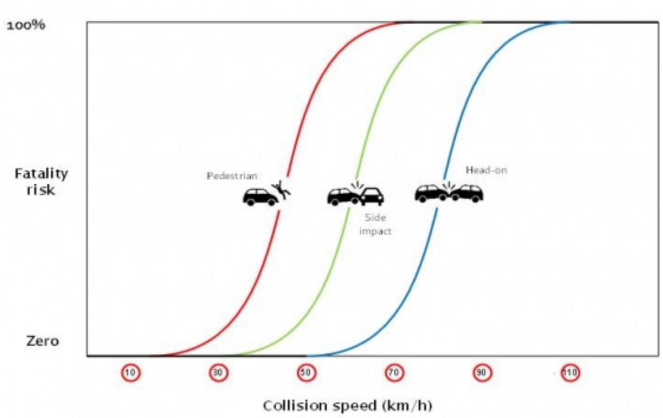
# 3. KEY ROAD DESIGN ASPECTS IN THE CONTEXT OF SAFE ENGINEERING

Speed is an important aspect closely linked with road design. In road design, "design speed" is used as a design control and is used to determine the various geometric features of the roadway. The assumed design speed should be logical for the topography, anticipated operating speed, adjacent land use, and functional classification of the road. On the other hand, travel speed or "operating speed" is the speed at which vehicles generally operate on a road. Excessive speed is the most significant contributor to fatal and serious crash outcomes. When a pedestrian is struck by a car at 30 km/h, they have a reasonable chance of survival, but above this, the chances reduce dramatically. The critical threshold for cars colliding at an intersection is 50 km/h, above which chances of survival decrease rapidly. For head-on crashes, the figure is 70 km/h for well-designed vehicles of equal mass (figure 3.1). Providing effective speed management can have profound benefits in terms of safety and other positive outcomes for urban, interurban, and rural roads.

**Figure 3.1:** Speed/injury risk curves.




Source: Greater Wellington Regional Council, Survivable Speeds, Wellington, New Zealand. 2015. For additional information see www.gw.govt.nz/survivable-speeds/.

## 3.1. Design speed and operating speed

### General description

Design speed is defined as "the maximum safe speed that can be maintained over a specified section of a highway when conditions are so favorable that the design features of the highway govern". In many countries, there are also concepts of ruling design speed and a minimum design speed for a particular type of facility. While the idea is to use the ruling design speed for the design of geometric elements, in no case should it go below the minimum design speed for that facility. Minimum design speed is specifically crucial to avoid inferior design due to restrictions in land availability and so forth.

Unfortunately, a designer has few variables that may be used to convey the design speed to a driver, especially outside built-up (urban) areas. The relationship between the ruling design speed, curve radii, and their superelevation, that is, side friction demand, should be consistent and so should the forward sight distance along the route or at intersections. Therefore, the level of demand on the driver is very important. See section 2.2 for more information regarding the principle of predictability and "no surprises."

There are significant safety factors built into the parameters that are dependent on the selected design speed. As far as practicable, the road should be designed to operate at a speed equal or slightly higher (5 km/h) than the posted speed limit. This can be assessed by "sensitivity testing" the design for drivers travelling at higher speeds. Two examples of how this could be achieved are assessing the superelevation on the curves and the sight distance requirements. However, it should be acknowledged that geometry is not an appropriate mechanism by which to control speed, primarily because it relies too heavily on driver interpretation and feel. This is particularly relevant, for example, when horizontal straights and straight gradients are used in generally flat terrain.

In current practice, the term "operating speed" is defined as the speed at which drivers are observed operating their vehicles during free-flow conditions. This may not be at a safe speed and should not be used to define the appropriate speed limit. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature (Fitzpatrick et al. 1995). However, there have been many definitions of the operating speed (NCHRP 2003). (See references in Further Reading.)

The posted speed or speed limit is the speed displayed with a regulatory sign and is used in most countries to set the legal maximum or minimum speed at which road vehicles may travel on a given stretch of road. Speed limits are often close to the 85th percentile operating speed of the facility, but as highlighted above, this measure should not be used to set speed limits for existing roads. However, in many low- and middle-income countries (LMICs), speed limits are set at levels that are too high given the prevailing road corridor conditions (geometry and roadside) and the mix and volume of road users, particularly near built-up and market areas where there are many pedestrians and cyclists. It thus becomes difficult to achieve safe travel conditions under these circumstances, and several infrastructural, and enforcement-related interventions become essential.

## Safety implications

While the relationship between the operating speed and posted speed limit can be defined, the association between design speed and either the operating speed or posted speed limit cannot be defined with the same level of confidence. Further, below are common challenges that may arise while working with design speed.

- First of all, it is possible that due to higher design standards and prevailing traffic conditions, the operating speed of a particular facility ends up being higher than the design speed. Such high operating speed would result in unsafe conditions for the existing land use and endanger road users of the facility.
- On the other hand, it is also possible that due to restrictions of site conditions, the minimum design speed could not be followed, which raises the issue of consistency in design.
- Additionally, design elements following minimum design speed as a criterion may lead to value design that may not always lead to safer performance.

## Good design practice/ treatments/solutions

- Setting a target maximum operating speed is often very important, especially in LMICs, where speed enforcement is mostly absent.
- It is also essential to use infrastructure-based as well as enforcement-based road safety interventions to help restrict the maximum operating speed in a facility.
- The importance of such interventions is increased when the difference between the operating speed and posted speed limit is high, and the consequence of higher operating speed may lead to fatal and severe crashes.
- Infrastructure-based management of speed should ideally limit speeds to safe levels, which certainly means at the design speed. Often even this is not enough for safe operation.

## Further Reading


- NCHRP Report 504. 2003. "Design Speed, Operating Speed, and Posted Speed Practices." National Cooperative Highway Research Program, Transportation Research Board of the National Academies, Washington, DC. ISBN 0-309-08767-8 Must read:

chapter 3, Interpretation, Appraisal, Applications.

- Fitzpatrick, K., Blaschke, J. D., Shamburger, C. B., Krammes, R. A., and Fambro, D. B. 1995. "Compatibility of Design Speed, Operating Speed, and Posted Speed." Final Report FHWA/TX95/1465-2F. Texas Department of Transportation, College Station, TX. Must read: 5, Concerns with design speed, operating speed, and posted speed relationships; 7, Conclusions and recommendations.

## 3.2. Speed Management and Traffic Calming

### General description

Effective speed management involves identifying the actual functional road use for different parts of the network (reflective of all road user groups), selecting a safe speed limit to match that use, and providing appropriate infrastructure to support these speed limits where required (also see the discussion in section 2.2 on self-explaining or predictable roads). This can include developing treatments to reinforce the change in the road environment and appropriate speed requirement. It may also require support from police in enforcing the required speeds, particularly where matching the safe speed, design speed, and speed limit has not been adequately considered in the design process. Increasingly, in-vehicle technologies are assisting in ensuring appropriate speeds are maintained.

In regard to road design, speed management needs the strong support of road infrastructure to ensure road users can clearly understand their required speeds. Particularly in lower speed environments, well-designed roads also contribute significantly to a road user's choice of speed. This can often be achieved through traffic calming measures including:

- Gateway treatment at the entrance of the settlements and/or speed management and traffic calming along the highways with a higher need for access due to the change in land use.
- Narrowing through:
    - Widening sidewalks,
    - Adding bollards or planters, or adding a cycle lane or on-street parking,
    - Widening the centerline (figure 3.2),
    - Curb extensions/buildouts (figure 3.3),
    - Narrowing the width of the roadway at

**Figure 3.2:** Carriageway narrowing, delineators, and speed humps.

Source: Afukaar F. K. 2008. Evaluating Road Safety Interventions: The case of Ghana. Accessed at https://rtirn.net/PDFs/Evaluating_Road_Safety_Intervention_The_case_of_Ghana.pdf. December 12, 2019.

