also uses more space than parallel parking. It also causes more disruption and possible conflicts with moving vehicles, as drivers' visibility is restricted when reversing out.

This solution decreases visibility for pedestrians crossing the road, if the spaces between vehicles are narrow. It also creates with conflicts when vehicles reverse out. It has a stronger impact on the visual environment, more dominated by vehicles.

Perpendicular parking spaces are suitable in wide roads with high parking demand. If there is space, parking can be in the median strip, eliminating the need for reversing movements: drivers can drive in and out of the space by moving forward.

EXAMPLES

Perpendicular parking is common on wide roads and in off-street parking lots.

Conversions from parallel to perpendicular parking usually have the aim of increasing parking supply near shopping areas.

As part of the 13th/Division Street Safety Project, a part of 9th Street in San Francisco was changed from angular to perpendicular parking in 2016.

EVIDENCE

In a survey to French older drivers, perpendicular forward parking was reported as the most frequent manoeuvre at home and the second most frequent elsewhere.

Douissembekov et al 2014 Parking and manoeuvring among older drivers: a survey investigating special needs and difficulties. Transportation Research F 26A, 238-245.

Perpendicular parking reduces speed by 11.27 km/h (more than 8.05 km/h for parallel parking).

Elliot et al 2003 Road design measures to reduce drivers' speed via "psychological" processes: a literature review. Transport Research Laboratory Report TRL 564.

Unlike parallel parking, perpendicular parking does not have a significant effect as a buffer protecting pedestrians from vehicle pollution. It can even increase exposure.

Gallagher and McNabola 2011 Optimizing the use of on-street car parking system as a passive control of air pollution exposure in street canyons by large eddy simulation. Atmospheric Environment 45, 1684-1694.

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Angle parking spaces



Oulu, Finland ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Also known as echelon parking. Parking spaces at angle of 30-60 degrees to the road's footway. Vehicles park side to side along an area, usually on the kerbside zone of the carriageway.

Buffers between vehicles can be narrower than in perpendicular parking, so a higher density of vehicles is possible. The spaces are marked on the pavement. Overhanging vehicles can obstruct pedestrians and cyclists.

Angular parking accommodates more vehicles per length of road, but also uses more space than parallel parking. It also causes more disruption and possible conflicts with moving vehicles, as drivers' visibility is restricted when reversing out.

This solution decreases visibility for pedestrians crossing the road, if the spaces between vehicles are narrow. It also creates with conflicts when vehicles reverse out. It has a stronger impact on the visual environment, more dominated by vehicles.

Angled parking spaces are suitable in wide roads with high parking demand. If there is space, parking can be in the median strip, eliminating the need for reversing movements: drivers can drive in and out of the space by moving forward.

EXAMPLES

Perpendicular parking is common on wide roads and in off-street parking lots.

In September 2020, Orange (a regional centre in New South Wales, Australia), proposed to replace parallel with angle parking, as a part of the Future City project to revitalise the city centre, increasing parking supply.

There are also several examples in New Zealand. In June 2020, a street in Putaruru was converted from parallel to angle parking to retain the same parking supply after converting parking on one side of the street to a truck loading bay.

EVIDENCE

A study in Manchester found that angle parking causes shorter delays than parallel parking when drivers enter parking spaces, but longer delays when vehicles are leaving.

Yousif and Purnawan 1999 On-street parking: effects on traffic congestion. Traffic Engineering and Control 40, 424-427.

A conversion from parallel to angle parking in a city in the USA increased the number of parking-related collisions (absolute and per vehicle-km). But did not increase collisions per vehicle parked.

McCoy et al 1991 Safety evaluation of converting on-street parking from parallel to angle. Transportation Research Record 1327, 36-41.

Unlike parallel parking, angle parking does not have a significant effect as a buffer protecting pedestrians from vehicle pollution. It can even increase exposure.

Gallagher and McNabola 2011 Optimizing the use of on-street car parking system as a passive control of air pollution exposure in street canyons by large eddy simulation. Atmospheric Environment 45, 1684-1694.

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Park & Ride

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Car parking area next to a train, light-rail, or bus station to encourage drivers to use cars for only part of their trips. Parking is free or charged at a reduced rate. The area is usually large, sometimes in multi-level or underground structures.

Park and ride facilities are usually aimed at commuters. They are useful for drivers because they reduce the time driving under congested condition and cruising for parking, and the cost of parking in central areas.

Park and ride is more suitable around stations far from the centre and in low density areas (allowing few walking trips to the station). If it is in an inconvenient location, drivers may drive all the way to final destination.

Park and ride spaces should be next or within short walking distance to the station. Good pedestrian access is necessary. The spaces should not take priority over space for other modes (buses, cycling) feeding the station.

Parking in the park-and-ride lots may be linked to use of the public transport services available at the station (for example, through smartcards), to prevent non-users of public transport to use the spaces as a standard parking lot.

EXAMPLES

Park and Ride facilities have emerged in 1973 in Oxford (UK). They are common in the UK. Several stations (Parkway stations) serve mainly a park and ride facility, rather than a town.

Park and Ride is common around Europe. In the Netherlands, Park and Ride facilities were introduced in 1979 near Amsterdam. There are still many facilities around the country.

Park and Ride is also common in outlying suburban rail and light-rail stations in the USA.

EVIDENCE

A review in the UK showed that some park and ride users had switched from modes other than car or were making additional trips. Congestion did not decrease in the cities studied.

Parkhurst 1995 Park and ride: could it lead to an increase in car traffic? Transport Policy 2, 15-23.

A review of bus-based park and ride schemes in the UK found that they increase distance travelled, due to low load factors on dedicated buses, replacement of public transport trips, and new trips made.

Meek et al 2008 Role of bus-based park and ride in the UK: a temporal and evaluative review. Transport Reviews 28, 781-803.

A survey in the Netherlands identified additional unintended effects: replacement of cycling trips and use the facilities for parking (without riding).

Mingardo 2013 Transport and environmental effects of rail-based Park and Ride: evidence from the Netherlands. Journal of Transport Geography 30, 7-16.

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Kiss & Ride

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Designated areas next to public transport nodes (train, light-rail, bus stations) or other places (schools, employment centres) for passengers to be picked up/dropped off by personal vehicles. There is no charge for stopping.

The spaces can only be used for a short time (a few minutes). Drivers must stay inside the vehicle, or nearby, while waiting. The spaces may complement park and ride spaces, but should be closer to the station, to reduce the time they are occupied.

Kiss and ride zones may operate only for a few hours (e.g. peak time, school opening/closure times), with the space assigned to other uses (e.g. longer term car parking, bicycle parking) at other times.

This measure reduces cruising for parking and reduces the need to stop in locations that are unsafe (e.g. with no pedestrian crossings, or near junctions) or disrupt other road users (e.g. double parking, or parking next to cycle lanes).

Compliance can be an issue. Drivers may occupy the space for more than allotted minutes, preventing others from using it. They may also use it as a standard parking space, for longer hours. Adequate signage and enforcement is needed.

EXAMPLES

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EVIDENCE

In a study in Charlotte (USA), the kiss-and-ride option for a trip lead to an average of 31 vehicle-kms per person, less than driving (46km) but more than car pool (23km) and using park and ride (21km)

Duncan and Cook 2014 Is the provision of park-and-ride facilities at light rail stations an effective approach to reducing vehicle kilometres traveled in a US context? Transportation Research A 66, 65-74

In a study in Toronto, higher parking cost values for park and ride decreased the propensity to park and ride use vs. using kiss and ride.

Weiss and Habib 2017 Examining the difference between park and ride and kiss and ride station choices using a spatially weighted error correlation (SWEC) discrete choice model. Journal of Transport Geography 59, 111-119.

In a study in New York, parking lots with larger, more-accessible drop-off points had greater kiss-and-ride percentages. Lots with illegal-parking problems had lower percentages.

Schank 2002 Encouraging kiss-and-ride at commuter railroad stations. Transportation Research Record 1793, 7-14.

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Charging facilities for electric vehicles



Amsterdam, The Netherlands ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Installation of public charging facilities for electric vehicles. The adjacent space is for the exclusive use of electric vehicles that are recharging. It is not a parking space for electric vehicles that are not recharging.

Space is needed for the charger and for additional equipment (wires, signs, lighting). These can be accommodated on the same space used by the charging vehicle (on a parking bay), or on the footway.

The availability of regular charging facilities in a city gives more confidence to drivers who worry about the short driving range of electric vehicles, compared with gasoline-powered vehicles.

Charging facilities in public spaces also help users who cannot install charging facilities in their homes because they live in apartments with no off-street parking. In addition, charging is often free.

The location of charging spaces can be mapped and made available to drivers from mobile devices. The location should be near roads with high traffic volumes, of easy access, and not in areas prone to flooding.

EXAMPLES

Norway had 16000 public charging stations as of August 2020. The number grew from 3000 in 2011. Chargers are sometimes on the footway, sometimes on the carriageway.

