4. VULNERABLE ROAD USER INFRASTRUCTURE DESIGN

General description

Vulnerable road users generally refers to those modes of travel that do not include cars, public transport, or licensed commercial vehicles—those where the road users are protected from injury by an enclosed vehicle. It includes both nonmotorized travel and motorcycles.

Motorcycle and moped use are on the increase. These offer a solution to growing traffic congestion, parking problems, and the high cost of private car ownership. Users range from leisure bikers on high-powered machines to young people and professionals commuting by moped. More detailed discussion on their safety issues is provided in section 4.3.

An emerging form of personalized travel is the use of e-scooters, which are being used extensively in several countries. However, at the time of writing no specific consensus has yet been reached in many cases regarding the legal situation on their use on either roadway or footway/cycleway. Their relative speed to both normal motorized and nonmotorized traffic is a particular concern, as is adequate protection of riders.[39]

Independent nonmotorized travel (NMT), which includes both walking and cycling, is an essential part of any journey in low- and middle-income countries (LMICs), and all trips include an element of walking or independent movement. However, the provision for undertaking these types of trips is often disjointed or included as an afterthought of the improvement of motorized travel.

Increasing global problems of climate change and obesity are emphasizing the importance of such independent movement, which is often the only form of travel available in many LMICs, to increase personal health and reduce CO2 emissions. The development of appropriate and continuous networks that allow for as much independent travel as possible is a key element in sustainable travel. The positive improvement of these forms of travel in any road safety work is essential.

LMICs are particularly favorable for implementing independent NMT policies. While policies in many Western countries are focused on increasing the share of nonmotorized trips, LMICs already have a substantial proportion of their residents moving in a sustainable way.

The key to successful designs for safe NMT is to ensure that these trips should be direct, coherent, comfortable, safe, and enjoyable. There is also evidence from LMICs that NMT users, particularly cyclists, prefer safer routes compared to shorter routes within certain limits.[40] While in many cases NMT users will follow the motorized route network, this should not be a precondition. Independent networks free from motorized traffic provide safer, more direct, and enjoyable routes.

Where they do have to follow motorized routes then they need to be incorporated as part of a "complete streets" design (see section 2.4.3). In 2012 international Road Assessment Programme (iRAP) reported that 84 percent of the approximately 50,000 km of roads

39 ETSC. 2019. Safer Roads, Safer Cities: How to Improve Urban Safety in EU.

40 Majumdar, B. B., and Mitra, S. 2018. Analysis of bicycle route-related improvement strategies for two Indian cities using a stated preference survey, Transport Policy, Volume 63, pages 176–188.

assessed in low- and middle-income countries where pedestrians are present carry traffic at 40 km/h or more and have no footpaths.

Safety implications

- Roadway design generally caters for the needs of four-wheeled motorized traffic, neglecting the needs of pedestrians, cyclists, or motorcyclists.
- Facilities for a "typical" pedestrian may not accommodate a significant portion of users, including older adults, people with disabilities, and children.
- Increased vehicle speeds are associated with increased injury severity and death for vulnerable road users. The provision of arterial roadways, intersections, and fast traffic lanes without adequate attention to facilities for other modes results in an increased likelihood that they will be killed or injured when using the road.
- Motorcycles, bicycles, and pedestrians are less easy to see, especially by faster moving vehicles.

Figure 4.1: Separation of a vehicular travel way, cyclist path, and walkway on an urban arterial with concrete paving blocks on walkway and sealed cyclist path.

Source: ITDP, 2019

- High speed and volumes of motorized vehicles require the separation and protection of both pedestrians and cyclists (figure 4.1). The risk of pedestrian injury is high when pedestrians share the road with vehicles travelling at fast speeds (greater than 30 km/h). Vehicle–pedestrian collisions are 1.5 to 2.0 times more likely to occur on roadways without sidewalks.[41]
- Roadway designs in which facilities such as defined walking routes and signalized crossings are missing, inadequate, or in poor condition increase the risk of injury for pedestrians.
- Pedestrians falling into roads occurs where there is too little friction or traction between the footwear and the walking surface due to wet surfaces, weather hazards, and flooring or other walking surfaces that do not have same degree of traction in all areas (figure 4.2). In addition, obstructed visibility of footpaths (e.g., improperly placed signs or trees, poor lighting) also increases the risk. The quality of footpaths is important for the safety of footpath users, including people with disabilities. Disable-friendly
- Intersections are associated with high rates of collisions and injuries because they include many conflict points.
- Uncontrolled intersections exacerbate such conflicts, as vulnerable users may encounter oncoming vehicles that are not required to stop or yield travelling at elevated speeds.
- Vertical separation (overbridges and underpasses) is expensive and require large amounts of space. They may also be inaccessible to some users, or even be unsafe from a personal security perspective.

Specific design requirements for pedestrians, cyclists, and motorcycles are considered in the following sections.

41 Knoblauch R. L., et al. 1988. Investigation of exposure-based pedestrian accident areas: crosswalks, sidewalks, local streets, and major arterials. Washington, DC, Federal Highway Administration.

Figure 4.2: No tripping hazards or slipper floors.

Source: Deep Dive on accessibility and transportation/The World Bank.

4.1. Pedestrian Facilities Design—Footpaths

Good design practice/ treatments/solutions

Separate footway provision

- In LMICs, mixed use of the road space is common in both urban and rural areas. A key consideration in providing safe routes and facilities for vulnerable users is the speed, size, and volume of all vehicle types.
- To promote a safe environment for walking, pedestrians must be provided with a complete network with sufficient space to walk along the public right-of-way.
- In urban and suburban areas where pedestrian volumes may be high, the most common form of provision is the inclusion of a paved or sealed footway immediately adjacent to, and raised above, the vehicular carriageway (figures 4.3 and 4.4).
- If speed and volumes are low, then less segregation and protection are necessary, and in certain instances the vulnerable users may dominate the street space (figures 4.5 through 4.7).
- 1.8m is considered the absolute minimum clear width to allow pedestrians to pass each other without having to move into the vehicular path. Increased width may be needed as pedestrian flows increase to prevent overspill into other use areas (i.e., cycle lanes or traffic lanes).

Note: COVID-19 implications on footway width may require an increase to 2.5 m.

- A positive crossfall toward the roadway is required on footways to assist drainage. Typically this is 2.5 percent or 1 in 40, although lower gradients may be used in areas with harsh winters and ice. Gradients greater than 3.3 percent (1 in 30) make it difficult to walk on, particularly when pushing strollers or for wheelchair users.
- The width of footpaths, a necessity for safe footpaths, is primarily determined by the type and density of land development and the volume and needs of pedestrian and vehicular traffic. Typically, these are expressed in different levels of service for

Figure 4.3: Typical Urban footpath—Ghana.

Source: © John Barrell.

Figure 4.4: Urban footpath with protection from traffic and dangerous slope, Ghana.

Source: © John Barrell.

Figure 4.5: Shared space in urban area.

Source: © Soames Job. .

Figure 4.6: Shared space—India.

Source: © Soames Job

Figure 4.7: Mixed traffic in rural road.

Source: World Bank

pedestrian footpaths based on flow rates, space per person, and description of flow.

- In addition to the minimum passing width noted above, it is also necessary to consider the adjacent land uses and the likelihood of encroachment into the clear pedestrian route.
- A zoning concept that divides the corridor into three main zones—the frontage zone, the pedestrian zone, and the furniture zone—can allow for the safe and convenient use of pedestrian space. Each of these zones plays an important role in a well-functioning pedestrian corridor.
- Footways should be raised above the vehicular carriageway by at least 75 mm, with a defined boundary on both sides.
- If motorists are known to regularly mount the edge of a footway along a length of curbline, the use of a high curb face should also be considered as an alternative to using a line of bollards. A curb face of 125 mm–140 mm will usually stop motorists mounting the edge of the footway when stopping.
- It is crucial that the footpath is not obstructed for pedestrian use and to understand the characteristics of the full range of the pedestrian population that may use the facilities to ensure the design of pedestrian facilities accommodates the range of pedestrian abilities (figure 4.8).

Figure 4.8: Obstructed footpath, and lack of drop curb in Manila.

Source: © Blair Turner/GRSF

Figure 4.9: Well zoned footway with clear pedestrian route and tactile guidance in China.

Source: © John Barrell

Figure 4.10: Poorly maintained pedestrian guardrail—Maintenance Inspection.

Source: TRL.

Figure 4.11: Unprotected footpath on rural national road.