**Figure 3.3:** Road narrowing with traffic islands and extended curbs.

Source: Ghana Highway Authority, 2007.

**Figure 3.4:** Rumble strips on highways.

Source: © Sudeshna Mitra/GRSF/World Bank.

pedestrian crossings,

- Chokers (localized narrowing),
- Road diets which reallocate space on a street, for example, allowing parking on one or both sides of a street to reduce the number of driving lanes, or adding a central turning lane, and
- Pedestrian refuges or small islands in the middle of the street to reduce lane widths.

- Vertical deflection, or raising a portion of a road surface as a platform can create discomfort for drivers travelling at high speeds including the use of:
  - Speed bumps, humps, cushions, and tables,
  - Raised pedestrian crossings and intersections,
  - Speed dips,
  - Changing the surface material or texture, and
  - Rumble strips (figure 3.4).
- Horizontal deflection which requires vehicles to deviate slightly, and includes chicanes, pedestrian refuges, curb extensions, and chokers. Roundabouts also reduce speeds through this mechanism.
- Blocking or restricting access measures to block or restrict access such as:
  - Median diverters to prevent left turns or through movements into a residential area.
  - Converting an intersection into a cul-de-sac or

**Figure 3.5:** Speed bump placed by community on road passing through village—Ethiopia.

Source: © Soames job/GRSF/World Bank.

**Figure 3.6:** City street in Colombia with makeshift rumble strip.

Source: © Soames job/GRSF/World Bank.

dead end.

- Boom barrier, restricting through traffic to authorized vehicles only.
- Closing of streets to create pedestrian zones.

It is worth noting that people generally understand the high risk of speeds and often want lower speeds on roads passing through towns and settlement areas. It is however best if the design of speed humps and other traffic calming infrastructures are not left to communities who feel neglected as shown in figures 3.5 and 3.6.

## Safety implication

- Effective speed management can reduce vehicular travel speeds, with subsequent safety benefits.
- Where safe speeds are provided (matching required road and roadside activity), there can be a significantly reduced frequency and severity of

collisions (up to and even exceeding 60 percent reductions in death and serious injury).[31]

- Even with minor changes in speed, there can be significant safety benefits.
- Appropriate speed management can reduce the need for police speed enforcement, freeing up resources for other enforcement activity.
- There are also numerous benefits beyond those for road safety, including potential greater incentives for using active modes (particularly walking and cycling, which produce broader health benefits; reduced emissions, noise and fuel consumption; and more "livable" space for residents and visitors.

## Good design practice/ treatments/solutions

The current implementation factors in traffic calming include:

- For maximum effect, combinations of traffic calming measures should be used, preferably as part of an integrated transport strategy.
- Community engagement on safety benefits may be required to avoid negative public feedback due to perceived inconvenience and a misconception of additional injury. This should be factored into timelines for project delivery.
- Where relevant, schemes should be designed to cater for cyclists and essential emergency services and other heavy vehicles so that these are not hindered.
- Narrowing the vehicle travel lanes is effective at reducing speed and providing space for sustainable modes.
- Cost-effective traffic calming design solutions should be used.
- In many cases cheaper options (such as line markings to narrow lanes rather than fully constructed islands) can be as effective.
- Monitoring the effects of the treatments is also important, potentially starting with the lower cost, to fully understand how each one contributes and therefore where the highest value is achieved.
- Clear signing may be required, especially at isolated traffic calming devices, to alert road users and prevent traffic calming measures from becoming traffic hazards. Some treatment types can act as a road or roadside hazard.
- Speed limits should be consistent and aligned to the function, standard, and use of the road.
- Speed humps and other devices need to be well designed to provide maximum safety benefits. Nonstandard designs that are not well understood by road users may create a hazard.
- Some treatment types (humps, rumble strips, chicanes) can act as roadside hazards if not properly designed, signed, and maintained.
- Speed limits should seem realistic and credible so that drivers will adhere to them.
- Maintenance of speed calming infrastructure should be prioritized after implementation to ensure continuous safety.
- As an interactive traffic calming measures using technologies, a speed feedback sign (also called a driver feedback sign, or variable message sign) is used in some countries such as Australia, Canada, the United Kingdom, and the United States. A speed feedback sign is generally constructed of a series of light emitting diodes (LEDs) that displays actual vehicle speed to drivers as they approach the sign (figure 3.7). A US study found that speed feedback signs can be effective in reducing mean and 85th percentile speeds in a variety of situations[32] (see 5.13 Road signs for sign installation).

This unmarked speed hump (figure 3.8) increases road

31 Damsere-Derry, J., Ebel, B. E., Mock, C. N., Afukaar, F., Donkor, P., and Kalowole, T. O. 2019. Evaluation of the effectiveness of traffic calming measures on vehicle speeds and pedestrian injury severity in Ghana. Traffic Injury Prevention, 20(3), 336–342.

32 Forbes, G., Gardner, T., McGee, H. W., and Srinivasan, R. 2012. Methods and practices for setting speed limits: An informational report (No. FHWA-SA-12-004). United States. Federal Highway Administration. Office of Safety.

crash risk compared to appropriate marking (figure 3.9) due to failure to see the speed hump by motorists. Speed humps and other traffic calming measures should be clearly marked and signed; adequate funds should be allocated for maintenance.

**Figure 3.7:** Speed feedback sign.


Source: Richard Drdul/FHWA.

**Figure 3.8:** Unmarked ("invisible") speed hump—Zanzibar.

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

**Figure 3.9:** Marked speed hump for traffic calming

Source: © James Robert Markland/World Bank

## Case Studies

### Speed calming infrastructure in South Africa

**Figure 3.10:** Raised pedestrian crossing and mini circle

Source: Arrive Alive. Traffic Calming, Speed Calming and Road Safety; Traffic Calming and Pedestrian Safety. Accessed at https://www.arrivealive.mobi/. December 17, 2019.

**Figure 3.11:** Use of mixed traffic calming infrastructure—narrowing, speed humps, and delineators

Source: Arrive Alive

In South Africa, more than 35 percent of road crash fatalities are pedestrian fatalities. The South African road authority uses a prioritization system for traffic calming infrastructure due to limited funds. The requests to implement traffic calming measures such as speed humps, raised pedestrian crossings, and mini circles (as shown in figures 3.10 and 3.11 above) come from the public, councilors, staff members, and observations by authorities. A sample of the results in South Africa show that the traffic calming humps improved safety with respect to the severity of collisions. Serious pedestrian-vehicle collisions (PVCs) dropped by 23 percent and 22 percent, while fatal collisions decreased by 68 percent and 50 percent in some areas.[a]

Traffic calming has been shown to be effective in reducing the number of PVCs but needs to be supported by additional measures to further improve the safety of pedestrians.

a Nadesan-Reddy, N., and Knight, S. 2013. The effect of traffic calming on pedestrian injuries and motor vehicle collisions in two areas of the eThekwini Municipality: A before-and-after study. SAMJ: South African Medical Journal, 103(9), 621–625.

**Figure 3.12:** Children had no safe and dedicated crossing point and very often were in constant conflict with motorists.

Source: (left) Lusaka Times. Vera Chiluba Primary School: Road re-design that promotes road safety. Accessed at https://www. lusakatimes.com/2019/11/11/why-we-support-mayor-sampa-lowering-of-speed-limits-around-schools/. December 17, 2019. (right) Guardian News & Media Limited. Why are Ghana's roads so deadly? Latest fatality sparks fury in Accra. Accessed at https://www.theguardian. com/cities/2018/nov/27/why-are-ghanas-roads-so-deadly-latest-fatality-sparks-fury-in-accra-adenta-madina. December 19, 2019.