The Netherlands had 41000 public charging stations in 2019. The number grew from 1800 in 2011. Chargers are sometimes on the footway, sometimes on the carriageway.

The number of charging stations in the UK (9000) has surpassed the number of fuel stations in August 2019. In cities, charger and other equipment are on footways.

EVIDENCE

A review found that availability of charging stations tends to be associated with probability of buying an electric vehicle.

Coffman et al 2016 Electric vehicles revisited: a review of factors that affect adoption. Transport Reviews 37, 79-93.

The density of charging stations was significantly related with the probability of buying an electric vehicle, for both personal and business customers, in a study in Norway.

Zhang et al 2016 The impact of car specifications, prices and incentives for battery electric vehicles in Norway: choices of heterogeneous consumers. Transportation Research C 69, 386-401.

A study in Japan found that private users are willing to detour up to about 1750m on working days and 750 m on other days to fast-charge their vehicles. Commercial users are willing to detour up 500m.

Sun et al 2016 Fast-charging station choice behavior among battery electric vehicle users. Transportation Research D 46, 26-39.

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Space for ride-hail services stops

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Dedicated spaces for ride-hail vehicles to pick-up and drop-off passengers, at all times or only when demand for ride-hail services is higher (weekends, late afternoon/evening). Taxis and private vehicles may also be able to stop.

One of the advantages of ride-hail services is flexibility in the start and end point of trips. So designated spaces for pick-up/drop-off are only useful in locations that generate many trips (e.g. next to stations, and in shopping and leisure areas).

Drivers and passengers need to be redirected to these spaces, through information displayed on mobile devices. The spaces can also be identified with signs.

A maximum stopping duration needs to be specified (a few minutes), otherwise waiting vehicles will double park, causing congestion. On the other hand, if the spaces are often empty, there is a risk they are used for long-term parking by private cars.

These spaces are useful in busy areas, in places and at times where buses or other public transport are not available. But they also use space that could be used for other uses (e.g. taxi stands, bicycle parking).

EXAMPLES

One busy section of Massachusetts Avenue, an arterial road in Cambridge (USA) was redesigned in 2018, with parking spaces converted to loading bays and ride-hail pick-up/drop-off zones.

In 2015, a charity (Livable City) and a ride-hail company (Lyft) piloted a program in San Francisco that assigned pick-ups to places that reduced conflicts with other modes, near a busy station.

A similar arrangement was created in 2019 Seattle on a night-time leisure area (Peak/Pine). Ride-hail vehicles have designated spaces where they can park for a maximum of 3 minutes.

EVIDENCE

Modelling in Lisbon show that replacing parking spaces with spaces for temporary stopping of ride hailing vehicles would increase traffic flows

ITF 2018 The shared-use city: managing the curb

A study in California found that 44% of ride-hail vehicles double-parked to pick-up/drop-off passengers on a busy street. Ride-hail vehicles were double-parked for a total of 37 min/h, reducing traffic flow 34%.

Lu 2018 Pushed from the curb: optimizing the use of curb space by ride-sourcing vehicles. Master thesis. University of California Los Angeles.

In a study in 5 American cities, 69% of ride-hail vehicles were observed violating parking regulations.

Brown et al 2020 Impeding access: the frequency and characteristics of improper scooter, bike, and car parking. Transportation Research Interdisciplinary Perspectives 4: 100099.

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Space for car hire/share vehicle parking



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Dedicated spaces to pick-up and drop-off shared vehicles. Car/van share systems (also known as car clubs) allow users to rent vehicles through hourly rates or with a subscription and book them through personal electronic devices.

The spaces should be for the exclusive use of shared vehicles at all times, as trips by shared vehicle may end at any time. The spaces need to be identified with signs. The car share operator may be required to meet the costs of providing the space.

Designated parking spaces are a factor for the use of car share because cruising for parking adds to the time the vehicle is being used, increasing the charge. However, they need to be close to residential areas and employment centres.

If users are not required to return the vehicle to the same parking bay, some spaces may be empty for long periods, if not many trips end in the area. This reduces the efficiency of road space use, and may lead to illegal parking by private vehicles.

The spaces should be easy to find (e.g. on main streets or nearby), have good lighting, and be accessible to users with disabilities. They can be next to cycle parking areas or bus stops or stations, to facilitate interchange.

EXAMPLES

In 2019, the city of Paris launched, with four different operators, a new car sharing system (Mobilib), with 1213 dedicated parking spaces, including 713 for electric and hybrid vehicles.

Local authorities in Australia agree with large car share companies for the assignment of dedicated parking shares, in exchange for a payment.

In 2010, San Francisco amended its planning code so that new developments need to provide a certain proportion of car share parking spaces.

EVIDENCE

A scenario analysis in Switzerland found that increasing the number of car share parking spaces can increase the number of rentals and decrease travel times from parking spaces to final destinations.

Balac et al 2015 Evaluating the influence of parking space on the quality of service and the demand for 2 one-way carsharing: a Zurich area case study. Presented at the 95th Transportation Research Board Annual Meeting.

In a survey to car share users, giving more car share vehicles near home was the second most cited desired improvement for car share programs.

Metro Vancouver 2014 The Metro Vancouver Car Share Study Technical Report.

In a study in Italy, time spent parking was found to be negatively related to the choice of a travel model (private car or car share).

Catalano et al 2008 Car sharing demand estimation and urban transport demand modelling using stated preference techniques. European Transport 40, 33-50.

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Accessible parking space



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Parking space for the exclusive use of persons with disabilities. Drivers can only use the space with a permit, which must be displayed upon parking the vehicle. The space is identified with signs and pavement symbols. The space is often free of charge.

The parking bay should be wide (at least 3.5m), to allow more space for drivers and passengers with mobility restrictions or disabilities. It may also include kerb ramps and clear paths in the footway, for easier access.

Persons with disabilities may also be exempted from parking restrictions, limits to maximum parking duration, and parking charges in other parking spaces.

Defining eligibility is an issue. Wheelchair users are always eligible, but pregnant women, elderly, and individuals with mobility restrictions can also be. This increases efficiency of space use but wheelchair users may not be able to find a free space.

Accessible spaces should be dispersed through wide areas, not concentrated in same place. They should be located near to entrances of major destinations (e.g. shopping areas/centres, public buildings).

EXAMPLES

Disabled parking spaces exist in many countries, with minimum recommended width varying from 2.5 (South Korea) 4.0 (Australia). Permit systems also vary in terms of eligibility.

Disabled parking permits in the European Union are standardized and can be used across all countries in the union. Disabled parking spaces are common in all countries, but specifications vary.

In Singapore there are two classes of disabled parking permits (drivers and passengers). As of 2017, there were 6,000 government-run disabled parking spaces. One must be provided for each 50 parking spaces.

EVIDENCE

In a study in China, the odds ratio of preferring a wider parking space, compared with the standard width, was 40 for older wheelchair users, and 6 for those using mobility aids.

Lu et al 2020 Do the elderly need wider parking spaces? Evidence from experimental and questionnaire surveys. Sustainability 12:3800.

Introducing a permit system and broadening the eligibility in a Japanese prefecture increased usage of disabled parking spaces to 60%. 40% of wheelchair users said parking conditions worsened.

Lu et al 2014 Analysis of experience with formalizing handicapped parking system. Transportation Research F 26A, 62-71.

A review has found that illegal parking on disabled parking spaces is frequent. The proportion of illegal parking is above 50% in many studies.

Fletcher 1996 Illegal parking in spaces reserved for people with disabilities: a review of the research. Journal of Developmental and Physical Disabilities. 8, 151-165.

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Motorcycle parking



Huangshan, China ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Dedicated space for parking motorcycles. It can be located next to car parking spaces or separately. Each space should be 2-2.5m long and 1m wide. Parking is usually free, but can be charged, if additional facilities are provided.

Dedicated spaces for motorcycles reduce the propensity for parking on the footway, reducing obstructions to the movement of pedestrians. However, spaces should not be too near pedestrian crossings, which reduces visibility of wheelchair users.

Spaces for motorcycle parking can fit in narrow spaces where even a single car space could be provided. It also takes less space from other uses (e.g. bicycle parking, bus stops) at busy locations, compared with car parking.

Safety and security are a concern. The spaces should be well drained and not on a gradient. Barriers prevent cars from encroaching on motorcycle parking space. Structures to lock motorcycles and good lighting is also needed.

Parking should be provided next to key destinations (e.g. shops, public buildings, stations). A small number of spaces dispersed through an area or in places with poor passive surveillance may fail to reassure motorcyclists that the spaces are secure.

EXAMPLES

In Taiwan, motorcycle parking is free or cheap. There are many spaces but great demand for them. New Taipei Civic Square has a park and ride facility with 1800 motorcycle spaces.