Source: PIARC

- Pedestrians have a wide range of characteristics and needs, such as walking speed, spatial needs, mobility issues, and cognitive abilities. They need clear guidance for safe routes and identification of conflict points with vehicles, for example, the use of tactile paving and a visual contrast of surfaces (figure 4.9).
- Pedestrian facilities need to be regularly maintained to ensure their safety and function (see figure 4.10 for an example of poorly maintained guardrails).
- In rural areas, where pedestrian traffic might be less frequent, walkable shoulders may be sufficient where vehicle flows are high. Care will also be needed to ensure that these shoulders do not become running or stopping lanes that might endanger pedestrian use (see figure 4.11 as an example of pedestrians exposed to high risks due to the lack of protection from vehicle traffic).
- For low vehicle flows and low speeds, no provision of separate footways may also be an appropriate solution, but care is needed to both manage vehicle speed and make sure that vulnerable users are not hidden by the alignment.
- Separate trails or shared-use paths can safely convey pedestrians along rural routes either adjacent to the vehicle route or completely separately (figure 4.12).

Figure 4.12: Segregated pedestrian/nonmotorized transport facility on rural road.

Source: PIARC.

Figure 4.13: Clear urban footway on median—Kenya.

Source: © Watetu Mbugua/GRSF/World Bank.

Figure 4.14: Lively sidewalk project—transformation from no footpath to protected footpath.

Source: Prefeitura Municipal de Fortalenza and Bloomber Philanthropies, PIARC

- On rural routes, and particularly on high volume urban highways, adequate separation and protection for the pedestrian route are essential (figure 4.13).
- Ideally pedestrian routes should be separated to the rear of the clear zone to minimize impact from errant vehicles
- A buffer zone between pedestrian movement and vehicles can be provided for signage, lighting, or planting. Care should be taken that these do not form roadside hazards (See section 5.7 on roadsides).
- If segregation is not possible, then an adequate vehicle restraint system needs to be provided. This may also deter pedestrians from crossing the route; however, additional measures may also be necessary to prevent unsafe interaction between pedestrians and traffic and safe convenient crossing points provided to deter the unsafe crossing.
- Pedestrians and vehicles are able to share the same space safely where speeds are less than 20 km/h. In these shared zones, pedestrian movements have equal priority with vehicles and vehicle speeds are low. Often this is a result of the high number of pedestrian movements compared to vehicles. Crucially these are not major transport corridors, and alternative through routes for vehicles must be available.
- At speeds of 30 km/h, separate provision needs to be made where frequent pedestrian use is expected (see figure 4.14).

4.2. Pedestrian Facilities Design—Crossings

Good design practice/ treatments/solutions

A crucial aspect of designing a safe and accessible pedestrian route is adequately dealing with crossing requirements of the motorized corridor. This can be done in several ways that are dependent on the concentration and volume of pedestrian and vehicle movements.

Often pedestrians need to be guided to appropriate crossing points or deterred from crossing in unsafe locations. This is often achieved by using pedestrian fencing or guardrails close to the curb edge. Unless alternative safe crossing points are available that are perceived as being convenient to use, any barriers may soon become damaged or stolen to recreate the more direct (even though dangerous) crossing point.

When considering pedestrian crossings at intersections, the ability to cross the minor road safely is as important as the crossing of the main road in order to provide consistent route continuity for pedestrians. The level of provision on the minor road need not be the same as on the major road, but it is usually safer to maintain the same level of control on each arm.

Additional consideration may need to be given at school crossing locations given the extra vulnerability of children. This may include lower speed zones, additional signage, enhanced crossing facilities, or even crossing supervisors. Equal consideration needs to be given to pedestrians' crossing of minor roads and accesses away from formal junctions.

Grade-separated/controlled crossing

- Grade-separated crossings (figures 4.15 through 4.17), whether under or over roadways, are expensive pieces of infrastructure to install and need to be justified by demand and provide convenient crossing, otherwise they will be ignored.
- Where high volumes of pedestrians are concentrated in infrequent and specific locations, grade-separated crossings can be appropriate, either as a pedestrian overbridge or underpass. They involve separating pedestrians from traffic by placing them at different levels and are often used where pedestrian crossing signals would cause delays and queueing or crashes (due to high traffic speeds). Pedestrian overpasses and underpasses require users to deviate from their preferred desired line—a direct crossing from A to B. Pedestrian route selection is typically determined by the shortest, fastest, or most convenient route.[42]

Figure 4.15: Grade separated footbridge—Ethiopia.

Source: © John Barrell.

Figure 4.16: Grade separated underpass—US.

Source: Greenbelt. Accessed at https://greenbelt2012.wordpress.com/2012/12/17/greenbelts-original-pedestrian-underpasses/.

Figure 4.17: Well designed foot bridge—Shanghai.

Source: © Alina F. Burlacu/GRSF/World Bank.

42 A. Agrawal, M. Schlossberg, and K. Irvin. 2008. How far, by which route and why? A spatial analysis of pedestrian preference Journal of Urban Design, Vol. 13. No. 1, 81–98.

Figure 4.18: Signalized pedestrian crossing.

Source: iRAP.

- Any deviation from this straight line, either vertically or horizontally, reduces the attractiveness of that route and increases the likelihood that it will not be used. Closure or obstruction of the direct route is needed to encourage use of the safer alternative.
- Ideally these facilities should have ramps rather than steps to accommodate the mobility impaired, but this often increases the length of any diversion (see 5.12 Curbs for good design examples at crossings).
- Clear sight lines on approach and through the crossing and sufficient lighting must be provided with no places for people to hide, as they can be seen as a security hazard with the opportunity for personal attacks, especially at night.
- The risk of personal attack reduces their attractiveness and increases the likelihood that crossings will not be used.
- To be effective they need very careful design and location to ensure ease of access. They also require sufficient lighting, adequate drainage, and proper maintenance to keep them in clean and tidy conditions.
- Often the provision of planned retail or vendors is good for increased security. Such design should be encouraged.
- Once constructed they cannot easily be moved to accommodate changing movement patterns!
- For underpasses it is possible to use a reduced height (2.5 m) and raise the carriageway by a maximum of 1.5 m, as well as lowering the footpath to reduce both cost and impact.

Figure 4.19: Scramble Intersection.

Source: London Evening Standard April 13, 2012.

Pedestrian crossing signals

It is much easier to provide crossings at the same level as the rest of the route, but then this requires segregation in time, i.e., specific times for pedestrians and vehicles to use the same space.

- Signalized pedestrian crossings at intersections (figure 4.18) aim to reduce vehicle/pedestrian conflicts.
- They provide right-of-way access to pedestrians during a green pedestrian phase when conflicting or all traffic is stopped.
- At intersections with high pedestrian volume, it is also common to treat them as scramble intersections (figure 4.19), where pedestrian movements from all directions are allowed in a single green phase, including diagonal movements.
- Pedestrian green time should be timed to give pedestrians long enough to complete their crossing before the signals change to allow vehicle traffic to start passing through the crossing again. (Assume pedestrian walking speed 1.2 m/s.)
- Long waiting times for pedestrians can increase the likelihood of violations.
- Sufficient time is needed for pedestrians to clear the crossing before traffic can start when neither movement is permitted to start (blackout period or "all red").
- There can be compliance issues with vehicles failing to obey signals, or failing to give way when turning at signals is a common issue. A lead phase

Figure 4.20: Well defined at-grade crossing—Rwanda.

Source: © John Barrell.

Figure 4.21: Raised crossing to slow approach speeds—Kenya.

Source: © John Barrell.

Figure 4.22: Well defined crossing with signing—Singapore.

Source: © Alina F. Burlacu/GRSF/World Bank

can be included at signals to give pedestrians an early start at signals before other road users are allowed to start. This is useful to reduce the incidence of turning vehicles striking pedestrians at intersections, as this gives greater visibility to crossing pedestrians.

- Tactile paving should be provided to guide the visually impaired pedestrians through the crossing, and parking should be removed from the immediate vicinity of the crossing to provide adequate sight lines.
- To maintain the safety and segregation of uses, it is important that filter lanes are omitted where pedestrian crossings are in place.
- Countdown timers at signals can also provide phase duration information to pedestrians. The timers display the time remaining until the end or start of a pedestrian green phase and remove some of the doubt for all users.
- In addition to signalized crossings, other crossings that give priority to pedestrians typically consist of signs and painted road markings ("zebra crossings").
- These formalize the crossing location giving pedestrians the right-of-way over vehicles. They also increase the awareness for other road users that pedestrians may be present, improving expectations about the need to stop.
- They also cater for the mobility impaired with footways ramped down to carriageway level or the carriageway lifted to footway level.
- Audible and tactile warning of the pedestrian crossing phase can also be provided on the traffic signal pole.
- Especially where vehicle approach speeds are high, at-grade raised pedestrian crossings can improve safety, but need to be clearly signed and have sufficient advance warning for drivers to react to their presence (figures 4.20 through 4.22).
- Extra care is required when designing signalized pedestrian crossings either at intersections, or away from intersections, in higher-speed, multilane environments. Vehicles may fail to stop either because they fail to see the signals or do not comply, and this results in high severity outcomes.
- Raised pedestrian crossings have a similar profile and speed reduction effect as flat top speed humps (safety platforms), but they differ in that they give priority to pedestrians rather than motorists.
- They consist of a raised platform with a marked pedestrian crossing on top.
- The raised crossing serves the purpose of slowing vehicles, as a speed hump or platform, but also increases the visibility of pedestrians due to the increased height.
- As they are raised to footway level, they do not need a ramped approach, but still need tactile paving to assist the blind and partially sighted.