**Figure 3.13:** School children are protected by an elevated zebra crossing which is a traffic calming feature in itself.

Source: (left) Lusaka Times, (right) Poswayo A. Street Shaper. December 2018. Accessed at https://globaldesigningcities.org/2018/12/12/street-shaper-december-2018/. December 19, 2019.

### Speed calming infrastructure for school zones in Zambia and Ghana

The Zambia Road Safety Trust (ZRST) is concerned about the impact of road traffic on children. About 1,550 children were killed or injured in 2014 in road traffic. The Lusaka mayor together with the ZRST plan to reduce speeds limits at all school zones from the widespread 40 km/h to 30 km/h. This has been done through improvement of pedestrian infrastructure—footpaths, zebra crossings, speed humps, road signs, and more (see figures 3.12 through 3.14 for before and after photos).

These improvements are part of an NGO, Amend, School Area Road Safety Assessments and Improvement (SARSAI) program focused on reducing injuries around school areas in urban Africa where children are known anecdotally to be at very high risk of a road traffic injury (RTI).

**Figure 3.14:** Installing speed table with checker marking. Left: before the intervention; Right: After the intervention.

Source: safe-crossings.org.

## Further Reading

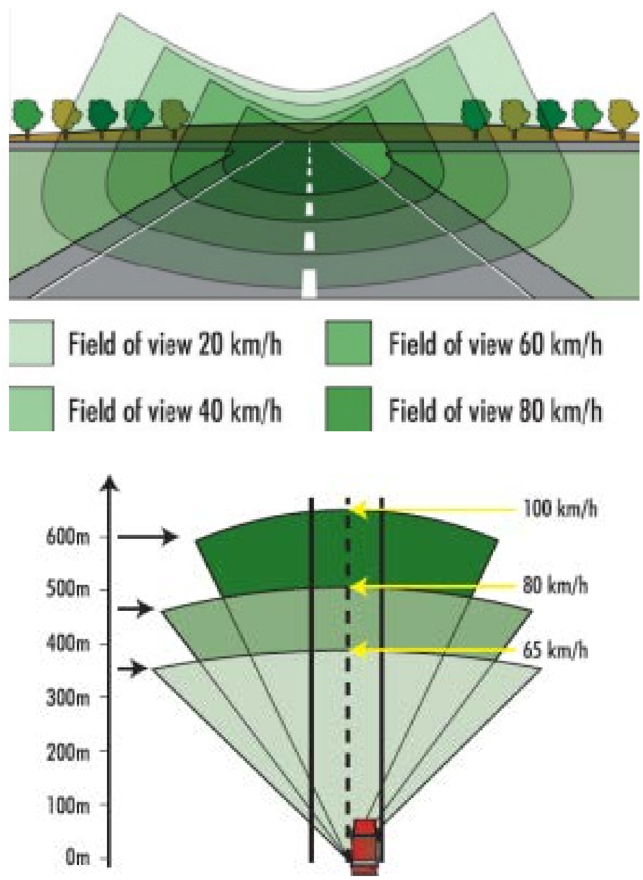
- South Central Regional Council of Governments. 2008. Traffic Calming Resources Guide. Must read chapter 2, Toolbox; chapter 3, Contents.
- GRSP Speed Management: A guide for practitioners and policy makers. GRSP, Geneva. Must read Appendix 4 and chapter 3 under subtitle 3.4.
- FHWA Traffic Calming Guidelines. Must read chapter 1, Introduction and Appendix A.

# 3.3. Sight distance

## General description

- Sight distance is needed to provide drivers with enough reaction and maneuvering (including braking) time to adapt to the road conditions.
- Decision sight distance is provided in complex or unexpected situations and allows for increased decision time.
- From human factors research, drivers need 4–6 seconds to respond to a new situation; this means 110 - 170 m ahead if the speed limit is 100 km/h or 90–135 m for 80 km/h. The faster people drive, the further they need to look ahead and vice versa (figure 3.15), in order to read, understand, and react

**Figure 3.15:** Example of speed and peripheral vision and speed and focus point.

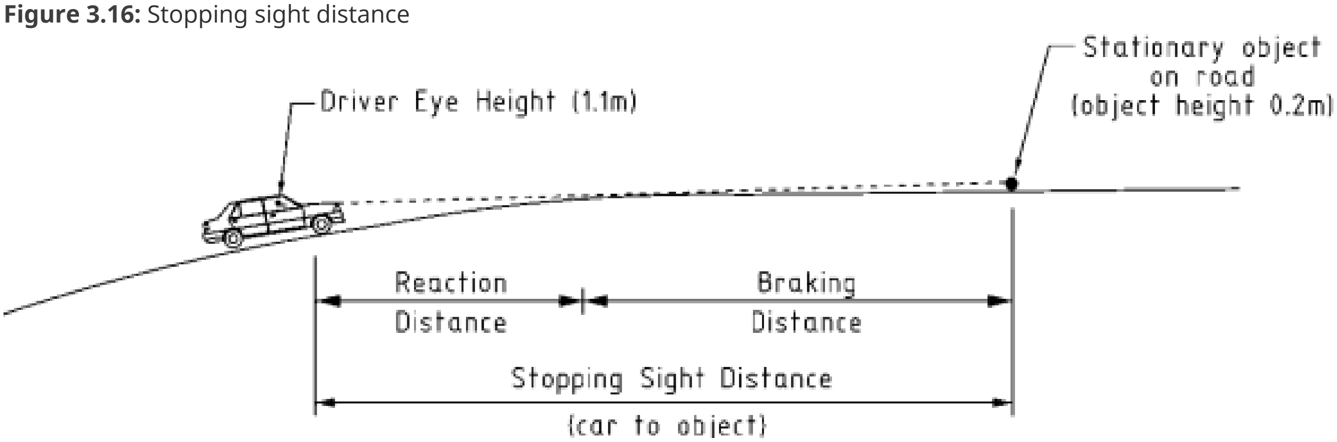



Source: PIARC, 2003.

in time to a hazard. Warning and information signs may sometimes be so sited that they have poor conspicuity, and the detailing of the road may not provide sufficient additional clues as to the hazard or decision ahead.[33]

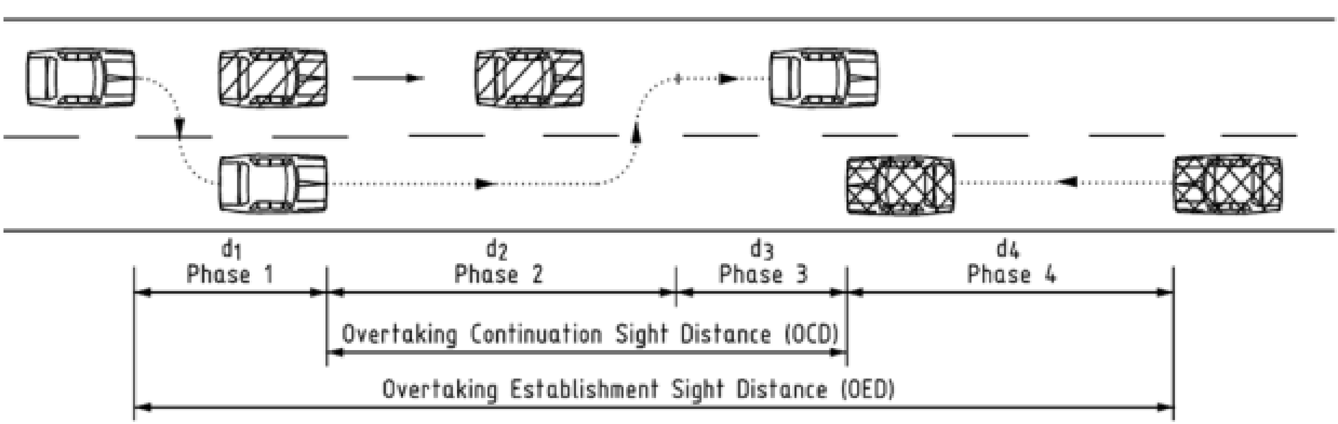
- Stopping sight distance is the minimum sight distance that must always be provided at any point on a roadway.[34]
- Stopping sight distance ensures a driver travelling at an appropriate speed can safely and effectively bring the vehicle to rest, including being able to see any objects along the vehicle path (figure 3.16).
- Passing or overtaking sight distance is provided in locations where passing in the opposing lane is allowed and allows for the safe completion of a whole maneuver (figure 3.17).
- Intersection sight distance involves a triangle of sight distances (figure 3.18) that enhance visibility and awareness for all road users.
- Intersection sight distance is typically defined as the distance a motorist can see approaching vehicles before their line of sight is blocked by an obstruction near the intersection.[35] The driver of a vehicle approaching or departing from a stopped position at an intersection should have an unobstructed view of the intersection, including any traffic control devices and sufficient lengths along the intersecting roadway to provide the driver with enough