In South East Asia (e.g. Vietnam, Thailand, Malaysia, Indonesia), motorcycles are 80-90% of motorised vehicles but are relatively few parking spaces, leading to illegal parking on footways.

In Paris, car parking spaces have been converted to free motorcycle parking spaces but there is still unmet demand. In 2014, 150,000 motorcyclists protested about lack of parking.

EVIDENCE

In a stated preference study in the UK, choice of motorcycle (vs. other modes) was significantly related to walking time for non-secured parking spaces, but not to walking time to secured spaces.

Burge et al 2007 Modeling of motorcycle ownership and commuter usage. Transportation Research Record 2031, 59-68.

In a study in Taiwan, on-street motorcycle parking charging was negatively related to motorcycle use.

Wen et al 2007 A dynamic analysis of motorcycle ownership and usage: a panel data modeling approach. Accident Analysis and Prevention 49, 193-202.

The availability of parking spaces at stations was found to explain intentions to use a combination of motorcycle and public transport in Hanoi (Vietnam).

Hoang and Okamura 2020 Analyzing behavioral intentions in new residential developments of motorcycle dependent cities: the case of Ho Chi Minh City, Vietnam. Case Studies on Transport Policy 8, 163-172.

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Taxi stand



New York City, USA ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Also known as taxi rank. Dedicated spaces for several taxis to line up while waiting for passengers. Spaces can be divided according to taxi company, or type of service (short or long distance).

Taxi stands are usually full-time (i.e. parking of private cars and loading activities are not permitted at any time). Taxi stands cannot be used by vehicles from rail-hail companies to wait for or to pick up or drop off passengers.

Taxi stands are required near major destinations or at the edges of pedestrian streets. They should be easy to find (through clear signage) and visible. Pedestrian crossing facilities are required nearby.

Taxi stands should have waiting areas, with enough space for queuing passengers and luggage. They should also have shelters, lighting and surveillance, to improve convenience and security of waiting passengers.

The movement of taxis in and out of taxi stands should not generate conflicts with cyclists, buses, and general traffic. Facilities on the footway, and queues, should not obstruct pedestrians.

EXAMPLES

Taxis stands are common outside airports, railway stations, and other main public transport hubs, as well as hotels and shopping centres.

In large cities, including New York, Hong Kong, most taxis respond to hailing on the street or calls, rather waiting at taxi stands.

There was a program to install additional taxi stands in busy areas in Shanghai in 2012, with the objective of reducing congestion caused by taxis cruising for customers.

EVIDENCE

Taxi stand signage (pointing where taxi stands are located) was identified as the most important factor explaining taxi users' satisfaction. Taxi stand location was also a significant factor.

Alonso et al 2018 Modelling user perception of taxi service quality. Transport Policy 63, 157-164.

In a study in Hong Kong, taxi stand facilities and walking time required to take a taxi were some of the least important factors for users.

Wong and Szeto 2018 An alternative methodology for evaluating the service quality of urban taxis. Transport Policy 69, 132-140.

In a study in 5 American cities, 88% of taxis were observed violating parking regulations.

Brown et al 2020 Impeding access: the frequency and characteristics of improper scooter, bike, and car parking. Transportation Research Interdisciplinary Perspectives 4: 100099.

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Add loading bays



London, UK ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Designated space for loading/unloading activities. It can be provided near commercial/industrial premises that require regular deliveries and collections and can only be accessed from the front.

Loading bays can simply be designated parking spaces for commercial vehicles only. However, enforcement is needed to prevent other vehicles from parking on these spaces.

Designated loading bays at the kerbside zone of the carriageway reduce disruption to pedestrian movement on the footway. They also reduce the need to double park next to parked cars, disrupting cyclists and motorised vehicles.

Loading bays are often only used for short periods during the day, taking space from other road uses. To increase efficiency, loading bays can be time-restricted, i.e. exclusive to loading activities only at some times (e.g. early morning, evening).

A management system could be implemented so that users can book a loading bay, to ensure that the space will be free when the vehicle arrives. This reduces delays and allows for other uses when the loading bays are not needed.

EXAMPLES

In 2019, as a part of a Transit-Truck Priority trial scheme, four traffic lanes were removed from a section of 14th Street in New York, converted to loading space. Two other lanes became bus-truck only.

One busy section of Massachusetts Avenue, an arterial road in Cambridge (USA) was redesigned in 2018, with parking spaces converted to loading bays and ride-hail pick-up/drop-off zones.

During the COVID 19-pandemic, parking spaces in Church Street (Twickenham, London) were converted to loading bays, to facilitate deliveries, during early morning.

EVIDENCE

A stated preference study in Rome found that transport providers attach value to the increase in the number of loading bays and the probability of finding a free bay.

Marcucci et al 2015 Urban freight, parking and pricing policies: An evaluation from a transport providers' perspective, Transportation Research A 74, 239-249.

In a simulation study, loading activities in an area with designated loading zone positively influenced cyclists' performance, in comparison with activities in an area with no designated loading zone.

Jashami et al 2020 The Impact of commercial parking utilization on cyclist behavior in urban environments. Transportation Research F 74, 67-80.

In a study in Seattle, on average, commercial vehicles, spent 2.3 min cruising per trip. Cruising decreased as more kerbspace was allocated to commercial vehicles parking.

Dalla Chiara and Goodchild 2020 Do commercial vehicles cruise for parking? Empirical evidence from Seattle. Transport Policy 97, 26-36.

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Loading on footway



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Allow loading/unloading activities on the footway, usually at some times of day only (e.g. early mornings, evenings). A designated space can be marked on the pavement. Signs should inform the permitted times and vehicles.

Loading spaces on the footway reduce the need for providing a kerbside loading bay or a parking space that could be used by commercial vehicles. It also reduces the incidence of double parking.

This solution also minimizes the distance from vehicles to business premises, reducing delays and inconvenience. Access to pedestrianized street can also be allowed at certain times, to reduce distance.

Accessing footways for loading disturbs pedestrians and may lead to collisions. It also damages the footway surface. This means this solution is only feasible in the case of light goods vehicles.

The solution also requires the removal of permanent barriers to access footways (e.g. bollards, guard railings, street furniture). These can be replaced by movable barriers (e.g. depressible bollards).

EXAMPLES

Loading is usually allowed on pedestrianised areas in shopping streets. This is identified with signs, not with marks on the pavement.

In roads without kerbside parking spaces, loading often happens on the footway. In some countries, some places are marked.

In roads with kerbside parking, the vehicle may stop in the parking space, but goods are often unloaded on the footway before being carried to the premises.

EVIDENCE

There are no published studies about the effects of this measure.

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Change location of parking/loading space



Chisinau, Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Change the location of parking/loading spaces. The aim is to provide parking space where is more needed or to release space where there is demand for other uses (e.g. bus stops, cycle parking/hiring, parklets) or the location is unsuitable for parking.

The location can be changed to reduce walking distances, locating parking nearer to trip destinations (e.g. shops, public buildings) and loading bays closer to business premises. However, these areas may also have high demand for other road uses.

Parking location can also be changed to reduce vehicle movement in some areas (e.g. city centres, near schools), or simply to increase walking distances, as a measure to dissuading the use of individual transport.

Parking areas can also be relocated to reduce conflicts with other road uses and collision risk. For example, they should not be too near to road junctions or pedestrian crossings, or where they restrict sightlines of cyclists.

Parking spaces can also be clustered in same location, to release space elsewhere (e.g. for example relocating parking to minor streets to add a traffic lane to a major road).

EXAMPLES

The Telegraph Avenue Complete Streets Project in Oakland (USA) involved the installation of a protected cycle lane, in 2016. Existing parking spaces were relocated.

In 2017, a new public space was created in Chancery Lane in London, as a part of the Chancery Lane Area Enhancement Strategy. The existing motorcycle parking was relocated to a space two streets away.

In Toronto, a park and ride space was relocated in 2011 (to a place within walking distance) to release space for the expansion of Islington station.

EVIDENCE

A stated preference study found that walking time from parking to final destination is valued more than time searching for a parking space, and this is valued more highly than in-car travel time.

Axhausen and Polak Choice of parking: stated preference approach Transportation 18, 59-81.

In a study in Norway, the likelihood of driving was negatively associated with distance to parking spaces near residences.

Christiansen et al 2017 Parking facilities and the built environment: Impacts on travel behaviour. Transportation Research A, 198-206.

A literature review concluded that drivers are sensitive to increased walk time, but there is also evidence of long walking trips to free parking spaces.

Marsden 2006 The evidence base for parking policies - a review. Transport Policy 13, 447-457.

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Parking/loading space location: kerbside



Chisinau, Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Location of car parking spaces on the kerbside zone of the carriageway, rather than on the median strip, or side streets. The space can be formed by using road shoulders, removing one traffic lane, or narrowing existing lanes.

The spaces can form be a continuous strip or be alternated with other uses (cycle parking, footway extensions, green areas, parklets). Spaces can be parallel, perpendicular, or at an angle to the kerb.