Figure 4.23: Pedestrian refuge alone

Source: © John Barrell.

Figure 4.24: Controlled crossing with refuge.

Source: © John Barrell.

Figure 4.25: Lack of pedestrian space on median—mauritius—safety inspection.

Source: TRL.

Figure 4.26: Painted and narrowing approach to crossing.

Source: © Alina F. Burlacu/GRSF/World Bank.

- Other speed reducing features can be used in advance of pedestrian crossings and typically result in a lower likelihood of a crash occurring, and lower severity when collisions with pedestrians do occur.
- Narrowing of the roadway can also provide a safety benefits; as pedestrians have less distance to cross, facilities can be included to make pedestrians more visible, and speeds may be reduced. Alternatively, the crossing movement can be split into two with provision of a protected median or refuge for pedestrians (also see uncontrolled crossing section below).

Uncontrolled crossings

- Wide crossings (of more than two lanes) can be narrowed by providing central refuge islands to limit the amount of time pedestrians are exposed to traffic.
- Pedestrians and drivers need to maintain alertness where pedestrians are crossing multilane roads, as they are often hidden from drivers' view, and vice-versa, by vehicles in adjacent lanes.
- Pedestrian refuges are raised median islands in the middle of the road that provide an area for pedestrians to safely wait until an appropriate gap allows them to cross (figures 4.23 and 4.24).
- Islands need to be wide enough to protect pedestrians with strollers (and cyclists) from passing traffic (1.8 m) (figures 4.25 and 4.26).
- This simplifies the crossing maneuver for pedestrians by creating the equivalent of two narrower one-way streets instead of one wide two-way street.
- Refuges are particularly useful for those who are wheelchair-bound, elderly, or otherwise unable to completely cross the road in one movement.
- Islands can also have additional benefits, including

acting to separate traffic moving in opposite directions, controlling vehicle speeds by narrowing the roadway, and providing motorists with an indication of where pedestrians might cross a roadway.

- Footway ramps with tactile paving need to be included to make them appropriate for all mobility conditions.
- Refuges alone do not give any priority for pedestrians to cross.

Case Study

Figures 4.27 through 4.29 illustrate the installation of pedestrian crossing facilities.

Figure 4.27: Transformation from no crossings to well defined raised crossing with signing.

Source: Prefeitura Municipal de Fortaleza and Bloomberg Philanthropies, PIARC.

Figure 4.28: Installing pedestrian refuge—Vietnam.

Source: iRAP

Figure 4.29: Installing raised crossing with signings and protected footpath—Zambia

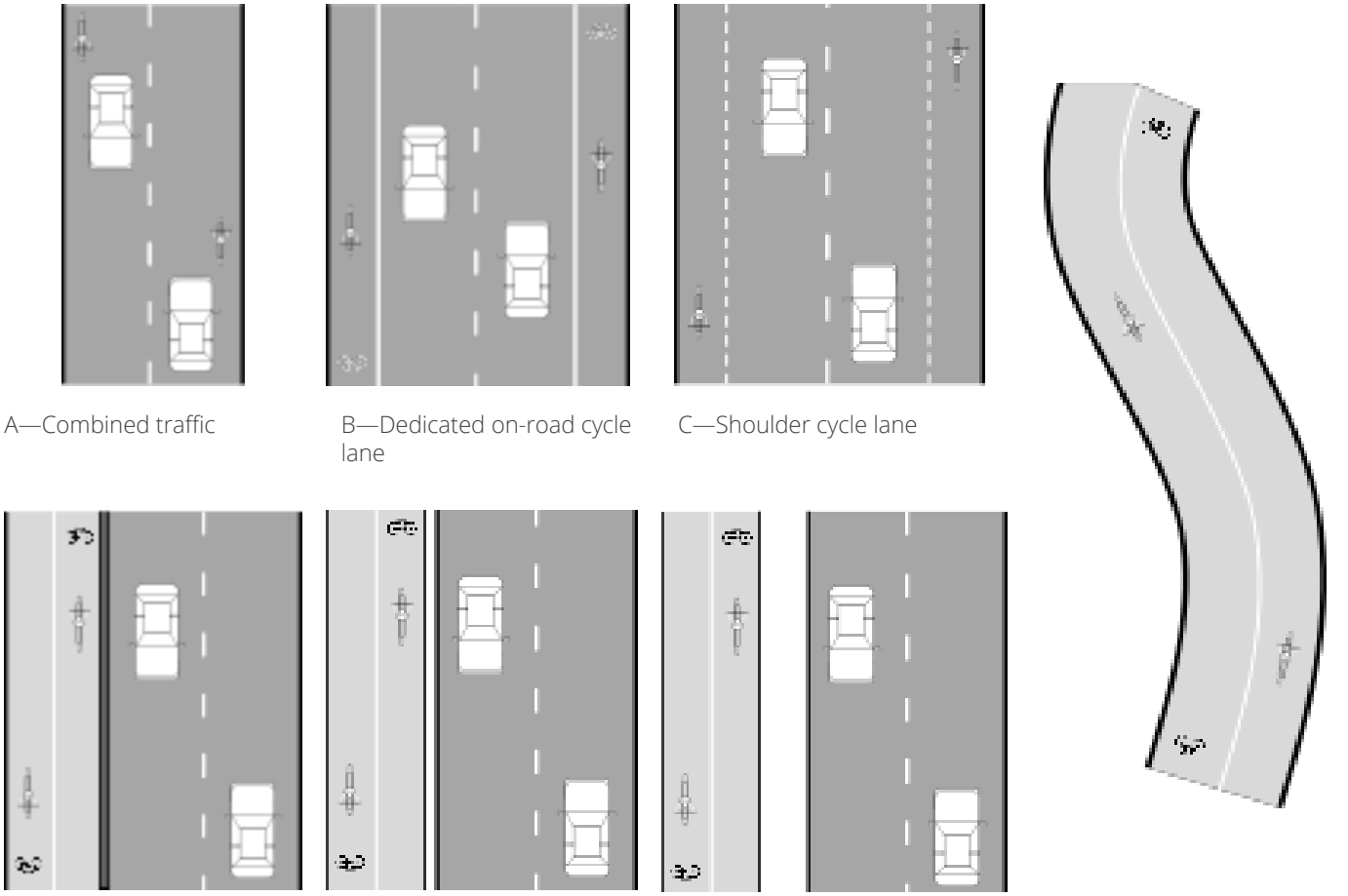
Source: iRAP.

4.3. Cyclist Facilities Design

Safe cycle provision can be achieved in a number of different ways, from separate cycle networks to on-road painted cycle lanes (figure 4.30).

Cycle highways are separate paths for cyclists (and pedestrians) away from motorized traffic (see figure 4.30- G above and figure 4.31). They can facilitate daily, long distance cycle journeys. This may be as a regional connection, a commuter route into a business district, or between residential areas.

Figure 4.30: Examples of cycle paths



A—Combined traffic

B—Dedicated on-road cycle lane

C—Shoulder cycle lane

D—Separate curbed cycle path

E—Separate cycle lane with narrow separation

F—Separate path for pedestrians and cyclists

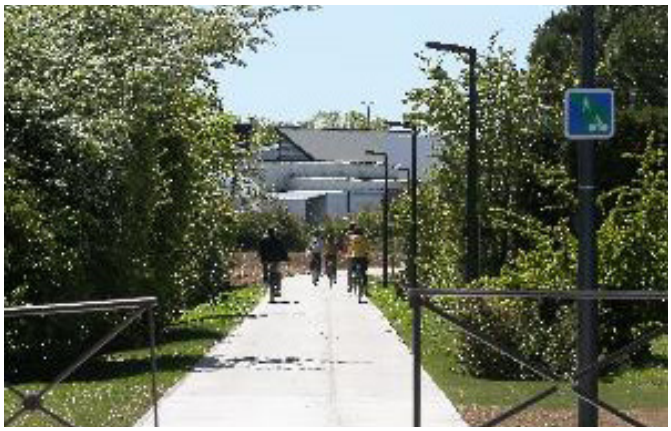
G—Pedestrian and cycle route independent of roadway

Source: © Milly Lumumba/GRSF/World Bank.