**Figure 3.16:** Stopping sight distance




Source: Austroads, 2021. Austroads. 2021. Guide to Road Design Part 3: Geometric Design.

**Figure 3.17:** Overtaking maneuver and sight distance.




Source: Austroads. 2021. Guide to Road Design Part 3: Geometric Design.

33 PIARC. 2018. Practical Guide for Road Safety Auditors and Inspectors.

34 Austroads. 2016. Achieving Safe System Speeds on Urban Arterial Roads: Compendium of Good Practice.

35 FHWA Federal Highway Administration. 2011. Intersection Safety: A Manual for Local Rural Road Owners, US.

time to anticipate and avoid potential collisions.

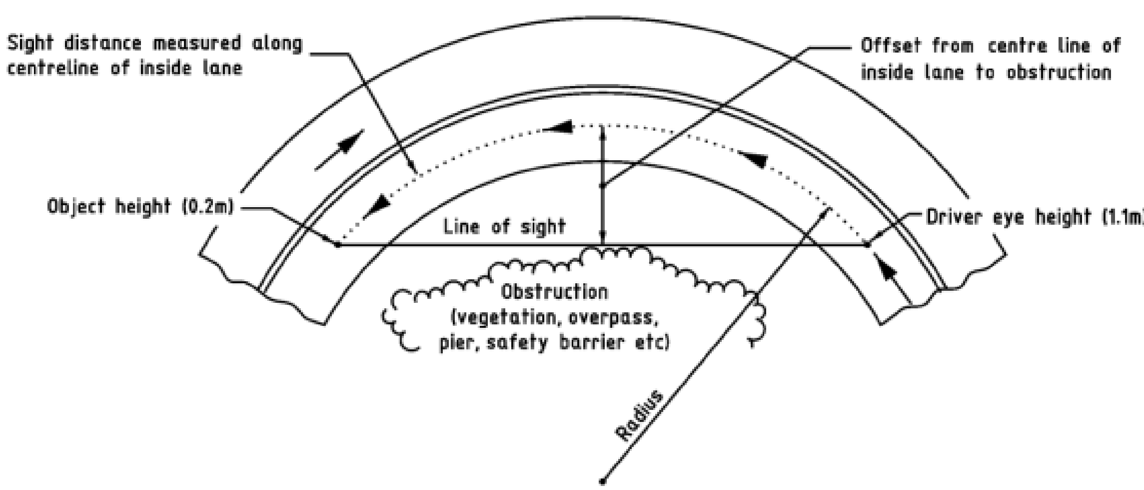
- Pedestrians also need to see and be seen, and crossing movements are often concentrated at or near intersections.
- Meeting sight distance provides for narrow roads and allows for the closing speed of opposing vehicles.
- In urban areas, corners frequently act as a gathering place for people and businesses, as well as the locations of bus stops, cycle parking, and other elements. The design should facilitate eye contact between these users, rather than focus on the creation of clear sightlines for moving traffic only.[36]
- Insufficient sight distance can be a contributing factor in crashes. Examples of obstructions include herds of animals, plants, parked vehicles, utility poles, buildings, and the horizontal and vertical alignment of the roadway (see sections on Horizontal curvature and Vertical curvature and gradient). Figure 3.19 illustrates sight distance at a curve including necessary offsets from obstructions.

A UK study shows improved visibility and/or increased

**Figure 3.18:** Examples of driver's sight triangles at intersections

Source: NACTO, 2019

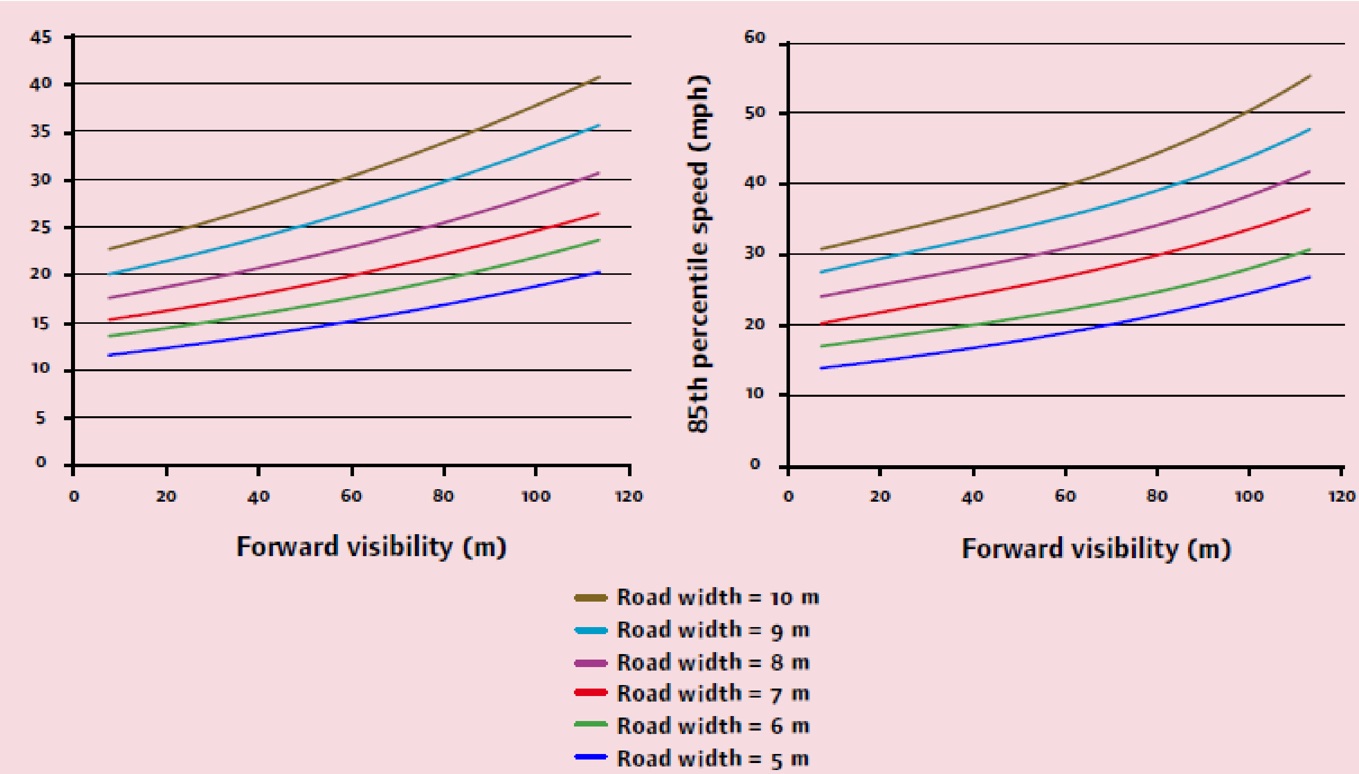
**Figure 3.19:** Illustration of driver's sight distance at curves.