Kerbside parking tends to create conflicts with bicycles, especially on -carriageway cycle lanes. A buffer zone is required, or a reverse angle parking configuration, rather than parallel parking. Conflicts may also arise near bus stops.

Cars parked on the kerbside zone act as a buffer between moving vehicles and pedestrians walking along the footway. At the same time, they are an obstruction and reduces sightlines of pedestrians crossing.

Dedicated loading bays on the kerbside avoid commercial vehicles using the footway, obstructing pedestrians and damaging the surface. However, this increases the distance from vehicles to premises.

EXAMPLES

The kerbside zone is the most common location of on-street parking in cities around the world.

In US cities, on-street kerbside parking has been added in many roads as a part of road diet measures that removed traffic lanes. The aim was to attract more people to the road, improving businesses and liveability.

The tendency in Western European cities has been to provide less, rather than more kerbside parking, to release space for wider footways and cycle lanes.

EVIDENCE

The presence of kerbside parking can reduce the capacity of a bicycle lane by 47%, due to reductions in lane width and disruption from parking manoeuvres.

Ye et al 2018 Impact of curbside parking on bicycle lane capacity in Nanjing, China. Transportation Research Record 2672, 120-129.

The presence of kerbside parking increases the visual complexity of driving environment, which leads to a reduction of speed but also to an increase of speed variability and of drivers' workload

Edquist et al 2010 The effects of on-street parking and road environment visual complexity on travel speed and reaction time. Accident Analysis and Prevention 45, 759, 765.

A review found that the presence of kerbside parking is associated with pedestrian injury risk among children

DiMaggio and Li 2011 Roadway characteristics and pediatric pedestrian injury. Epidemiologic Reviews 34, 46-56.

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Parking/loading space location: on median



Brussels, Belgium ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Location of car parking spaces on the median strip, rather than on the kerbside zone of the carriageway or on side streets. The space can be formed by using empty space, removing one traffic lane, or narrowing existing lanes.

The spaces can form be a continuous strip or be alternated with other uses (cycle parking, green areas). Spaces can be parallel, perpendicular, or at an angle to the kerb (if there is one) or to the central line of the median strip.

Median parking avoids conflicts with bicycles and buses that arise with kerbside parking. However, a buffer zone is required between parking spaces and traffic lanes, to minimize conflicts with moving vehicles.

Cars parked on the median strip can also be an obstruction and reduce the sightlines of pedestrians crossing the road. On the other hand, if walking is allowed along the median, parked cars act as a buffer between moving vehicles and pedestrians.

Median parking also requires car users to cross the road to access the footway and their final destination. The provision of pedestrian crossing facilities is required.

EXAMPLES

Median parking was added in 2007 to Recanto das Emas Avenue, an arterial road in Brasília. In 2011, cycle lanes were also added to the median.

South Broad Street, an arterial road in Philadelphia has a median strip used for car parking. Although illegal, there is no enforcement. An activist group has filed a lawsuit against the parking authority.

In other places, illegal median parking is legalized as few drivers comply. This happened in Dolores Street in San Francisco in 2017, where median parking was legalized at some times.

EVIDENCE

There is little evidence on the effects of median parking spaces, in comparison with other parking space locations, or with no parking spaces.

Evaluation of median parking in an avenue in Brasília showed an increase in traffic injuries and fatalities, from collisions between vehicles and between vehicles and pedestrians.

Pereira and Santos 2016 Regulatory median parking: a case study on Recanto das Emas Avenue, Brasília, DF, Brazil. Transportation Research Procedia 18, 220-225.

A study in the USA found that angular or parallel parking in the median strip caused confusion, congestion, and high collision rates.

Hanna 1953 Median dividers on urban streets. Traffic Quarterly. Columbia University Press, Volume 7.

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Parking/loading space on side streets



Lisbon, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Provide parking and loading space on side streets, off a main/commercial road. This includes alleyways and non-residential service roads. This measure is accompanied by improved access to the side streets from the main road.

This is a convenient arrangement for loading activities, as it allows for direct access to commercial premises, which often have back entrances. This also reduces the presence of goods vehicles on main roads.

The arrangement also facilitates private car parking, providing space that is difficult to find in commercial streets. But there are safety issues - parking in quiet lanes can increase car theft and assaults to car users. Lighting/surveillance are needed.

The widths of the side roads and the corner radii should allow the access of large vehicles. The entrances to side streets should have kerb cuts, but the continuity of pedestrian and cycling network should be ensured.

The use of side roads for parking and loading takes up space that could be used instead for quiet and direct pedestrian and cycling links or for new shopping or leisure areas with outdoor seating.

EXAMPLES

Loading bays on side streets are common in shopping streets, as commercial premises can often be accessed, and have larger entrances, from those streets

Parking on side streets is also common around pedestrianised areas or areas with traffic or parking restrictions.

Relocating car parking to side streets is one of the recommended strategies for bus roads in the New Zealand's Road and Streets Framework.

EVIDENCE

Space in alleyways in a Seattle observational case study were vacant 50% of the time during business hours on a weekday. 60% of parked vehicles were there for less than 15 minutes.

Machado-León et al 2020 Bringing alleys to light: an urban freight infrastructure viewpoint. Cities 105: 102847

A stated preference study found that walking time from parking to final destination is valued more than time searching for a parking space, and this is valued more highly than in-car travel time.

Axhausen and Polak Choice of parking: stated preference approach Transportation 18, 59-81.

Allowing trucks to park only on side streets (and restricting cars from parking there), decrease search time and walking distance for truck users, with no significant effect on car users.

Nourinejad et al 2014 Truck parking in urban areas: application of choice modelling within traffic microsimulation. Transportation Research A 64, 54-64.

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Parking restrictions



Tiraspol, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Prohibition of vehicle parking in a road segment or in an area, at some times or at all times. The restriction can also apply to stopping and loading activities. It can apply to some types of vehicles only (e.g. heavy vehicles).

Enforcement is crucial, with physical barriers (e.g. bollards), cameras, or inspection. Exemptions can apply to some vehicles (e.g. electric or car-club vehicles, taxis), users (disabled, residents), or uses (e.g. loading, servicing).

The aim can be to release space for other uses in narrow or busy roads, or to reduce the circulation of vehicles in some areas (e.g. city centre, historical areas, near school) and to encourage car users to use public transport or non-motorised modes.

The restrictions can also be for safety reasons. For example, near road junctions, parking is usually banned at all times, as it decreases the visibility of motorised, vehicles, bicycles, and pedestrians.

This measure can be an alternative, or used in conjunction with other measures (e.g. imposing a maximum parking duration or parking charges). Unlike parking charges, it does not generate revenue.

EXAMPLES

In Japan, on-street parking is restricted in most cases. A parking space certificate, proving access to off-street parking, is needed to register a car.

Western European countries have regulated parking since the 1960s.

In 2017, Oslo has started implementing a plan to ban all on-street car parking in the city centre.

EVIDENCE

A study in Norway found that limited access to parking (either free or paid, near or far) is the most effective way of reducing car use for commuting trips.

Christiansen et al 2017 Parking facilities and the built environment: impacts on travel behaviour. Transportation Research A 95, 198-206.

A literature review concluded that in many instances, parking restrictions do not contribute to make city centres less attractive (in terms of decisions by shoppers to visit them).

Marsden 2006 The evidence base for parking policies - a review. Transport Policy 13, 447-457.

Weight and time restrictions have operational/financial impacts on distribution companies, but maybe no environmental improvement, as more trips could be made, with lighter vehicles or concentrated in short periods.

Allen et al 2003 Modelling Policy Measures and Company Initiatives for Sustainable Urban Distribution. University of Westminster.

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Limits to maximum parking duration



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Limit the maximum time a vehicle can occupy a parking space. The measure can apply at some hours, or days only, and to all or only some types of vehicle. Some users (e.g. disabled) may be exempted.

The aim can be to prevent vehicles from using the space during the whole working day, limiting the number of different users that can use the space (preventing the use of the space for quick shopping trips, or for loading activities).

Efficiency of road space will decrease if a maximum duration is imposed in areas where demand is not high, or if the maximum is too short for the type of activities car users engage with in the area. This may lead to underutilized parking spaces.

Enforcement of this measure is crucial, with cameras or inspection. The increase in the number of vehicles moving in and out of parking spaces can also cause a regular disruption to cyclists or motorised vehicles.

This measure is useful in busy roads with high demand for parking. It can be an alternative or used in conjunction with parking restrictions at certain times and parking charges. Unlike parking charges, it does not generate revenue.

EXAMPLES

Some European countries (starting with France, in the 1950s) have a system where some parking spaces are free but time-restricted. A "parking disc" needs to be displayed showing the time when the vehicle was parked.

Edinburgh has had a controlled parking zone in the city centre since 1974. Non-residents must pay for parking and maximum stay times apply.