Cycle highways are separate paths for cyclists (and pedestrians) away from motorized traffic (see G above and figure 4.31). They can facilitate daily, long distance cycle journeys. This may be as a regional connection, a commuter route into a business district, or between residential areas.

They have been described as the backbone of the wider cycling network, as the cycle highways often connect multiple local networks. The UK has a national cycle network that has been developed over many years, utilizing old rail corridors, canal towpaths, and quiet low volume roads. The most recent development has been the Barclays Cycle Superhighways in London, all of which are to encourage safe and comfortable cycle journeys. Cycle highways provide direct, flat, and continuous tracks that often link popular origins and destinations.

Figure 4.31: Green Corridor—La Rochelle France.



Source: European Committee. Accessed at https://ec.europa.eu/transport/themes/urban/cycling/guidance-cycling-projects-eu/cycling-measures/cycle-highways_en.

They have been described as the backbone of the wider cycling network, as the cycle highways often connect multiple local networks. The UK has a national cycle network that has been developed over many years, utilizing old rail corridors, canal towpaths, and quiet low volume roads. The most recent development has been the Barclays Cycle Superhighways in London, all of which are to encourage safe and comfortable cycle journeys. Cycle highways provide direct, flat, and continuous tracks that often link popular origins and destinations.

Cycle streets (also known as "boulevards") are a form of mixed-traffic street where the needs of cyclists (and possibly pedestrians) are prioritized over motor vehicles. Cycle tracks provide a physically separated space in which people who cycle can travel without mixing with motor vehicles—through either a physical barrier or raising the track to a higher level (or both), incorporating appropriate side clearance (see E or F in figure 4.30). Cycle lanes can be relatively quick and inexpensive to implement, making them one of the most common forms of cycle paths implemented in cities. They can be either on-road (see B or C in figure 4.30) or off-road or shared footways (see D in figure 4.30), and allow people who cycle to take advantage of the accessibility that the existing road network provides.

Good design practice/ treatments/solutions

Cyclists consist of a wide range of abilities and uses, from occasional recreational use to regular commuters and sports cyclists. The needs of each group are different and need to be accommodated in any specific provision.

Basic quality design principles aim to increase actual and perceived safety, and include:

- Limiting conflict between cyclists and other cyclists, pedestrians, or motorists.
- Ensuring low-stress environments where mixing with other users is limited and controlled.
- Separating main routes for cyclists from pedestrian routes.
- Reducing motor vehicle traffic volumes and speeds around cyclists, especially when road users mix.
- Separating cyclists from fast/heavy motorized traffic, reducing the number of dangerous encounters—including separation on routes and/or at intersections and on-street parking.
- Ensuring conflict points at intersections and crossings are clearly presented so that users are aware of the risks and can adapt behavior appropriately.
- Visibility of cyclists to motorists should be maximized at the approach to intersections.
- Ensure cycling infrastructure is well maintained—especially quality of pavement and continuity through intersections. Wide shoulders may be provided to allow for cyclists' use, along with protection from vehicular traffic using shoulder rumble strips or physical barriers (figures 4.32 and 4.33).

Cycle tracks

- For cyclists, the use of segregated cycle tracks (figures 4.34 through 4.37) is the ideal solution; the use of such lanes by motorcycles/ three wheelers needs to be taken into account, which can make

Figure 4.32: Cyclists using a narrow shoulder—Rwanda.

Source: © John Barrell.

Figure 4.33: Cyclists on sealed shoulder with overlay to roadway causing level difference—Rwanda.

Source: © John Barrell.

Figure 4.34: Urban cycle track in China.

Source: © John Barrell.

Figure 4.35: Cycle track in Beijing, China.

Source: © Blair Turner/GRSF/World Bank.

Figure 4.36: On-road segregated cycle path on a highway in Ethiopia.

Source: Dipan Bose/World Bank

Figure 4.37: Well designed cycle lane—Shanghai.

Source: © Alina F. Burlacu/GRSF/World Bank.

the situation more difficult for pedestrians (and cyclists).

- To be effective, they require parking enforcement to avoid vehicles blocking them, and careful treatment at junctions.
- Along straight sections of the carriageway, cycle tracks provide greater protection for people who cycle compared with cycle lanes, as they are physically separated from the traffic lanes.
- Buffer zones between cycle tracks and parked vehicles or moving car traffic are strongly recommended.
- At intersections designs must ensure that the visibility of people cycling to motorists is maximized.
- Where possible, priority should be awarded to people who cycle at intersections on cycle tracks (especially where it is given to traffic on the adjacent carriageway).
- Clear markings and accompanying signage should be in place to increase the visibility of the cycle tracks.
- They should be wide enough for people who cycle to feel comfortable and safe (minimum 3 m) and allow overtaking between cyclists moving in the same or opposite directions.
- Overall width will depend on the volume of cyclists.
- Where they allow two-way cycling, centerline marking should be used along the track and at intersections to raise awareness.
- The surface of cycle tracks should be smooth (closed surface paving) and level and well maintained.
- Roadside objects can present a hazard to cyclists, especially at higher speeds, and so should be removed or protected where possible.
- Preferably the surface should be colored and cycling symbols used to improve awareness and understanding.

Cycle lanes

- When the design of the cycle lane follows best practice and implementation is part of a coherent network, cycle lanes offer a safe and convenient route for people who cycle to travel around a city.
- In rural areas, cycle lanes can also be provided on the paved shoulders (caveats as for pedestrians use discussed above apply).
- They should only be applied on streets with medium or low motor vehicle volumes and speeds.
- Where vehicle speed and/or volume are high, then separate cycle lanes should be used (figure 4.38 and 4.39).
- Cycle lanes should be wide enough for people who cycle to feel comfortable and safe, allowing for comfortable clearance of other users, with surfaces smooth and level.

Figure 4.38: Shared footway/cycleway Tanzania.

Source: © John Barrell.

Figure 4.39: Cycle lane separated from main road vehicle traffic—Bucharest, Romania.

Source: © Alina F. Burlacu/GRSF/World Bank.

Figure 4.40: Unsuccessful cycle lane separated from vehicle traffic/ parking—Bucharest, Romania.

Source: © Alina F. Burlacu/GRSF/World Bank.

- Minimum recommended width is 2.5 m for a single direction.
- Clear markings and accompanying signage should be in place to increase the visibility of the cycle lanes.
- Buffer zones may be considered between the cycle lane and motorized traffic where safety is of concern, particularly where there is heavy freight traffic.
- Buffer zones between the cycle lane and parked vehicles are strongly recommended.
- Cycle lanes separated from motorized traffic simply by painted road markings lead to parking and moving traffic encroachment (figure 4.40).

Contraflow cycle lanes

- Contraflow refers to cycles travelling in both direction on the same facility.
- This can contribute to improving conditions for cycling, including increased accessibility, coherence, and convenience, especially in urban one-way networks.[43]
- Contraflow cycling can also contribute to improving conditions for cycling more generally within a city, improving the convenience to travel. This can be implemented through:
    - Unsegregated two-way cycling on an unmarked road (quieter roads), which can be implemented through the use of signage.
    - The use of designated contraflow lanes on one-way roads with a high traffic volume.
- Since almost all conflicts take place at road crossings, it is often considered sufficient to mark contraflow lanes at the crossings only (10 m length).
- Usually, on straight stretches, no markings are required.
- This lower cost allows the cyclist to ride centrally in the road when there is no traffic ahead, reducing the risk of dooring or vehicles parking out, and makeing it easier to change the direction of the one-way road.
- Implementation of contraflow lanes may involve segregated lanes and pavement build-outs and should be decided based on factors such as the traffic volume and speed, and road width.

Cycle streets

Cycling should be the dominant mode, while the number of motor vehicles should be minimized, and so cycle streets are most likely to be implemented on through or main cycle routes where motorized traffic requires access to local destinations (figure 4.41). Design and signage should clearly assign priority to cyclists, and the route should be attractive to cyclists due to its comfort and directness.

Figure 4.41: Cycle street—UK.

Source: Gear Change A bold vision for cycling and walking

43 https://ec.europa.eu/transport/themes/urban/cycling/guidance-cycling-projects-eu/cycling-measure/contra-flow-cycling_en.

Figure 4.42: Advance cycle stopline (bike box) with contraflow cycle lane.

Source: Brighton & Hove City Council.