Source: NACTO. 2019. Urban Street Design Guide: Accessed at https://nacto.org/publication/urban-street-design-guide/.

36 NACTO. 2019. Urban Street Design Guide: Accessed at https://nacto.org/publication/urban-street-design-guide/.

**Figure 3.20:** Correlation between visibility and roadway width and vehicle speeds.




Source: Department for Transport, UK.

roadway width were found to correlate with increased vehicle speeds (figure 3.20). Increased width for a given visibility, or vice versa, was found to increase speed. This implies that reducing sight distance can contribute to reducing vehicle speeds at intersections (noting that minimum sight distance criteria must be maintained).

## Safety Implication

- Insufficient sight distance, and the corresponding reduced time to react, increases the risk of rear-end crashes on the approaches and high angle crashes within the intersection. This is because motorists may be unable to see and react to traffic control devices (i.e., signals and stop signs) or approaching vehicles from both major and minor roads.
- There are clear increases in safety risk because of reduced visibility and significant legal implications if any crash were to happen as a result.
- In Australian studies, sight distance improvements result in a reduction of about 30 percent of crashes for both the open roadway and at intersections where crashes had frequently occurred previously—a medium level of confidence is placed in this figure.[37]

## Good design practice/treatments/ solutions

- Adequate sight distance is essential to provide drivers with enough reaction and maneuvering time to adapt to the road features and to other road users. This involves improving the triangle sight distance at intersections, enhancing visibility for all road users at the intersection, and, in some cases,

37 Austroads. 2012. Effectiveness of Road Safety Engineering Treatments.

reducing excess sight distance that could encourage early decision-making, bearing in mind that it is always necessary to maintain the minimum sight distance required.

Countermeasures for insufficient sight distance in specific situations (e.g., horizontal curves, intersections, etc.) are detailed in each section. Below is a summary of strategies to improve sight distance. Depending on the crash risks and crash types, a combination of countermeasures should be considered. The measures taken should aim to achieve a situation in which the available sight distance is made sufficient through reduced operating speeds (not just speed limits) or other measures.

- **Signs and markings:** For a conventional unsignalized intersection, an enhancement to the typical signs and pavement markings should be considered, although the effect may be limited.
- **Traffic calming devices:** Sight triangles required for stopping and approach distances are typically based on ensuring safety at intersections with no controls at any approach. This situation rarely occurs in urban environments and occurs only at very lowspeed, lowvolume junctions. At uncontrolled locations where volume or speed presents safety concerns, add traffic controls or traffic calming devices on the intersection approach52 (see section 3.2 on Speed management and traffic calming).
- **Relocating obstacles:** If the most frequent crash types are angle crashes due to insufficient sight distance with an overgrowth of foliage, the most effective countermeasure would be to clear the intersection's sight triangles to improve sight distance. Similarly, signals, signs, buildings, and so forth also should be relocated when they obscure sight distance.
- **Physical barriers and medians:** As only placing signs is proven to be unreliable to control movements, physical barriers and medians should be installed to reinforce to drivers what is expected as far as safe maneuvers are concerned. In general, where locations have insufficient visibility, passing maneuvers that involve crossing the centerline of undivided roadways or crossing the median of the roadways without physical barriers or auxiliary lanes must be prohibited [38] (see section 5.6 on Passing lanes).
- **Conversion of Y-type junction to a perpendicular junction (T-type) with signalization as necessary:** This will not only improve visibility, but also give a clear explanation on the right-of-way, resolve dangerous conflict points, and improve safety conditions for pedestrians and other vulnerable users. It is a relatively cheap and safe solution. It should be checked that the visibility at the T-junction is adequate on both the minor road and major road, and signalized where necessary.
- **Reconstruction of intersections and curves:** Modifying a horizontal/vertical alignment is often too costly and can have significant impacts to adjacent land uses. It is much better to design the road well before it is built than to rebuild it.

## Further Reading


- AASHTO. 2018. The Green Book. Must read chapter 3.2, Sight distance.
- PIARC. 2019. Road Safety Manual. Accessed at https://roadsafety.piarc.org/en. Must read chapter 8.2, Designing infrastructure to encourage safe behavior.
- Austroads. 2016. Achieving Safe System Speeds on Urban Arterial Roads: Compendium of Good Practice. Must read chapter 4, Speed as a contributor to urban arterial crashes; Appendix A Engineering treatments.
- FHWA. 2011. Intersection Safety: A Manual for Local Rural Road Owners. Accessed at https://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/. Must read chapter 3, Safety analysis.


38 AASHTO. 2011. A Policy on Geometric Design of Highways and Streets, 6th edition.

- NACTO. 2013. Urban Street Design Guide. Accessed at https://nacto.org/publication/urban-street-design-guide/. Must read chapter, Intersections; Intersection design elements.


# 3.4. Linear Settlements

## General description

Linear settlements (figure 3.21) are a group of buildings, small villages, or other developments (including residential properties, roadside stalls, markets and other businesses) along major routes, leading to a mismatch between road design and use of the road. This situation also applies where trunk roads pass through towns. Traffic problems occur due to poor road network planning, poor enforcement of planning rules (where these do exist), and pressure from local businesses who see these locations as providing useful commercial access to passing motorists. These problems are accentuated by a lack of understanding of the safety risks that are present.

## Safety implications

- Linear settlements lead to a mixing of high speed through traffic and local slow-moving traffic and vulnerable road users. This mixed function can lead to very high risks, particularly for vulnerable road users who may be attempting to cross and walk alongside the road (figures 3.22 through 3.26 illustrate dangerous pedestrian crossing movements in such high-risk environments due to lack of/poorly designed facilities).
- Other risks include poorly designed pickup and set down points for public transport (whether formal or informal), which also pose risks for pedestrians attempting to cross or walk along the road.
- There may also be slow-moving local traffic which may be maneuvering, including turning movements into and out of local access points or side roads, and making U-turns. Despite these road user movements, the design of these roads often remains unchanged, with wide roads, poor facilities for vulnerable road users and local traffic, and high speeds.

**Figure 3.21:** Example of a linear settlement.


Source: © 2021 CNES/Airbus/Google Earth

**Figure 3.22:** No footpath or crossing facility for pedestrians.

Source: © Soames Job/GRSF/World Bank.

**Figure 3.23:** Lack of pedestrian crossings.

Source: FIA Foundation

**Figure 3.24:** Pedestrian bridge but not used.

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

**Figure 3.25:** No footpath for pedestrians.

Source: © Soames Job/GRSF/World Bank

**Figure 3.26 Poorly designed median for no crossing location—Romania.**

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

- In essence, what were previously highways have been converted over time to local streets in regard to road use, but the road design may be unchanged. This creates confusion for road users and high levels of risk. This issue can occur at very discrete points on the road (one or two vendors selling goods to passing road users) through to sections that may be several kilometers in length.

## Good design practice/ treatments/solutions

Various solutions can be applied to addressing this problem of linear development. These solutions are of two main types: regulatory and infrastructure.