In shopping streets in Versailles (France), parking is limited to 15 minutes at daytime. A red LED light starts to blink after the allotted time to alert drivers and enforcement agents, until the car leaves the place.

EVIDENCE

A study in Switzerland found that imposing a 7h maximum parking duration reduced cruising time by 16%. A 5h maximum reduced cruising time by 52%, compared with no maximum.

Cao et al 2017 Impacts of the urban parking system on cruising traffic and policy development: the case of Zurich downtown area, Switzerland. Transportation 46, 883-908.

In a study in Belgium, a maximum parking duration of 4 hours was found to influence the decision to park off-street, rather than on-street parking spaces, compared to no maximum.

Khaliq et al 2018 Modeling car drivers' on-street parking decisions using the integrated hierarchical information integration approach. Transportation Research Record 2672, 23-33.

A study in Edinburgh found that a 2.5 km expansion of a controlled parking zone (where parking is charged and time-limited) could lead to a 21% reduction in private car use for commuting trips.

Rye et al 2006 Expansion of a controlled parking zone (CPZ) and its influence on modal split: the case of Edinburgh. Transportation Planning and Technology 29, 75-89.

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Parking charging



Kuopio, Finland ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Imposing a charge for the use of parking spaces. The charge usually depends on the length of time the vehicle is parked. Some users can be exempted or pay less, e.g. disabled, local residents, taxis, car share vehicles, and electric vehicles.

Parking charges depend on demand and supply of parking space. They are higher in locations that provide access to many destinations (e.g. jobs, shops, services). In other locations, it is cheaper or free.

Charges may also differ by vehicle (e.g. higher for larger vehicles) and by time of day (reflecting the level of demand throughout the day). Charges can also be dynamic (based on real-time information of occupancy of parking spaces).

The system generates a revenue, which can be used to manage the system but also to provide public services, including improving roads and subsidizing public transport.

Payment methods include parking meters, pay-and-display systems, or electronic payment. Enforcement is required to ensure charges are paid and vehicles do not remain parked after the time the driver has paid for.

EXAMPLES

Parking meters were introduced in 1935 in Oklahoma City, USA. They remain the most common payment method for parking charges

Edinburgh has had a controlled parking zone in the city centre since 1974. Residents must purchase a permit and non-residents must pay for parking (which is also time-restricted).

A new parking charging system was introduced in 2013 in Stockholm, increasing charges in several zones

EVIDENCE

A meta-analysis of 50 studies showed that higher parking charges are associated both with lower parking duration and with lower number of vehicles using parking spaces.

Lehner and Peer 2019 The price elasticity of parking: a meta-analysis. Transportation Research A 121, 177-191.

A study in Edinburgh found that a 2.5 km expansion of a controlled parking zone (where parking is charged and time-limited) could lead to a 21% reduction in private car use for commuting trips.

Rye et al 2006 Expansion of a controlled parking zone (CPZ) and its influence on modal split: the case of Edinburgh. Transportation Planning and Technology 29, 75-89.

The increase of parking charges in Stockholm increase the ease of finding a vacant parking space and led to underutilized parking spaces in some areas.

Cats et al 2016 Survey methodology for measuring parking occupancy: impacts of an on-street parking pricing scheme in an urban center. Transport Policy 47, 55-63.

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Charging for stopping/loading

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Charge for commercial vehicles stopping in parking spaces for loading/unloading activities. The charge applies at some times of day only. This policy may be accompanied by a maximum stopping duration.

The system may include the option to book a loading bay, to ensure users that the space will be free when the vehicle arrives. This reduces delays and allows for other uses when the loading bays are not needed.

The charging may apply to stopping or to the loading activity, so it can be based on duration or weight. A loading bay can also be assigned to a specific business, through payment of an annual fee.

Imposing a charge for loading may lead to illegal stopping activity by commercial vehicles on footways, or double parking next to other vehicles, creating conflicts with other road users, which lead to delays and potential safety issues.

This measure is useful in busy roads with high demand for parking or for other kerbside uses at some times. It is an alternative to an outright ban of loading activities at those times.

EXAMPLES

Use of kerbside loading bays is free of charge in most cities, but often restricted to certain hours.

Chicago has installed Commercial Loading Zones in the city centre in 2017. Users buy 15-minute periods of time, which can be used in any zone.

Washington DC has a similar Commercial Loading Zone scheme. Users pay an annual permit, daily permit, or per use. Maximum allowed time is 2 hours.

EVIDENCE

A study in Toronto found that drivers of commercial vehicles are willing to trade-off walking time to loading zones, with the cost of a permit for parking or the expected value of fines for illegal parking.

Rosenfield et al 2016 Investigation of commercial vehicle parking permits in Toronto, Ontario, Canada. Transportation Research Record 2547, 11-18.

A stated preference study in Rome found that transport providers attach value to the increase in the number of loading bays and the probability of finding a free bay.

Marcucci et al 2015 Urban freight, parking and pricing policies: An evaluation from a transport providers' perspective, Transportation Research A 74, 239-249.

Another stated preference study in Singapore found that excessive pricing of loading bays increases illegal parking, but excessive enforcement increases demand for loading bays, leading to queuing.

Dalla Chiara et al 2020 Policy-sensitive model of parking choice for commercial vehicles in urban areas. Transportation Science 54, 606-630.

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Dynamic parking charging

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Variable parking charges, depending on demand for parking space. Charges are determined based on real-time information (captured through sensors on the parking bays), about the levels of occupancy of parking spaces over an area.

Drivers can see information on parking space availability, and book a place, through a mobile phone application. Information on remaining time for parked vehicles can also be provided to drivers and traffic wardens.

Dynamic pricing is more effective in the management of demand for parking space than fixed pricing because it has the potential to shift parking to under-utilised spaces or trips to off-peak times or to other modes.

The system maximizes revenue, as the charges are aligned with the users' willingness to pay. This requires an accurate forecast of demand for parking at each price, based on observed behaviour.

Dynamic pricing and real-time parking space information reduces the need for cruising for parking. It may also save space if the payment is done electronically only, so it does not require any furniture.

EXAMPLES

The Sfpark system in San Francisco, launched in 2011, is a demand-responsive scheme for charging parking. It has been extended to the whole city in 2018.

Other US cities have used similar models. For example, LA Express Park in Los Angeles was launched in 2012 in the city centre and then progressively expanded to other areas.

In North Madrid, on-street parking is managed by a private company (Indigo), applying dynamic pricing based on mobility and environmental objectives set up by the city council.

EVIDENCE

A modelling study showed that dynamic pricing can maintain an occupancy level of parking spaces below 85% on each block, which eliminates cruising for parking.

Mackowski et al 2015 Parking space management via dynamic performance-based pricing. Transportation Research Procedia 7, 170-191.

Another modelling study showed that dynamic pricing improves both revenue and level of use of parking spaces.

Tian et al 2018 Dynamic pricing for reservation-based parking system: a revenue management method. Transport Policy 71, 36-44.

A survey in Los Angeles found that many participants misunderstood dynamic pricing charging.

Glasnapp et al 2014 Understanding dynamic pricing for parking lots in Los Angeles: survey and ethnographic results. HCI in Business Lecture Notes in Computer Science 8527, 316-327.

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Enforcement of parking/loading regulations



X, X ©Paulo Anciaes

TYPE: Regulation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Physically impede vehicles to park in restricted areas (including footways and pedestrian crossings, and other designated no-parking spaces) or monitor and penalize vehicles parked in restricted areas or times or beyond the allotted time.

Vehicles can be physically blocked from parked in restricted space by using barriers or bollards. Monitoring is done with enforcement personnel or in-pavement sensors. Penalties include fines, towing vehicle, or blocking it using wheel clamps.

Removing footway parking is particularly important as parked vehicles are an obstacle and force pedestrians to walk on the carriageway. This is especially impactful for pedestrians with visual and mobility impairments.

The fine should be high enough to dissuade drivers from parking illegally and to ensure that the revenue covers the costs of enforcement. But there are equity issues if the fine is the same for all drivers, regardless of ability to pay.

Parking restriction enforcement tends to generate conflicts between car drivers and enforcement personnel and protest from residents and local businesses.

EXAMPLES

In 2014, Singapore Land Transport Authority started a large program to install cameras to detect illegal parking. Zones with cameras are indicated by signs, to alert drivers.

Throughout the developing world, pavement parking is the norm, and there is little enforcement.

Lisbon has a severe problem of footway parking, resilient to enforcement. In some places footway space has been designated by authorities as parking space, with vehicles straddling the kerb.

EVIDENCE

Enforcement of parking restrictions benefits pedestrians: An experiment in China found pedestrians were influenced negatively by the presence of parked vehicles on the pavement.

Kang et al 2013 Statistical analysis of pedestrian perceptions of sidewalk level of service in the presence of bicycles. Transportation Research A 53, 10-21.