Figure 4.43: Right-of-way intersection (for cyclists)—Holland.

Source: Dutch Cycling Embassy

Intersections

The traffic intensity, speed and number of traffic lanes should guide the choice of the most appropriate intersection design. At any intersection, there will be conflict points between transport modes, but effective intersection design can reduce possible conflicts and increase safety and comfort for cyclists.

Knowledge is increasing about types of infrastructure that can be provided at intersections to improve safety for cyclists. Good design will generally include the following principles:

- Avoid mixing motor traffic with cyclists where the traffic flow and/or speed is typically high.
- On carriageways with low traffic volumes and low traffic speeds (typically 30 km/h or less), cyclists usually mix with other road traffic, and cycling specific infrastructure is typically not necessary at intersections.
- Maximize separation of cyclists from dangerous traffic movements.
- Separate traffic light phases for people cycling and people motoring or separate routes by over/underpasses.
- Maximize the visibility of cyclists.
- Make drivers aware of cyclists on the approach to an intersection.
- Use bike boxes (figure 4.42) and advanced green lights to allow cyclists to proceed through an intersection ahead of other road traffic.
- Intersections should be easy to identify, understand, and safe to use by all transport users. This requires specific designs to underline the priority status of cyclists.
- For any type of intersection, the primary consideration for safety is visibility of cyclists.
- In situations where cyclists and motor traffic are approaching the intersection in close vicinity (i.e. cycle lanes or mixed traffic), it is assumed that drivers are aware of cyclists.
- In situations where cyclists are separated from the carriageway, it is advised that the cycle path should be designed alongside the carriageway on the approach to the intersection to increase drivers' awareness of cyclists.
- Advanced cycle stop line/bike box gives cyclists advantage away from signal stop lines.
- Turning provisions may be needed at intersections for motorized vehicles cutting through cycle lanes to ensure cyclists are highly visible. This includes colored road surfacing for the cycle lane and additional signage.

Figure 4.44: Roundabout for cyclists—Netherlands.

Source: Bicycle Dutch.

Single lane roundabouts are considered the safest intersection design for all users on moderately busy roads if designed correctly. They reduce the speed of approaching traffic and allow the smooth flow of traffic through the intersection. Two-lane roundabouts can be particularly dangerous for cyclists due to the movement of motor traffic between lanes.

Figure 4.45: Floating roundabout for cyclists—Netherlands.

Source: Ronald Otten/Bicycle Dutch.

- Right-of-way intersections (figure 4.43) are the simplest intersection solution on roads with low traffic intensities, while signalized intersections are recommended when a cycling route crosses a main road with high traffic volumes, and particularly if there are multiple lanes.
- Single lane roundabouts (figure 4.44) are usually a safer alternative to signalized intersections due to the lower speed environment these create and reduced conflict points, although they cannot handle as many vehicles.
- When a busy cycle route crosses a main road with high traffic volumes, a grade-separated crossing is preferred (figure 4.45).

General Cycle Case Study/Example

Nairobi, Kenya: Nairobi was the first pilot country for a "Share the Road" design. A showcase road has been constructed that was entirely financed by the government. The adaptation of the 1.70 km UN Avenue included the construction of a three-meter-wide sidewalk on both sides, and a three-meter two-way segregated cycle lane (figure 4.46). The rehabilitation also included redesigning the intersection on Limuru Road and adding a slip-turn lane with a corner island to facilitate pedestrian crossing. The bus stop was relocated a few meters to avoid conflict with turning vehicles. The road was selected because there were recurrent severe crashes over a short period of time, which highlighted the need to improve road conditions.

Separating pedestrians and cyclists from vehicles through NMT infrastructure has reduced the severity and number of crashes. However, improved driving conditions have actually increased vehicle speeds as well as their number. Traffic calming measures, such as raised zebra crossings and refuge median islands, improve crossing conditions. But in sections where vehicles continue to circulate at high speeds, the painted-only pedestrian crossings have little effect on traffic.

Despite changes in the bike pathway to facilitate NMT,

Figure 4.46: Bicycle lanes separated from pedestrians.

Source: Share the Road Design Guide UNEP/FIA.

Figure 4.47: Installing crossings with advance cycle stopline—India.

Source: iRAP.

after six months of operation, the number of cyclists remained steady on the road section. Surveys show that most cyclists use the avenue as an access route, while pedestrians generally start or finish their trip in the neighborhood. Cycling trips tend to be longer than the intervention area.

As an additional case study, figure 4.47 illustrates the installation of crossing facilities including an advance cycle stopline in India.

Further Reading

- WHO. 2013. Pedestrian safety: a road safety manual for decision-makers and practitioners, https://www.who.int/publications/i/item/pedestrian-safety-a-road-safety-manual-for-decision-makers-and-practitioners. Must read chapter 2, Pedestrian safety in roadway design and land-use planning,
- UN-Habitat & Institute for Transportation and Development Policy. July 2018. Streets for walking & cycling—Designing for safety, accessibility, and comfort in African cities: Must read the section for foot path, cycle track, intersection, and design process.
- ARRB Project Report No: PRS17017. 2017. Road safety measures to achieve Safe System outcomes for pedestrians.
- FHWA. 2007. Pedestrian Road Safety Audit Guidelines and Prompt Lists FWHA-SA-07-007. Must read chapter 4, Using the guidelines and RSA prompt lists and chapter 5, Guidelines—detailed descriptions of prompts.
- United Nations Environment Programme. 2013. Share the Road—Design Guidelines for NonMotorised Transport in Africa. Must read chapter 1, Policy for Walking and Cycling, chapter 2, Improving Pedestrian Facilities, and chapter 3, Cycling Infrastructure.

4.4. Motorcyclist Facilities Design

General description

Motorcycle and moped use is on the increase and offers a solution to growing traffic congestion, parking problems, and the high cost of private car ownership. Users range from leisure bikers on high-powered machines to young people, professionals commuting by moped, and transporters of goods, and public transport users (figures 4.48 and 4.49). They are a popular form of transport because they are relatively cheap compared to other forms of motorized vehicles, provide mobility to millions of people worldwide, and

Figure 4.48: Motorcycle goods transport—Kenya.

Source: © John Barrell.

Figure 4.49: "Boda Boda" motorcycles Kenya.

Source: © John Barrell.

their requirements should be reflected in road design and traffic management measures.

Although few physical engineering facilities to improve motorcycle safety exist, some measures have been identified and are considered important. Furthermore, motorcyclists will benefit from speed reduction measures where there is mixed traffic, as they are less visible to drivers (having a smaller profile) and often appear where least expected.

Particular care needs to be given to the design of road and traffic engineering facilities where a large number of motorcyclists can be expected in the traffic stream. Although such measures will not completely eliminate motorcycle crashes, they will minimize their occurrence and reduce their severity when they do occur.

Safety implications

- Unlike other forms of motorized transport, there is very little protection for motorcycle riders and passengers due to their size, lack of stability, and maneuverability.
- A recent iRAP assessment of 1,400 km of highways in Bangladesh indicated the severity of road safety hazards for motorcyclists as the assessment revealed that 71 percent of assessed highways are 2-star or less (out of a possible 5-star) indicating a relatively high level of risk of deaths and injuries. Addressing the safety of motorcycles and the riders is therefore an enormous challenge to transport engineering professionals.
- When crashes do occur, they often have very severe consequences, especially at higher speeds or in situations where larger vehicles are involved.
- The chance of a motorcycle rider or passenger surviving a collision with a car is greatly reduced at speeds over 30 km/h.
- While many motorcycle crashes involve collisions with other vehicles, a significant number are single vehicle crashes. These crashes include a rider:
  - Losing control and running off the road;
  - Overtaking or crossing the centerline (usually on curves);
  - Hitting another vehicle (or other obstruction) from behind; or
  - Being thrown from the motorcycle and hitting the road surface.
- The road environment has a significant influence on the risk of crashes involving motorcyclists. Contributing factors include:
  - Interaction with larger vehicles (cars, trucks);
  - Road surface issues (such as roughness,

potholes or debris on the road) and poor skid resistance;
    - Water, oil, or moisture on the road;
    - Excessive line marking or use of raised pavement markers;
    - Poor road horizontal and vertical alignment;
    - Presence of roadside hazards; and
- Number of vehicles and other motorcyclists using the route.
- Motorcycles also have very different road performance characteristics than other types of vehicles. They:
    - Are less stable;
    - Can accelerate much more rapidly than other vehicles;
    - May appear in positions where other road users do not expect them;
    - May also suddenly change their lane position to avoid a surface hazard or irregularity;
    - Are much more maneuverable than cars or heavier vehicles; and
    - Can negotiate constraining alignments much more easily.
- This latter characteristic poses major challenges for road designers and is a significant influence on the risk of crashes involving motorcyclists, as is the quality of the road surfacing and maintenance with potholes and utility covers.
- Where drivers emerge from side roads—or come to the end of segregated lanes—their view can be obscured, making it more likely they will fail to see motorcyclists.
- Wide entries to priority intersections can encourage drivers to pull up on the offside of the rider, especially if the latter is on a low-powered machine. This increases the potential for injury when moving off and competing for the same forward lane space.
- Excessive entry width of the entry can also encourage two cars to pull up side by side, obscuring the adjacent driver's view of oncoming traffic on the main road and increasing risk for motorcyclists.
- The positioning of street furniture and vegetation affects clear visibility, which is critical for safety at intersections.