- Regulatory approaches include development and enforcement of strict road and land use planning to prevent the development of houses and businesses at the side of the road. This may also require appropriate legal and enforcement powers and adequate resources to apply these. These approaches may also require education of the local community regarding the road safety risks and possible penalties for breaking planning laws.
- Roadside markets (e.g., informal commerce/vendor) pose a major hazard in linear settlements and road users by obstacles (e.g., stalls, shoppers, and parking for shopping) and narrowing of the footpath/road (figure 3.27). These must be addressed through the provision of safe off-road market facilities with parking spaces (figure 3.28).
- A variety of infrastructure solutions are also available. The highest cost and most substantial response are to provide a bypass road around the affected area (figure 3.29). It is important to ensure the new route has strict planning controls, and that new residential and commercial development are

**Figure 3.27:** Hazardous roadside stall

Source: © Kafkasyali/deamstime.

**Figure 3.28:** Separated roadside market space with parking, Dar es Salam corridor between Morogoro and Mafinga, Tanzania.

Source: © James Robert Markland/World Bank.

**Figure 3.29:** Examples of bypass roads.

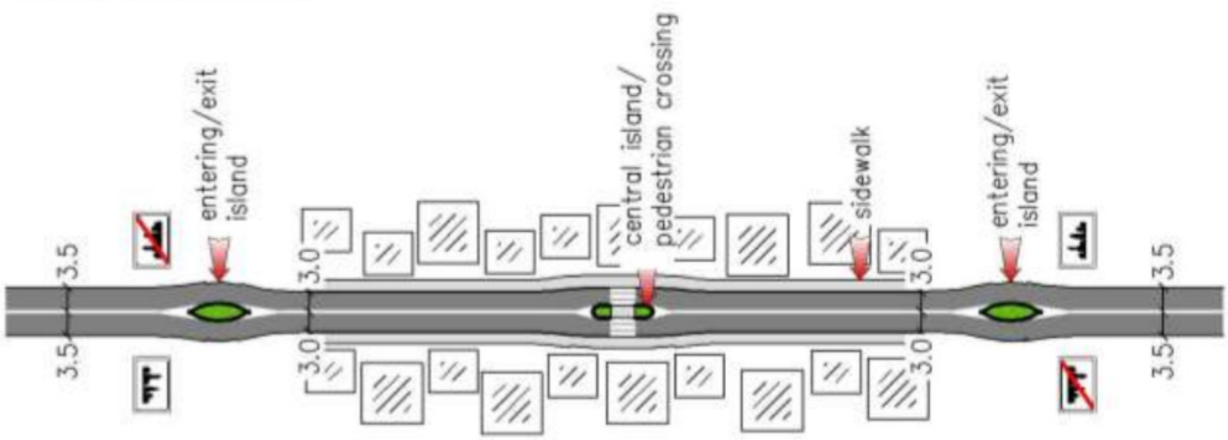
Source: © Google Earth.

not allowed on this bypass route. This approach also requires infrastructure improvements for the linear settlement (the existing road) to provide better, lower speed facilities to cater for the road users that are present. This often involves road narrowing, widening of footpaths, and the provision of safe pedestrian crossing facilities. With significant reductions in traffic, what may have been a four-lane road (two lanes in each direction) can now be narrowed to just two lanes, with adequate provision for pedestrians and other slower road user groups. Figure 3.30 shows an example of road elements along a road in a built-up area.

- Other options include provision of a service road which provides lower speed access for local traffic and vulnerable road users (figure 3.31 and 3.32). These may be used as a location for permanent businesses, public transport stops, or for temporary markets and sellers. For smaller areas of roadside activity, a well-designed lay-by may be adequate. Further measures are likely to be required on the main through road, as there will typically be a need for local road users to cross the road. There also needs to be good provision for entry and exit points between the through road and service road.
- A further option includes reduction in speeds for all road users, supported by infrastructure. This typically includes provision of "gateway" treatments (figures 3.33 through3.35) prior to the start of the area of increased development. These encourage lower speeds on approaches through oversized signs on both sides of the roadway, narrowing (either through constructed or painted islands), or even different road texture or coloring. These

**Figure 3.30:** Sketch of road elements within built-up areas.

**Sketches (with dimensions):**




Example of road elements within the built up areas

Source: Vollpracht et al. 2018

**Figure 3.31:** Service road—India.


Source: © Sudeshna Mitra/GRSF/World Bank.

**Figure 3.32:** Moldova—service road for slow vehicles

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

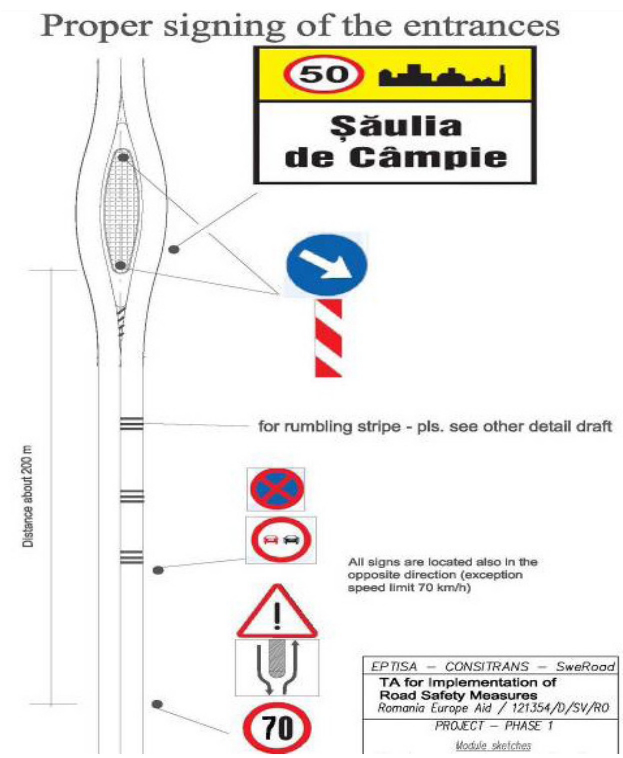
**Figure 3.33:** Speed sign and speed hump for gateway treatment—India.


Source: © Sudeshna Mitra.

**Figure 3.34:** Gateway treatments in India

Source: © Sudeshna Mitra.

**Figure 3.35:** Mixed gateway treatment—Romania




Source: Compania Nationala de Autostrazi si Drumuri Nationale. 2007. Catalog de măsuri pentru siguranţa circulaţiei în satele liniare.

measures can often be low cost and have been shown to produce considerable road safety benefits. The reduced speed may need to be sustained through other infrastructure features, including road narrowing, humps, and other traffic calming (see section 3.2). Particular care is required to provide low speed, safe crossing points for pedestrian (also see section 4.2).

## Further Reading


- Kostic, N., Lipovac, K., Radovic, M., and Vollpracht, H. 2013. Improvement of Road Safety Management and Conditions in Republika Srpska, World Road Association (PIARC), Routes/Roads 360, 54–63.
- Vollpracht, H. 2010. They call them coffin roads, World Road Association (PIARC), Routes/Roads 347, 42–52.
- DfID. 2003. Roadside, Village and Ribbon Development, Highway Design Note 4/01, UK Department for International Development, United Kingdom. http://transport-links.com/research-archive/case-highway-design-note-4-roadside-village-and-ribbon-development/.
- Brumec, U., and Bricelj, A. 2011. Urbanism as a major factor of roads' function and safety, 14th International Conference on Transport Science, Portoroz, Slovenia. Must read chapter 2 and chapter 4.
- Sharma, A. K., Bahadur, A. P., and Tandon, Yashi. 2011. Linear Settlements and Safety Issues along Highways in India: A Case for integrated Approach for Highway Development, 24th World Road

Congress, Mexico City, Mexico. Must read: chapter 1, Background and chapter 2, Highway improvement typologies-traffic segregation

- Vollpracht, H. et al. 2018. Practical Guide for Road Safety Auditors and Inspectors, Automobile and Motorcycle Association of Serbia. Accessed at https://amss-cmv.co.rs/wp-content/uploads/2017/12/Practical-Guide-for-Road-Safety-Auditors-and-Inspectors-EN.pdf. Must read chapter 1, Road function.