A stated preference survey in London found that pedestrians were willing to pay £4.54/year as extra tax for having no motorised vehicles on the pavement on a given street

Sheldon et al 2007 Valuing urban realm - business cases in public spaces. Association for European Transport Papers Repository.

A study in Lima (Peru) found a greater risk of pedestrian-vehicle collisions if there are cars parked on the footway.

Quistberg et al 2015 The walking environment in Lima, Peru and pedestrian-motor vehicle collisions: an exploratory analysis. Traffic Injury Prevention 16, 314-321.

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Part-time parking/loading space

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Designated space for parking and/or loading only at some times only. At other times, the space can be used for movement (of general traffic, buses-only, cyclists-only, or pedestrians), bus stop, bicycle parking, markets, outdoor cafés, or a parklet.

The assigned time is usually off-peak time during the day, evenings and/or night-time (for parking) and early mornings (for loading). Evening loading is not usually allowed in areas with many pedestrian flows and place activities.

Part-time parking spaces are usually on the kerbside zone of the carriageway or the median strip. Loading spaces are more flexible: they can be on the kerbside zone, on the footway, or on a pedestrianized street. Both can be on a part-time bus stop.

The status of the space as a parking or loading bay may be identified with signage and marks on the pavement. These can be fixed (indicating detailing hours of operation) or electronic (displaying the status of the space in each moment).

Compliance can be a problem: vehicles can remain parked after the end of the allotted time, disrupting the next uses, e.g. causing congestion if the next use is a traffic lane, and delays and inconvenience for bus passengers if the next use is a bus stop.

EXAMPLES

In one section of Connecticut Avenue NW in Washington, which crosses an area with mixed land uses, parking and loading is permitted only in the non-peak periods. In the peak-periods, the space is used as traffic lane.

In the late 1990s, Barcelona has introduced multifunctional lanes in the centre, used for car parking (21:00-8:00), deliveries (10:00-17:00), and general traffic (8:00-10:00, 17:00-21:00).

There was a trial in 2011 near a Copenhagen school of assigning five parking spaces to different modes at different times: 7:00-17:00 to cycle parking and 17:00-7:00 to car parking.

EVIDENCE

Simulation of flexible kerbside space (allocating space to pedestrians, cyclists, taxis, and deliveries at different times), showed it would reduce average delay in the morning peak (192 to 51 seconds) and lunch time (67 to 54 seconds).

ARUP 2018 FlexKerbs - Evolving Streets for a Driverless Future

Multifunctional lanes in Barcelona (with space allocated to parking, deliveries, and general traffic, at different times) reduced travel time by 12-15%.

Hayes et al 2006 MIRACLES (Multi Initiative for Rationalised Accessibility and Clean Liveable Environments) Deliverable 4.2 Annex 3 – 2nd Implementation Report for Barcelona.

A trial for part-time car vs. bicycle parking in a Danish school was well accepted by users but showed some problems with the transitions, with cars or bicycles still in the spaces after the permitted time.

Atkins 2012 Evaluation Report on Flex-Parking in Copenhagen [in Danish].

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Dynamic parking/loading space

TYPE: Time allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Parking space that becomes active when demand increases. At other times the space may be for movement or for other uses. The space can be activated based on data on volumes of vehicles parked in other parking spaces or vehicles in upstream traffic.

The space can be identified with LED pavement lights and signs (indicating the parking space and the need to move to other lanes, for other traffic). Enforcement is needed to ensure the space is not used for movement when active.

The transitions from/to parking space can cause confusion for drivers and conflicts between them and the current users of the lane (e.g. cars, cyclists). A suitable time lag is required before the parking space is active.

The more dynamic the space, the fewer the uses it can have when it is not active. A fully dynamic lane can be a bicycle parking space or place for place activities but not a lane for moving traffic.

The space can also be static lanes at night-time, either inactive (if there is low demand for parking) or active (if there is high demand).

EXAMPLES

There are no examples of fully dynamic parking or loading spaces, i.e. spaces that become parking spaces in response to increased demand.

In 2015, a charity (Livable City) and a ride-hail company (Lyft) piloted a program in San Francisco that assigned pick-ups to designated places, shown on the drivers and passengers interfaces.

Grid Smarter, a private company, developed Kerb, a software for the management of kerb side, that allows commercial vehicles to book virtual loading bays.

EVIDENCE

There are no published studies on dynamic parking spaces.

Some insights can be gained from studies on dynamic parking pricing. A modelling study showed that this measure can eliminate cruising for parking.

Mackowski et al 2015 Parking space management via dynamic performance-based pricing. Transportation Research Procedia 7, 170-191.

Other insights can be gained from studies on part-time parking. A simulation study shows that flexible kerbsides (with parking at some times only) reduces average delay.

ARUP 2018 FlexKerbs - Evolving Streets for a Driverless Future

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Consolidated freight distribution

TYPE: Space allocation

MAIN TARGET STREET USE: Motorised vehicles (parking and loading)

DESCRIPTION

Distribution of goods to several business premises in an area of the city from a single distribution facility located near that area. This facility is known as urban consolidation (or distribution) centre.

The distribution from the consolidation centre is made by light goods vehicles, often electric or gas-powered, or by non-motorised freight vehicles (cargo cycles, hand carts). Small deliveries can be made by scooter or walking.

Consolidation centres can serve an area of the city (e.g. city centre), a whole town, or a single, large, business location (e.g. airport, shopping centre, construction site). The schemes are usually voluntary.

The promotion of consolidated freight deliveries can be complemented with policies such as restrictions to the type of vehicles entering the distribution area (e.g. no heavy vehicles) and limits to the distribution times.

One of the objectives is to occupy less roadspace for less time, releasing space for other uses. At the same time, consolidation reduces distance travelled and, if using clear vehicles, reducing environmental impacts.

EXAMPLES

The first examples of urban consolidation centres appeared in France and the Netherlands in the 1970s but they were not very successful. The idea was revived in the late 1990s.

There are several consolidation centres in Europe. One of the most successful is the Cityport in Padua (Italy). It opened in 2004 and makes deliveries using methane and electric vehicles

Another example is the cargohopper in Utrecht (Netherlands), an electric vehicle towing trailers that delivers from consolidation centres to businesses in the historic centre.

EVIDENCE

A review of 114 freight consolidation schemes in 17 countries found that they tend to reduce the time and space occupied by on-street deliveries, reducing congestion.

Allen et al 2012 The role of urban consolidation centres in sustainable freight transport. Transport Reviews 32, 473-490.

A trial freight consolidation scheme in central London, using electric cargo tricycles and vans reduced distance travelled and Co2 emissions per parcel in 20% and 54% respectively.

Browne et al 2011 Evaluating the use of an urban consolidation centre and electric vehicles in central London. LATSS Research 35, 1-6.

A review of 6 consolidation schemes in European cities identified two main challenges: level of demand and sharing of costs and benefits of the scheme

Allen et al 2014 A review of urban consolidation centres in the supply chain based on a case study approach. Supply Chain Forum 15, 100-112.

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PART 13

Green areas

Add greenery



Tiraspol, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Green areas

DESCRIPTION

Street greenery include trees, planted areas, grass strips, and flower beds. It can be located on the footway, kerbside zone, or the median strip, always acting as buffer zone between pedestrians, cyclists, and motorised vehicles.

Street trees require tree pits, i.e. surface and underground structures to facilitate the growth of trees and management of surface water. They use a minimum of 1.5m of road width. Conflicts with underground utilities need to be resolved.

Street trees should not reduce the space available for walking and crossing the road, or cause obstructions, especially to pedestrians with visual impairments. Leaf and fruit fall can also disrupt walking.

Large and mature trees bring more environmental benefits than small ones. But canopies can obstruct pedestrian and driver sightlines, and extensive roots affect footways, buried services and building foundations.

Planted areas are an alternative if there is no space for trees. They require a minimum of 1m of road width, regular maintenance, and enforcement to prevent encroachment from car parking and other uses.

EXAMPLES

The City of Sydney has planted an average of 1,000 street trees per year since 2007 and has a street tree master plan, with the target of increasing green canopy by 50%.

In 2011, the "My tree - My city. Count me in!" campaign in Hamburg involved planting 2639 trees. The Senate of Hamburg released 2 million Euros and citizens could also contribute.

As part of the Million Trees NYC program (2013-2016), an estimated 220,000 new street trees were planted in New York.

EVIDENCE

Street trees have many benefits: less flood risk, water/air pollution, soil erosion, temperature, noise, emissions, and crime; better health; higher property values; more interaction

Mullaney et al 2015 A review of benefits and challenges in growing street trees in paved urban environments. Landscape and Urban Planning 134, 157-166.

A review of 115 studies found that the benefits of trees are consistent across places and climates. But trees also have costs: maintenance, light attenuation, infrastructure damage, allergies.

Roy et al 2012 A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban Forestry and Urban Greening 11, 351-363.