Good design practice/ treatments/solutions

Increased safety can be achieved by the separation of motorcycles from other motor vehicles. This segregation can take one of two forms. Either exclusive motorcycle lanes or inclusive lanes can be provided. These joint lanes provide routes that pedal cyclists and other nonmotorized vehicles can also use. Motorcycles can also share bus priority lanes in certain countries.

Exclusive motorcycle lanes

Exclusive motorcycle lanes require a carriageway separate from that used by other vehicles.

- They can minimize crashes at intersections by providing segregated routes or control.
- Their width and appropriateness will depend on specific usage—the higher the use, the greater the width and junction control.

Inclusive motorcycle lanes

- Inclusive motorcycle lanes are installed on the existing road and are usually located on the driver nearside of the main carriageway (next to footways or shoulders) for each direction of traffic flow.
- Motorcycle lanes may be separated from the rest of the road by painted lines or physical barriers.
- Some motorcycle and motor vehicle separation can be achieved by allowing the shared use of bus lanes. However, full consideration of the traffic

flows of both types of vehicle is important—shared use at specified times of the day could be a possible acceptable measure.

- Alternative measures may be needed on shared links to prevent four-wheeled vehicle access, i.e., by using posts at the entry/exit points.
- Care is needed to not encourage the sharing of all facilities such as pedal cycle measures at intersections or even on footbridges, due to the differences in respective vehicle speeds.

Despite the provision of separate small moving vehicle (SMV) lanes, the shared use by nonmotorized vehicles (NMUs) and motorcycles is generally not allowed, and motorcycles must usually use the main carriageway.

Alignment

To cater fully for the needs of motorcyclists, road design needs to consider:

- Consistent horizontal alignment such as avoiding bends that tighten after entry.
- Smooth transitions in vertical alignment to minimize loss of tire adhesion and to prevent water collection. This has a greater effect on motorcycles than on twin-track vehicles (i.e., traffic calming ramps at junctions).
- Cross-sectional designs consistent with the speed of the road and the radius of the bends where adverse camber or inadequate superelevation can have graver consequences for motorcyclists than other vehicles.
- Specification and positioning of street furniture, including impact characteristics when struck by a fallen or sliding body, are crucial to minimize the number of obstacles, especially on higher speed bends, and to use supports that do not shear off leaving sharp remains or protrusions that could snag a fallen rider.
- On higher-speed roads consideration must also be given to the "swept path" of the rider leaning into bends to avoid roadside features and oncoming traffic.
- Compared to all other single-vehicle motorcycle crashes, motorcycle impacts with barriers were found to be significantly more likely on smaller radius horizontal curves and sections with grades in excess of 3 percent. With regard to the sole quantitative recommendation of placing countermeasures on horizontal curves with radii fewer than 820 feet (250 meters), designers should carefully consider whether direct application of this criterion is prudent given the available data.[44]

Intersections

At intersections inclusive motorcycle lanes rejoin the general traffic lanes to allow motorcyclists to change direction or route.

- A significant proportion of collisions between motorcycles and cars in urban areas are caused by drivers failing to see the approaching or adjacent motorcycle. This can be helped by advanced stop lines for motorcyclists similar to those common for pedal cyclists (figures 4.50 and 4.51).
- It is important to optimize sight lines and to provide good braking surfaces for all users.
- Motorcyclists should be able to brake and stop while upright, travelling in a straight line, and on a surface which offers consistent grip. High friction surfacing at intersections can maximize the rider's chances of braking safely.
- Ensure consistent and appropriate skid resistance including that of extra surface features such as colored patches and thermoplastic markings. Clear advance warning and direction signs should minimize the need for such surface signing. The requirement to lean when cornering increases the likelihood of loss of control when there is a substantial variation in the skidding resistance between two

44 Gabauer, D. J. 2016. Characterization of roadway geometry associated with motorcycle crashes into longitudinal barriers. Journal of Transportation Safety & Security, 8(1), 75–96.

Figure 4.50: Motorcyclists at intersection—Thailand.

Source: Bangkok post.

Figure 4.51: Advance motorcycle stop line.

Source: Westminster cycling campaign. http://www.westminstercyclists.org.uk/asl.htm.

different types of material. The following should be kept in mind:

- Avoidance of different surface materials, for example granite blocks, to emphasize a change in circumstances at turning points.
- Thermoplastic road markings, some types of block paving, and metal utility covers can be particular problems for motorcyclists in these situations.
- Careful thought should be given before using large areas of hatching.
- The use of a high quality, cold-applied, colored antiskid material provides the required visual effect without presenting a hazard for motorcyclists.
- Roundabouts also need to be designed with the correct entry path curvature and width to help reduce the speed of vehicles and ensure that approaching vehicles are not positioned at an excessively oblique angle.
- Concentric overrun areas feature on roundabouts to increase the deflection, reduce speeds, and be more conspicuous to approaching vehicles.
- Care needs to be taken with this kind of treatment to ensure that it does not introduce an additional hazard for circulating motorcyclists. For example, where overrun areas have a slight curb up-stand (10–20 mm) between the extended area and the remaining carriageway, as a motorcycle must lean over to negotiate a roundabout, crossing the up-stand can cause a rider to lose control.

- Single lane roundabouts are considered the safest intersection design for all users on moderately busy roads. They reduce the speed of approaching traffic and allow the smooth flow of traffic through the intersection. Two-lane roundabouts are particularly dangerous for motorcyclists due to the movement of motor traffic between lanes.

Roadside barriers

- Roadside crash barriers are designed to contain an impacting twin-track vehicle and prevent it from crossing the path of oncoming traffic or leaving the running lane and colliding with a severe hazard.
- The majority of the roadside safety barrier systems in use today are designed to bring passenger cars and/or heavy vehicles to a controlled and safe stop. However, when struck by errant motorcyclists,

Figure 4.52: Motorcyclist impact with wire rope barrie.

Source:FEMA.

Figure 4.53: Typical metal barrier.

Source: John Barrell.

these systems may fail to provide this same level of protection.

- Research shows that there are two dominant types of motorcycle-to-barrier crashes.[45] In the first type, motorcyclists hit the barrier while sliding on the ground, having fallen from their motorcycle. In this type of crash, the impact mainly occurs with the lower section of the barrier. In the second type, motorcyclists hit the barrier at an upright position while they are still on the motorbike. In this type of event, the impact mainly occurs with the upper section of the barrier.
- For riders who hit the barrier at an upright position, the sharp corners located at the top of the posts also pose a significant danger. The Norwegian Public Roads Administration's Handbook 231[46] has identified the top of the posts as being particularly hazardous for motorcyclists if they become dismounted from their motorcycle during an impact and fall on top of these, which is a view shared by Gibson and Benetatos (2000)[47] and Duncan et al. (2000).[48]
- Wire rope (figure 4.52) is another common barrier type which poses similar dangers to errant motorcyclists like steel systems (such as W-beams) do. Contrary to popular belief among motorcyclists, research shows that it is the exposed posts which pose the biggest danger, not the wire ropes. For example a study comparing W-beam barriers and wire rope barriers in motorcycle safety carried out in India found that wire rope barriers can restrain the rider on the road in all cases. Although injuries to lower extremities increased in some cases, potentially fatal injuries to the rider's head were reduced by the wire rope barrier.[49] Duncan et al. (2000) have stated that there is no substantial evidence to show that wire rope barriers pose a greater risk to motorcyclists than the objects from which they are designed to shield the road user, such as trees, posts, or oncoming traffic. Duncan et al. (2000) also added that there is no evidence of the "cheese cutter effect" during injury events.
- The gap beneath the main panel of continuous barrier designs can allow motorcyclists to slide through and collide with the fixing posts (figure

45 C. Erginbas, and G. Williams. 2015. "Motorcyclists and Barriers on the Highways Agency Road Network," TRL (Unpublished).

46 Norwegian Public Roads Administration, "MC Safety Design and Operation of Roads and Traffic Systems," Directorate of Public Roads, Norway, 2004.