## 3.5. Access Control

### General description

Access management/control is one of the critical elements of geometric design and is related to the management of interference with through traffic. Where access to a highway is managed, interference due to vehicles', pedestrians', and cyclists' entrance and exit is minimized, and the road users get designated entry and exit from the highway as per the desired mobility and surrounding land use. Roadside businesses develop haphazardly in the absence of access management, which has emerged as a major road safety concern in LMICs. While access and mobility are two major functions of a road system, these functions need to be balanced to maintain the road's purpose. A high-speed road with unlimited access will not serve the purpose of mobility, and at the same time, will pose a high risk to its road users. However, in the context of LMICs, the balance between access and mobility (movement and place) remains a significant challenge due to the high share of nonmotorized modes. The planning and design of the high-speed facilities often overlook nonmotorized vulnerable road traffic users' needs, leading to safety risks. A high share of nonmotorized road users requires innovative thinking to accommodate all road users' needs in LMICs.

The aims of access management are to limit the number of conflict points, separate the conflict points, and remove turning volumes and queues from through movements. The benefits include not only reducing crashes but also increasing capacity and reducing travel times.

### Safety implications

The safety issues commonly found in a mixed traffic context are as follows:

- Imbalance of access and mobility (movement and place) leading to high-speed environments where nonmotorized and vulnerable road users are not separated from high-speed traffic (figures 3.36 and 3.37).
- Inadequate consideration of the travel needs of nonmotorized road users in the planning and design process (figure 3.38).
- Improper and unsafe crossing opportunities for nonmotorized road users (figure 3.39).

**Figure 3.36:** Local traffic not isolated from the expressway.

Source: World Bank.

**Figure 3.37:** Direct access from local road to expressway

Source: World Bank

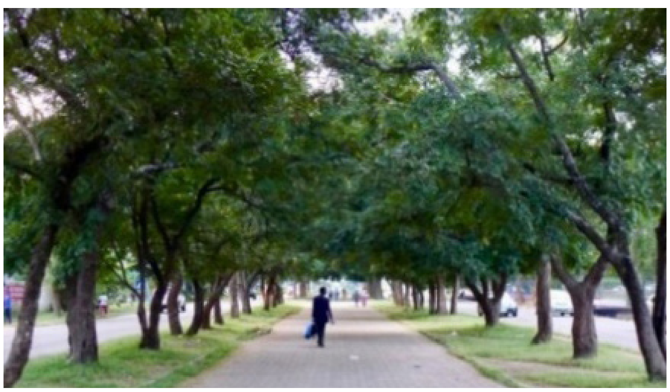
**Figure 3.38:** Lack of pedestrian footpath.

Source: © ONG LEESA/World Bank.

**Figure 3.39:** Opaque apron on footbridge may deter pedestrians from using the facility due to security concerns

Source: © World Bank.

**Figure 3.40:** A median walkway in Lusaka, Zambia.



Source: ITDP Africa.

**Figure 3.41:** Walking and cycling facilities with buffer zone.


Source: Shreya Gadepallii, Ranchi Mobility for All.

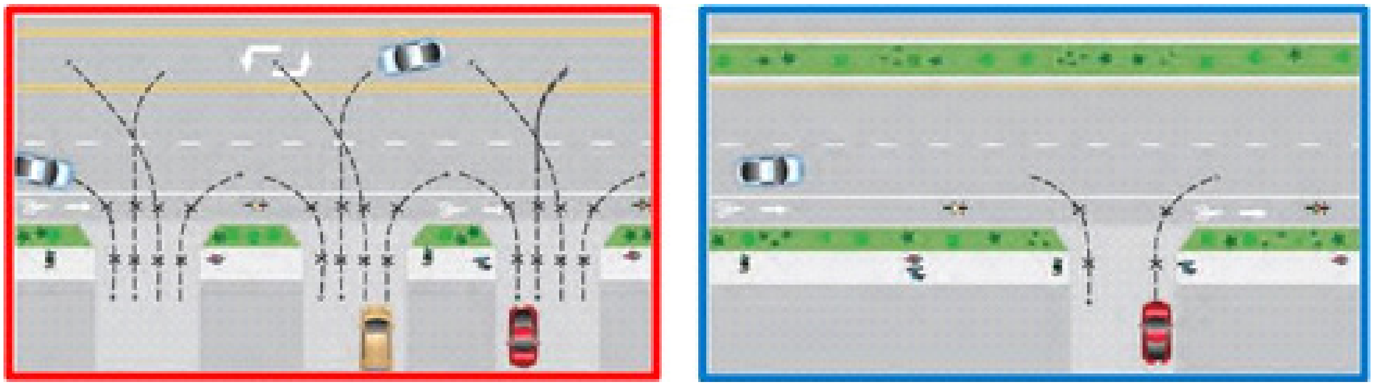
- The unsafe crossing of pedestrians in a high-speed environment, with large numbers of uncontrolled access from local streets onto the main highway.

## Good design practice/ treatments/solutions

For better safety outcomes, it is helpful to have separate corridors that have designated restricted usage or priorities, that is, not all corridors are provided for all users. Some may be designated to the movement of freight/car priority with limited access to vulnerable road users, while others prioritize public transport and cycling with high accessibility. In case such separation is not possible, to tackle the issue of unsafe access management, the following treatments and design practices need to be followed whenever a highway enters built-up areas and settlements.

- At-grade crossing facilities with marked uncontrolled crossings at two-lane and controlled and/or grade-separated crossings for wider roads such as four, six, or higher lane highways.
- Provision of footpath/sidewalk and cycle lanes to separate pedestrian and cyclist traffic from through traffic (figures 3.40 and 3.41).
- Provision of pedestrian guardrails to channelize pedestrians only at the marked crosswalk such that random crossing of roads at undesignated locations could be prevented.
- Safe and marked public transport stops with bay facilities for boarding and alighting.

**Figure 3.42:** Access management.



Source: Michele Weisbar/Los Angeles County. 2011. Model Design Manual for Living Streets. Accessed at http://modelstreetdesignmanual.com/model_street_design_manual.pdf.

- Where major roads are bordered by commercial or residential development, multiple minor accesses may be connected to a service road that connects into the main highway via a properly designed junction. See also section 3.4.

The presence of many driveways in addition to the necessary intersections creates many conflicts between

vehicles entering or leaving a street and bicyclists and pedestrians riding or walking along the street. When possible, new driveways should be minimized and old driveways should be eliminated or consolidated, and raised medians should be placed to limit left or right turns into and out of driveways (figure 3.42).

There is evidence from research conducted in LMICs that pedestrians prefer to cross at-grade and often don't use grade-separated crossing facilities (Tiwari et al.). The success of the usage of the grade-separated facilities thus depends on the ease of access, and the amount of diversion, security, and control of alternative access to unsafe crossings. Therefore, it is essential to make a balance and use innovative design, such that extra distance walked by the pedestrians could be reduced, which is probably the most critical challenge currently facing the road development projects in LMICs.

# 3.6. Construction, Operation, and Maintenance

## General description

As part of the construction, maintenance, and operation of a highway network, there will be a requirement to review safety features and implement measures to ensure safe use of the network by all users. This will often require road works, temporary closures, or incident management while allowing traffic to flow as freely as possible. In addition, additional reviews of safety features will be needed throughout the lifetime of the road to ensure that safe operation of the highway is maintained. Figures 3.43 through 3.47 illustrate some safe and unsafe practices in work zones.