Street flowers have been little studied. But a study in Japan found that they contribute to people's perceived aesthetic quality of a street and psychological well-being.

Todorova et al 2004 Preferences for and attitudes towards street flowers and trees in Sapporo, Japan. Landscape and Urban Planning 69, 403-416.

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Green area location: on footway



Tiraspol, Transnistria/Moldova ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Green areas

DESCRIPTION

Location of green areas (trees, planted areas, grass, flowers) on the road footway. Green areas can be a continuous strip or alternated with street furniture, seating areas, tables, cycle parking, and other footway uses

Green areas on the footway should not obstruct the clear path for pedestrians. Tree canopies can also reduce the sightlines of pedestrians and vehicle drivers. Leaf and fruit fall can also cause problems for pedestrians.

Green areas on the footway act as a buffer between pedestrians and activities on the kerbside area of the carriageway (bicycles moving, cars/taxis parking or stopping) or on traffic lanes (vehicles moving)

Green areas can be placed on footway extensions, occupying the whole extension or just part of it. Trees should not be near road junctions (within 3 m), as that reduces the visibility of vehicles turning and pedestrians crossing the road.

The roots of trees can affect building foundations and damage the footway pavement, creating obstructions and trip hazards for pedestrians, especially those with impairments. They may also conflict with underground utilities.

EXAMPLES

The footways are the most frequent location of street trees in all cities.

As part of the Million Trees NYC program (2013-2016), an estimated 220,000 new street trees were planted in New York, mostly on footways. Trees could be requested by residents.

Trees on footways have been removed in some places because of damages they cause to the pavement, the need to install new underground utilities, maintenance costs, or poor health of trees.

EVIDENCE

Footway trees have been linked with safety for older pedestrians - they protect pedestrians for collisions and provide pedestrians and drivers with a clear footway/carriageway separation

Kim 2019 The transportation safety of elderly pedestrians: modeling contributing factors to elderly pedestrian collisions. Accident Analysis and Prevention 131, 268-174.

In a study in Geelong (Australia), the number of street activities in outdoor cafes was related with an index of greenery as defining territory, traffic barrier, shade, beauty, and cleanliness.

Farahani and Beynon 2015 Pavement cafes as the activity zone in the social life of neighbourhood centres. Proceedings of the Conference of the Architectural Science Association, 193–202.

Levels of satisfaction with footways have been associated with tree height and width and shrub width, in a study in South Korea. All relationships are non-linear, increasing up to a level.

Lee et al 2009 Design criteria for an urban sidewalk landscape considering emotional perception. Journal of Urban Planning and Development 135, 133-140.

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Green area location: kerbside



Sydney, Australia ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Green areas

DESCRIPTION

Location of green areas (trees, grass strips, planters) on the kerbside area, replacing spaces for parking and loading. Green areas can be continuous or alternated with parking/loading spaces, bicycle parking, or other kerbside uses.

Planters can be used to delimit cycling infrastructure, footway extensions, or cycle parking, separating these elements from moving vehicles on the carriageway. They can also be used simply to narrow the carriageway, to reduce traffic volumes/speeds.

Strips with grass or other vegetation at the kerbside (known as swales) can channel surface water run-off and facilitate its absorption, reducing flood risk and pollution. They may also replace kerbs.

Trees or planters can be a solution to restrict space for car parking in the kerbside strip. However, green areas with low walls do not physically impede vehicles from parking on them - this solution requires enforcement measures.

Green areas on the kerbside strip act as a buffer between pedestrians walking along footway and moving vehicles on the carriageway, without being an obstruction to pedestrians (unlike some footway trees).

EXAMPLES

Road verges are the most frequent location of street trees in roads outside urban areas (because there is no footway). In cities, trees on kerbside strips are rare: most trees are on footways.

Australian cities (e.g. Sydney, Melbourne) have installed large planters on the kerbside strip in street corners, to reduce vehicle turning speed and reduce illegal parking.

Kerbside vegetated swales are treated as a priority measure in new and existing roads to manage drainage and surface water control by Auckland Transport (New Zealand).

EVIDENCE

In a driving simulator study, when roadside trees were close to the carriageway, drivers reduce speed and moved away from them (driving further from the road edge).

Calve 2015 Does roadside vegetation affect driving performance? Driving simulator study on the effects of trees on drivers' speed and lateral position. Transportation Research Record 2518, 1-8.

Landscaped vegetation in the zones of the road shared by pedestrian and driver perceptions contribute to more pedestrian activity and fewer midblock traffic collisions.

Nader 2007 Landscape design in clear zone: effect of landscape variables on pedestrian health and driver safety. Transportation Research Record 1851, 119-130.

A review found that kerbside vegetated swales are effective in the removal of pollutants associated with water runoff along roads, especially solids.

Gavril et al 2019 Processes improving urban storm water quality in grass swales and filter strips: a review of research findings. Science of the Total Environment 669, 431-447.

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Green area location: median



Braga, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Green areas

DESCRIPTION

Location of green areas (trees, planted areas, grass, flowers) on the median strip of the road. Green areas can be a continuous strip or alternated with street furniture, seating areas, tables, cycle parking, or car parking space.

Green areas can occupy the whole median strip (with no walking or cycling allowed, or possible). Alternatively, they can act as a buffer, separating the space for pedestrians and cyclists moving along the median and motorised vehicles on the carriageway.

If walking is allowed along the median strip, trees and structures with plants should not obstruct the clear path for pedestrians or reduce their sightlines, especially near crossing facilities.

Green strips (e.g. grass, lines of planters) can be used to define the median itself, instead of using kerbs or marked lines. They can be used simply to narrow the carriageway, to reduce traffic volumes and speeds.

Green areas in the median strip are useful to manage surface water run-off from the adjacent carriageway lanes. This can be achieved with grassed or vegetated channels (swales).

EXAMPLES

The Ecoducto Río de la Piedad, created in 2018, is a 1.6km linear park in the median of a motorway in Mexico City. It was designed by citizens and includes a restored stream, greenery, and a cycle/pedestrian path.

Octavia Boulevard in San Francisco, was built in 2002 from a reconverted urban motorway damaged by an earthquake. It includes a planted median strip.

The redesign of the Ninth Avenue in New York in 2008 included small green areas in the median strip, used to segregate cycle lanes from the other traffic and as pedestrian refuges.

EVIDENCE

Transformation of Via Julia (Barcelona) as a boulevard with a central elevated promenade with benches and trees created a space where many social activities take place, despite the traffic noise.

Garcia-Ramon et al 2004 Urban planning, gender and the use of public space in a peripheral neighbourhood of Barcelona. Cities 21, 215-223.

A case study in Berkeley (California) showed how a narrow, grassed, median strip was transformed into an active informal gathering place, despite safety risks and presence of "keep off" signs.

Sankalia 2014 The median picnic: street design, urban informality and public space enforcement. Journal of Urban Design 19, 473-495.

Large trees in median strip are been associated with more collisions and increased severity, but the association is weak.

Sullivan and Daly 2005 Investigation of median trees and collisions on urban and suburban conventional highways in California. Transportation Research Record 1908, 114-120.

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Swales

TYPE: Space allocation

MAIN TARGET STREET USE: Green areas

DESCRIPTION

Surface-level channels along the road to transport surface water run-off and facilitate its absorption. Swales are broad and shallow and are usually covered with grass or other vegetation.

Swales can be used in conjunction or as an alternative to underground piped drainage systems and pervious road surfaces. But they should not be above underground utilities that may need to be accessed for repair and maintenance.

Swales can be placed in the road median strip or between the footway and the carriageway (using kerbside space). They may also replace kerbs. Barriers may be needed to prevent moving/parking vehicles from occupying swales.

They can form a network within an area, but need to be covered at road junctions, pedestrian crossings, and crossovers to properties. However, this reduces access to swales for maintenance.

The suitability of swales on a road depends on slopes - should be between 1-4%. In roads with steep slopes, swales may contribute to floods, but in almost flat roads, the ditches may be clogged after rain falls.

EXAMPLES

Ditches (a deeper, narrower version of swales) are common in rural roads. Swales have become common in cities, as a way to prevent floods and preserve biodiversity in a time of environmental change.

Vegetated swales are treated as a priority measure in new and existing roads to manage drainage and surface water control by Auckland Transport (New Zealand).

The Cermak Road-Blue Island Avenue Sustainable Streetscape in Chicago, completed in 2012, included the creation of bioswales, as a part of the transformation of a run-down industrial area.

EVIDENCE

Swales significantly reduce the total volume and flow of water runoff during events with rainfall less than 3 cm, but are less effective in large storm events

Davis et al 2012 Hydraulic performance of grass swales for managing highway runoff. Water Research 46, 6775-6786.

A review found that swales are effective in the removal of pollutants associated with water runoff along roads, especially solids.

Gavrić et al 2019 Processes improving urban stormwater quality in grass swales and filter strips: a review of research findings. Science of the Total Environment 669, 431-447.