47 T. Gibson, and E. Benetatos. 2000. "Motorcycles and Crash Barriers," NSW Motorcycle Council, New South Wales.

48 C. Duncan, B. Corben, N. Truedsson, and C. Tiugvall. 2000. "Motorcycle and Safety Barrier Crash-Testing: Feasibility Study," Crash Research Centre, Monash University.

49 Patel, H., Jani, D., and Joshi, A. 2018. Comparison of potential injuries to the head and lower extremities of a motorcyclist during impact with W-beam and wire rope barriers using FE simulations. International Journal of Crashworthiness, 23(1), 11–17.

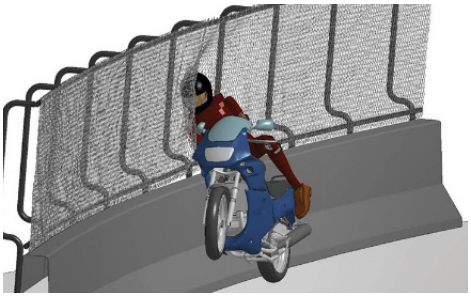
Figure 4.54: Motorcycle skirt added to metal barrier in Vietnam.

Source: iRAP.

Figure 4.55: Concrete barrier-separated motorcycle lane in Indonesia.

Source: The World Bank.

Figure 4.56 Modified U-shaped posts and attached to a curved concrete barrier



Source: © Texas A&M Transportation Institute/FHWA

4.53).

- Rails that protect riders from the posts and present a continuous surface (figure 4.54), impact attenuators that cover the support posts themselves, or continuous concrete barriers (figure 4.55) are being increasingly implemented to reduce concerns for motorcyclists.
- A study carried out in the US identified that a new chain link fence containment system supported by modified U-shaped posts and attached to a curved concrete barrier would prevent riders from ejecting over the barrier, thus reducing injury severity to the rider during the impact event (figure 4.56). This finding was confirmed by conducting finite element computer simulations and a full-scale crash test.[50]

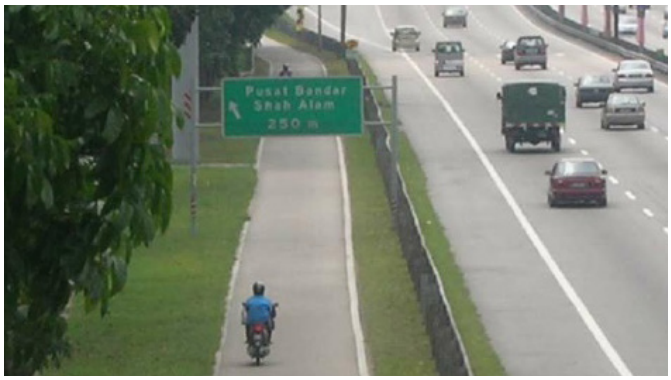
Case Study

The exclusive motorcycle lane in Malaysia (figure 4.57) is 14 km long and has led to a recorded reduction in crashes of 27 percent with a benefit to cost ratio of constructing the lane valued at about three. A subsequent extension constructed in 1992 is estimated to have reduced motorcycle crashes by 34 percent along the section of road concerned.

As an additional example, motorcycle lanes may also be inclusive as illustrated in figure 4.58.

50 Silvestri Dobrovolny, C., Shi, S., Kovar, J., and Bligh, R. P. 2019. Development and evaluation of concrete barrier containment options for errant motorcycle riders. Transportation research record, 2673(10), 14–24.

Figure 4.57: Exclusive motorcycle lane—Malaysia.



Source: © Hussain Hamid

Figure 4.58: Inclusive motorcycle lane—Malaysia.

Source: iRAP.

Further Reading

- Austroads guide on motorcycle and infrastructure. Accessed at https://austroads.com.au/publications/road-safety/ap-r515-16.
- WHO guide for powered 2 and 3 wheeled vehicles. Accessed at https://apps.who.int/iris/rest/bitstreams/1081388/retrieve.
- iRAP Road Safety Toolkit. http://www.toolkit.irap.org/.
- FHWA. 2016. Motorcycle Road Safety Audit Case Studies and Checklists. Accessed at https://safety.fhwa.dot.gov/rsa/resources/docs/fhwasa16026.pdf.
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4.5. Public Transport—Bus Stops; Bus Rapid Transport and Other Modes

General description

Public transport is generally thought of as referring to buses, coaches, and possibly trams (figure 4.59) that run regular and advertised schedules both in rural and urban areas wholly within the confines of the public right-of-way. In urban areas, public transport provides an efficient form of transport for large numbers of people and reduces congestion in busy cities.

Figure 4.59: Tram system—Ukraine.

Source: © John Barrell.

Figure 4.61: Matatu bus service—Kenya.

Source: © John Barrell.

However, buses and coaches are just a small part of the overall public transportation, public transit, or mass transit network. Public transport is a system of transport that is available for use by the general public, typically managed on a schedule, operated on established routes, and that charges a fixed fee for each trip dependent on journey length. Trips can be undertaken in vehicles of different size and different control conditions. In LMICs the variety of public transport is extensive, from formal Bus Rapid Transport (BRT) (see figure 4.60) running in defined and protected corridors to poorly regulated shared taxi or motorcycle/cycle taxis (see figures 4.61 and 4.62).

There are a wide variety of vehicles used for the transportation of passengers and their goods on

Figure 4.60: BRT Lane—Bolivia.

Source: World Bank.

Figure 4.62: Rickshaw taxi—India.

Source: World Bank.

roads such as cycle rickshaws, motorized rickshaws, cars (including taxis), minivans, buses, and trucks. These types of services are prevalent in Africa and Asia.

The degree of regulation and control on public transport services varies from country to country, and particularly in LMICs, this level of control may be very limited. While public transport is considered to be a safer form of transport, when services are poorly regulated, vehicles poorly maintained, and often overcrowded, when crashes do happen, they can result in a large number of fatalities. This is often the case in LMICs where overcrowding, speeding, and poor vehicle maintenance can result in frequent multiple fatality collisions.

Well-regulated public transport systems run along fixed routes with set embarkation/disembarkation points to a prearranged timetable, with the most frequent services running to a headway (e.g., "every 15 minutes" as opposed to being scheduled for any specific time of the day).

Paratransit is the term used for transportation services that supplement fixed-route mass transit by providing individualized rides without fixed routes or timetables. Paratransit services may vary considerably on the degree of flexibility they provide their customers. At their simplest they may consist of a taxi or small bus that will run along a more or less defined route and then stop to pick up or discharge passengers on request. At the other end of the spectrum—fully demand responsive transport—the most flexible paratransit systems offer on-demand, call-up, and door-to-door service from any origin to any destination in a service area. In addition to public transit agencies, paratransit services may be operated by community groups or not-for-profit organizations, and for-profit private companies or operators. Control and regulation of setting down and picking up points for these are difficult and can lead to the use of inappropriate and unsafe locations.

Shared taxis offer on-demand services in many parts of the world, which may compete with fixed public transport lines, or complement them by bringing passengers to interchanges. These less formal transit services are sometimes used in areas of low demand and for people who need a door-to-door service.

Safety implications

- Travel by formalized public transport is very safe and perceived to be so.[51] Estimates for Norway for 1998–2002 indicated 0.93 fatalities in road crashes per billion passenger kilometers for bus, versus 3.82 fatalities per billion kilometers for car occupants (driver and passenger) approximately a quarter that of automobiles.[52] Less well-regulated and overcrowded services in LMICs have a high incidence of fatalities when crashes occur.
- Being a large vehicle, a bus protects its occupants well. The smaller and less stable vehicles are more risky.
- Most injuries in collisions where regulated buses are involved are sustained by other road users.[53]
- Each vehicle type has its own specific safety problems, but one issue in common is that crashes involving such vehicles often result in multiple injuries and deaths (up to 80 or more in some regions with overloaded buses).[54]
- Another common issue is that there is danger, not only when moving around the road network, but also when picking up or dropping off passengers, and extra care needs to be taken at such locations.

51 Elvik, R., and Bjørnskau, T. 2005. How accurately does the public perceive differences in transport risks? An exploratory analysis of scales representing perceived risk. Accid. Anal. Prev. 37, 1005–1011.

52 Litman, T. 2020. Terrorism, Transit and Public Safety: Evaluating the Risks by Victoria Transport Policy Institute. March 20, 2020

53 Elvik, R. 2019. Risk of non-collision injuries to public transport passengers: Synthesis of evidence from eleven studies Journal of Transport and Health Vol. 13, pp. 128–136.

54 iRAP Road Safety Toolkit.