To ensure that the safety benefits of the road are maintained during its operational life, it is important to continue periodic reviews of the network in use. This is achieved through a regular program of road safety inspection and assessment. It involves the examination of an existing road with the objective of identifying aspects of the road or the road environment that contribute to safety risk, and where safety can be improved by modifying the road environment. This should not be confused with routine maintenance

**Figure 3.43:** Complete lack of signing and control—Kenya.

Source: © John Barrell.

**Figure 3.44:** Uncontrolled signing—Romania


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

**Figure 3.45:** Well signed and controlled site—Tanzania

Source: © John Barrell.

**Figure 3.46:** No provision for pedestrians—Qatar

Source: © John Barrell.

**Figure 3.47:** Well signed and guarded work zone—Abu Dhabi.

Source: © John Barrell.

inspections which examine the condition of the existing road infrastructure.

Even when no works are being undertaken on the operational network, it is still necessary to assess the safety of its use and performance. And even when roads are constructed to the latest and best safety standards, because of the continuously changing interaction between vehicle performance, road user behavior, and road infrastructure, the performance of highway features can change over time.

## Safety implications

- Even the best design will produce poor outcomes if construction is poor (including not following design, use of different materials or design solutions during construction, and not adequately adapting to local factors (such as utilities and traffic mix).
- Poorly defined work zones can increase road safety risk for all users (figures 3.48 through 3.51).
- Even where adequate and comprehensive work zone traffic management arrangements are provided, they do not change with each phase of operation and materials and objects are often not protected or are left behind when construction is completed in that area (figures 3.52 and 3.53).
- Construction materials/objects are often not removed even after the road is open to the public.
- Lack of maintenance and review of safety features can result in poor driver behavior (figures 3.54 and 3.55).
- Relatively little is known about the true effectiveness of the treatments under different circumstances in LMICs.
- Proper evaluations of road safety actions and interventions worldwide are rarely undertaken, and this is especially the case in low- and middle-income countries.
- It is necessary to rely on (and extrapolate from) evidence on the effectiveness of measures from high income countries where road user behavior and traffic mix will not be a perfect match.

**Figure 3.48:** Construction work going on without any temporary safety measures—West Bengal.

Source: World Bank.

**Figure 3.49:** Major excavation with no protection or segregation of work zone and general traffic—Kenya.

Source: © John Barrell

**Figure 3.50:** Construction with no protection or segregation of work zone and general traffic—Romania.

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

**Figure 3.51:** Complete lack of roadworker protective clothing or adequate workzone demarcation.

Source: World Bank.

**Figure 3.52:** Unprotected work areas and materials—India

Source: World Bank

**Figure 3.53:** Stacked construction material unprotected or contained along the highway—India

Source: World Bank.

**Figure 3.54:** Poorly maintained road surface—Romania.

Source: © Sudeshna Mitra/GRSF/World Bank.

**Figure 3.55:** Well-maintained road with clear road markings—India.

Source: Martijn Thierry/Jasper Vet—Safe Crossings.

## Good design practice/ treatments/solutions

- All work activities should be planned to optimize road safety, road space, and work efficiency while minimizing congestion, delays, and inconvenience for all road users.

### Construction and maintenance

- All reasonable steps should be taken to ensure that disruption due to the work is reduced to a minimum.
- Work zones must be clearly defined and protected to allow both roadworkers and the general public to adapt safely to the change in space and alignment.
- Traffic and roadworker safety in a roadworks work zone should be integral and high priority elements of every road construction project or road maintenance activity, from the planning process until project construction or maintenance work is complete.
- Work zone traffic management must not be associated with substandard traffic safety and if anything, the unusual and/or restrictive conditions found in work zones can require even higher standards of safety.

- Subject to achieving an acceptable level of road user and worker safety, traffic amenity in a work zone should be as close as possible to that provided for in the normal operation of the road, including speed, permitted movements, access to abutting property, and provisions for non-vehicular traffic. However, in many cases restrictions on some or all of these aspects are necessary. These restrictions require clear advance warning, signage, and direction to operate safely.
- The same geometric and safety design principles which apply to the design of permanent roadways also govern the design of work zone traffic management treatments. For example, lane drops, lane narrowing, sharp curves, or other abrupt or frequent geometric changes must be appropriately designed and implemented in terms of design speed, advance warning, signage, and delineation to provide road users with effective clear and positive guidance.
- This may also require the introduction of geometric changes in individual steps or stages, for example, the closure of two lanes on a multilane highway should be done in two individual stages to allow traffic to change lanes smoothly and safely, and a lane closure should not end and a sharp horizontal curve begin at the same point, but should be separated.

*Note:* The topic of work zone traffic management is a whole manual in itself and there is not sufficient space within this document to cover it fully. Numerous national guidelines are readily available as exemplars of good practice—see further reading below.

- Road construction materials (whether in use or surplus) should be contained within a demarcated construction zone. If materials need to be placed along the highway, delineation, demarcation, and signage should be given to warn and guide drivers.
- All construction materials/stored materials on the Right of Way (ROW) which can potentially harm road users or cause them to behave in such a way that can potentially lead them to an unsafe situation should be removed.
- All construction phases (i.e., different site layouts and access/routing arrangements) need to be subjected to an independent road safety audit.
- The whole of the construction process should be subject to a thorough safety assessment that considers the risk to both roadworker and road users during the implementation of any works, including road safety audits during construction. This is sometimes referred to as a "Safety in Design" Review. This compares options for design, construction, operation, and decommissioning of the asset and assesses which has the lowest risk to the workforce and the travelling public during each phase. This does not necessarily lead to a change in preference for options; however, the risks should be identified so that they are taken into account during subsequent phases of the project. A specific Traffic Management Plan needs to be developed that demonstrates safe routing of motorized and nonmotorized traffic during construction, together with appropriate protection of construction site workers.
- It is essential that the cost of routine inspections and maintenance are embedded in scheme appraisal and design from the outset.

## Operation

- When a scheme is implemented and open to use, it is still important to monitor and review the safety performance of the design to ensure that the predicted safety is achieved.
- Before implementing proposed treatments, it is normally necessary to assess their potential impact in order to make a business case for investment. Information on the effectiveness of treatments has generally been compiled from research undertaken in countries in Europe, and in the US and Australia.

- Low- and middle-income countries should seek to build an evidence base of what does (and does not) work in their own situations. This can be advanced by closely monitoring the safety performance of new and existing roads when in use.
- An understanding of local effectiveness will only be established if road authorities monitor and evaluate the performance of any measures implemented.
- Organizations therefore need to introduce a system for monitoring and reviewing the performance of any implemented road safety inspection or road safety assessment recommendations. This can then be used to identify the most appropriate safety improvements to incorporate into revised design standards. This is particularly important in any country where development of the road network is occurring at a fast pace and where research concerning road characteristics and their impact on road safety outcomes are not available.
- Road safety audit (see section 7.3) includes the post opening stages of a new road and reviews the actual safety in use compared with what was anticipated. A regular program of post-opening safety reviews can feed back into design changes relevant to local circumstances.
- A regular sequence of inspection and action ensures that both road condition and safety are reviewed, and appropriate remedial actions implemented to maintain optimum performance of the network.

## Further Reading

Wisconsin Department of Transportation. 2019. Work Zone Guidelines for Construction, Maintenance, and Utility Operations.

National Academies of Sciences, Engineering, and Medicine. 2018. Estimating the Safety Effects of Work Zone Characteristics and Countermeasures: A Guidebook. Washington, DC: The National Academies Press. https://doi.org/10.17226/25007.

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3. Existing Roads—Reactive Approaches.