Swales contribute to biodiversity. The number of species, species richness and diversity are higher in swales than in other green spaces (gardenbed and lawn-type spaces).

Kazemi et al 2011 Streetscape biodiversity and the role of bioretention swales in an Australian urban environment. Landscape and Urban Planning 101, 139-148.

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PART 14

Surface and underground

Pervious surfaces



Guarda, Portugal ©Paulo Anciaes

TYPE: Design

MAIN TARGET STREET USE: Surface

DESCRIPTION

Road surfaces that allow for the infiltration of water. Pervious surfaces can be permeable (gaps between impervious material) or porous (material that infiltrates water across the whole surface, or green surfaces)

These surfaces reduce the sealed surface of the road, reducing the accumulation of standing water in low-lying areas. This helps to control flooding and manage wastewater. Pervious surfaces are not suitable in roads with high gradients.

Pervious surfaces are especially useful in the parts of the road prone to accumulate standing water, including the footway, kerb extensions, and the median strip. Along these areas, pervious surfaces can be alternated with non-permeable surfaces.

Pervious surfaces are less suitable on the road carriageway because they are less strong than other types of surfaces. In other areas, they require regular cleaning and maintenance to prevent clogging.

They can be used on the carriageway of roads with low traffic volumes and speeds and few heavy vehicles, including alleyways, part-time pedestrianized streets with low traffic, driveways, road shoulders, and on-street parking spaces in residential areas.

EXAMPLES

Setts (also known as Belgian blocks) are rectangular stones used to pave carriageways of many quiet roads in Belgium. They are also used in Rome, Edinburgh, and New York, among other cities.

Most footways in Portugal are paved with small cobblestones arranged in patterns. Non-patterned cobblestones are also used in streets in other countries, often in pedestrianized areas.

Permeable concrete and porous asphalt are common in residential or pedestrianised streets and car parking areas.

EVIDENCE

A literature review found that porous surfaces were effective in controlling water runoff and removing suspended pollutants but permeable surfaces tend to have clogging problems

Schol and Grabowiecki 2007 Review of permeable pavement systems. Building and Environment 42, 3830-3836.

Another review concluded that pervious pavements facilitate the growth and survival of street trees.

Mullaney et al 2015 A review of benefits and challenges in growing street trees in paved urban environments. Landscape and Urban Planning 134, 157-166.

In an experiment, traffic noise on porous road surfaces was 4-5.5 dB(A) lower than on conventional ones. After 4 years, they caused more noise, but still 4dB(A) below conventional surfaces.

Nelson and Abbott 1990 Acoustical performance of pervious macadam surfaces for high-speed roads. Transportation Research Record 1265, 25-33

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Underground utilities under the footway



Figueira da Foz, Portugal ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Underground utilities

DESCRIPTION

Location of underground utilities under the road footway. Underground utilities include electricity and internet conduits, gas pipes, water supply and waste water pipes, stormwater drains, and sewers.

Compared with locating the utilities under the road carriageway, this solution requires less space, as utilities will be closer together, since the footway is usually narrower than the carriageway. But utilities can be split among space underneath footway and carriageway.

This solution also reduces disruption to motorised traffic on the carriageway (e.g. delays, lane or road closures) for upgrades, repairs, or maintenance of utilities, if open-cut methods are used to access them.

However, it causes disruption to pedestrians and place activities (e.g. sitting in outdoor cafes or buying from stalls), when the utilities need to be accessed for repairs and maintenance. It also causes conflicts with the roots of trees planted on the footway.

Utilities under the footway require less protection and less regular maintenance than utilities under the carriageway, as there is less pressure from vehicles. But the installation of utilities contributes to damage of the footway pavement.

EXAMPLES

Most utilities are buried at a shallow depth underneath road footways.

There is increased interest in the use of trenchless systems to access and install and repair utilities, minimizing damage and disruption.

There is also a growing number of examples of consolidated utilities, using tunnels including several utilities.

EVIDENCE

Trenching to install and repair underground utilities damages footways and requires footway pavement to be reinforced and repaired.

Environmental optimization of concrete sidewalks in urban areas. International Journal of Life Cycle Assessment 14, 302-312.

A review found that trenching to install or repair underground utilities underneath footways also damages the roots of street trees.

Jim 2003 Protection of urban trees from trenching damage in compact city environments. Cities 20, 87-94.

On the other hand, street trees also cause damage to underground utilities. A study estimated the costs as \$1.66 per year per tree, in 1996.

McPherson and Peper 1996 Costs of street tree damage. Arboricultural Journal 20, 143-160.

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Underground utilities under the carriageway



New York City, USA ©Paulo Anciaes

TYPE: Space allocation

MAIN TARGET STREET USE: Underground utilities

DESCRIPTION

Location of underground utilities under the road carriageway. Underground utilities include electricity and internet conduits, gas pipes, water supply and waste water pipes, stormwater drains, and sewers.

Compared with locating the utilities under the footway, this solution requires more space, as utilities will be closer together under the footway, which is usually narrower than the carriageway. But utilities can be split among space underneath footway and carriageway.

This solution does not require manhole covers in the footway, allowing for smoother footways. It also reduces disruption to pedestrians and to place activities on the footway for upgrades, repairs, or maintenance of utilities, if open-cut methods are used to access them.

However, it causes disruption to motorised traffic flows or to parking and loading activities at the kerbside, when the utilities need to be accessed for repairs and maintenance.

Utilities under the footway require more protection and more regular maintenance than utilities under the footway, as there is more pressure from vehicles. The installation of utilities also contributes to damage of the pavement of the carriageway.

EXAMPLES

Most utilities are buried at a shallow depth underneath road footways, not the road carriageway.

There is increased interest in the use of trenchless systems to access and install and repair utilities, minimizing damage and disruption.

There is also a growing number of examples of consolidated utilities, using tunnels including several utilities.

EVIDENCE

Trenching to install and repair underground utilities damages the carriageway pavement. A study in San Francisco showed that cuts result in a significant, immediate decrease in the condition of the pavement.

Chow and Troyan 1999 Quantifying damage from utility cuts in asphalt pavement by using San Francisco's pavement management data 1655, 1-7.

At the same time, circulation of heavy vehicles damages underground utilities buried under the carriageway.

Kraus et al 2014 Impact of repeat overweight truck traffic on buried utility facilities. Journal of Performance of Constructed Facilities 28: 04014004

Excavation to repair underground utilities under the carriageway also cause traffic delays and collisions.

Brady et al 2011 Mitigating the disruption caused by utility street works. Transport Research Laboratory Report 516.

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Consolidate underground utilities

TYPE: Space allocation

MAIN TARGET STREET USE: Underground utilities

DESCRIPTION

Also known as multi-utility tunnel. Locate various utilities in a single underground structure with easy access. Underground utilities include electricity and internet conduits, gas pipes, water supply and waste water pipes, stormwater drains, and sewers.

Consolidated utilities are a more efficient use of underground space and reduces conflicts with tree roots, compared with separate utilities. It also facilitates repair work and regular maintenance and upgrades, and minimizes disruption to road users.

The consolidated structure can be accessed from the footway or the carriageway, without the need for repeated excavation and reinstatement. Access can be separate to each utility or to the whole tunnel.

Multi-utility tunnels require a smaller space underground than separate utilities, and for a more rational arrangement of space. They require adequate ventilation and protection from floods. Wet utilities should be separated from others.

This solution requires a large investment and a long construction time, causing prolonged temporary disruption. It also requires the coordination of various public agencies and companies, each responsible for a different utility.

EXAMPLES

The first multi-utility tunnel was the Holborn Viaduct, in London in 1866. They are used in many countries now, with various sizes, shapes, and materials, and locate at various depths.

The 15km utility tunnel in Putrajaya (Malaysia), a planned city developed in the 1990s, houses power lines, water pipes, gas pipes, and communication cables.

The 3km multi-utility tunnel in Marina Bay (Singapore) houses power lines, water pipes, and communication cables.

EVIDENCE

Consolidated underground utilities are more economically sustainable than separate utilities, especially when street works are more frequent and utility density is high.

Hunt and Rogers 2014 Sustainable utility placement via multi-utility tunnels. Tunnelling and Underground Space Technology 39, 15-26.

Evaluation of a utilities tunnel in Tehran found the project is environmental sustainable, considering a number of indicators of the environmental impact of construction and operation.

Phillips 2016 A quantitative evaluation of the sustainability or unsustainability of three tunnelling projects. Tunnelling and Underground Space Technology 51, 387-404.

A study in Spain used a descriptive approach to show the advantages of consolidated utilities in terms of urban regeneration and visual aspects; but also technical, administrative, and legal issues in implementation.

Valdenebro and Gimena 2018 Urban utility tunnels as a long-term solution for the sustainable revitalization of historic centres: the case study of Pamplona-Spain. Tunnelling and Underground Space Technology 81, 228-236.

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