- Buses may also block the view of pedestrians attempting to cross at the signals. There is therefore an increased risk of crashes associated with unintentional noncompliance with the signals.
- Fares are often low, so operators of public transport often work long hours to stay in business.
- They might also drive at fast speeds to compete with other operators and may make sudden and frequent stops to pick up passengers.
- Public transport vehicles produce dangers for those who ride in (or on) them, but also may be of risk to other road users. This is particularly so as the size of the vehicle increases.
- Siting of bus stops that obscure intersections or signs, or obstruct traffic movements present particular safety problems for all users.
- Falls when walking to or from public transport stops contribute substantially to the total risk of door-to-door journeys using public transport.
- Better road maintenance, especially during the winter, can also reduce the number of falls.
- Bus lanes appear to lead to an increased number of crashes, at least injury crashes. The increase is greatest for American-style bus lanes, where share-a-ride schemes with private cars are also allowed. There may be several reasons why this type of bus lane leads to more crashes including:
    - Such bus lanes are often constructed in the central reservation or in the left lane of motorways, i.e., where the traffic is fastest.
    - In order to move in or out of such bus lanes, several lane changes may be necessary (large motorways in the US often have three, four, or five traffic lanes in the same direction).[55]
    - There may be major differences in speed between a bus lane and the other traffic lanes. Furthermore, buses and light cars both use the bus lane. This type of bus lane also appears to increase the number of crashes. In Norway, bicycles, mopeds, and motorcycles are also permitted in the bus lane. This means that the heaviest and the lightest vehicles use the same traffic lane.
    - When turning at an intersection, it may be necessary to cross the bus lane. In dense traffic, the differences in speed between a bus lane and the other traffic lanes may be relatively large.

Good design practice/ treatments/solutions

Bus Rapid Transit

- Bus Rapid Transit (BRT) (see figure 4.63) is a high-quality, efficient mass transport mode providing capacity and speed comparable with urban rail (light and heavy rail).
- In cities of the developing world, the implementation of median-running BRT systems has generally proven to have a positive impact on safety. Research from Australia indicates that bus priority systems (including signal priority and dedicated lanes) also had a positive safety impact.[56]
- On average, BRTs in the Latin American context have contributed to a reduction in fatalities and injuries of over 40 percent, and a reduction in Property-Damage Only (PDO) crashes of 33 percent on the streets where they were implemented. The mean effect is quite consistent across different regions of the world, as evidenced by the similar impacts of the Janmarg BRT in Ahmedabad, India.[57]
- The main reason that BRT systems have had

55 Elvik, R. et al. 2009. Handbook of Road Safety Measures, 2nd ed.

56 Duduta, N. et al. 2015. Traffic Safety on Bus Priority Systems, EMBARQ WRI.

57 Carrigan, A. et al. 2013. Social, Environmental and Economic Impacts of Bus Rapid Transit, EMBARQ WRI.

Figure 4.63: Dedicated bus lanes for bus rapid transit system.

Source: Dubuta, N. et al. 2015.

positive safety impacts in Latin America is because in order to accommodate the BRT infrastructure, the city removed lanes, introduced central medians, shortened and provided improved crosswalks, and prohibited crossing turns by general traffic at most intersections.

- In bus rapid transit systems, bus stops may be more elaborate than street bus stops, and can be termed "stations" to reflect this difference. They may have enclosed areas to allow off-bus fare collection for rapid boarding and be spaced further apart like tram stops. Bus stops on a bus rapid transit line may also have a more complex construction allowing level boarding platforms and doors separating the enclosure from the bus until ready to board.

Bus lanes

- These are dedicated lanes within the main carriageway to allow buses to bypass traffic congestion (figure 4.64). They are usually located at the nearside of the carriageway to allow easy access for passengers from an adjacent footway. They are often separated from main traffic by a single solid white line, although in some instances they can be separated by a median.
- Provision of dedicated bus lanes prevents use by general traffic and restricts parking and loading for adjacent properties. Obstruction of the bus lane by other vehicles negates the advantages of a dedicated lane and requires a dangerous maneuver for both vehicles to enter and leave the general traffic stream.
- Particular care is needed at intersections where the bus lane ends to allow all traffic to queue or buses to make turns across the main traffic flow.
- Additional benefit can be given to buses at signal-controlled intersections with specific stop lines and call stages.

Figure 4.64: Bus lane and priority signal—UK.

Source: Google Streetview.

Bus stops

- Bus stops are the places where passengers enter and leave the bus and change from being passengers to pedestrians (figure 4.65). Depending on the number, size, and frequency of vehicles using stops, their complexity can vary.
- Pedestrians must be able to access bus stops safely. If pedestrians have to cross busy roads where complex maneuvering occurs in order to access or leave buses, pedestrians will be at risk of crashes.
- In rural areas where services are less frequent, clear identification of formal stopping places is needed to prevent unsafe maneuvers and deterioration of the highway shoulder (see figure 4.66).
- Bus stops need to be clearly identified and safely accessed whatever form of vehicle uses them and wherever they are located.
- Bus stop infrastructure ranges from a simple pole and sign, to a rudimentary shelter, to sophisticated structures. The usual minimum is a pole-mounted flag with suitable name/symbol.
- Bus stop shelters may have a full or partial roof, supported by a two-, three-, or four-sided construction. Modern stops are mere steel and glass/Perspex constructions, although in other places, stops may be wooden, brick, or concrete built.
- Individual bus stops may simply be placed next to the roadway (often with no footway provision in rural areas), although they can also be placed to facilitate use of a busway. More complex installations can include construction of a bus lay-by or a bus bulb, for traffic management reasons, although use of a bus lane can make these unnecessary.
- Bus stops must not be located such that stopped buses will obstruct the sightline to the traffic signal.
- Where lay-bys do exist (see figure 4.67), they can be crowded with waiting passengers, and bus drivers tend not to use them. This behavior is frequently observed on heavily trafficked roads where the driver is more likely to experience difficulty in merging with the main road flow again.
- Several bus stops may be grouped together to facilitate easy transfer between routes. These may be arranged in a simple row along the street, or in parallel or diagonal rows of multiple stops. Groups of bus stops may be integral to transportation hubs. With extra facilities such as a waiting room or ticket office, outside groupings of bus stops can be classed as a rudimentary bus station. The stop may include separate street furniture such as a bench, lighting, and a trash receptacle.

Figure 4.65: Curbside trolleybus stop—Ukraine, with shelter and kiosk.

Source: © John Barrell.

Figure 4.66: Rural village bus stop—Burundi, no signs or facilities.

Source: © John Barrell.

Figure 4.67: Bus lay-by —Ghana and Romania, used as a garage facility.

Source: © John Barrell and Alina F. Burlacu/GRSF/World Bank.

- At the busiest urban center locations, complex interchanges may be necessary to accommodate both large numbers of vehicles and passengers. They need to segregate both users up to the point of boarding and allow individual bays for separate services.
- Whichever level of provision is made, the key elements are to ensure that:
  - Vehicles should be able to enter, stop, and leave the location safely and smoothly.
  - Lay-bys should be positioned on straight, level sections of road and should be visible from a good distance in both directions.
  - Access to a lay-by should be convenient and safe for vehicles and, also for pedestrians in the case of bus stops.
  - Advance warning signs should be erected to alert drivers of the approach to bus stops, and to the possible presence of pedestrians ahead.
  - Passengers are provided with sufficient advance warning (either within the vehicle or by external signage) to allow them to stand safely and comfortably.
  - Adequate queueing areas should be available so that waiting passengers do not use the road or a dedicated bus lay-by.
  - Pedestrian crossing facilities should be placed before the bus stop to aid visibility of crossing pedestrians and ease bus egress from the stop, whether at the curb or within a lay-by
  - Adequate and safe routes are provided to and from the stops to the surrounding pedestrian network.
  - Locations for stopping and waiting are clearly identified and protected.
  - Informal stopping on the highway or shoulder should be prevented.
- Improvements to footways and well-maintained pedestrian routes and short distances between bus stops can reduce walking distances and thus the number of injuries.

Further Reading

- Traffic Safety on Bus Priority Systems. 2105. EMBARQ WRI. Must read chapter 4 and chapter 8, about the case studies of BRT.
- *Bus Stop Design and Safety Guideline Handbook.* 2014. Imperial County Transportation Commission USA. Must read section 5, On street bus stop and section 6, Off street transit transfer stations.
- Public Transport Interchange Design Guidance, Auckland Transport NZ. 2013. Must read chapter 3, Design principles and chapter 4, Auckland interchange hierarchy.
- Interchange Best Practice Guidance. 2009. Transport for London, UK. Must read design themes and principles.