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1. INTRODUCTION

1.1. Integrating Safety into Road Design

Road crashes account for an estimated 1.35 million deaths and 50 million injuries worldwide each year, with over 90 percent of the reported deaths occurring in developing countries.\(^1\) Road crashes represent a major burden on health systems and other services, and inflict pain and suffering on communities and individuals. The combined injury and social costs of crashes pose a heavy financial burden on the economy. According to World Bank statistics, in low- and middle-income countries (LMICs) alone, deaths and serious injuries cost economies 1.7 trillion dollars and over 6.5 percent of gross domestic product (GDP).\(^2\) Governments around the world are working to reduce road-related trauma and have agreed to halve the number of deaths occurring on the roads by 2030.\(^3\)

There are known, cost-effective solutions that can be implemented to address this global crisis. The 2030 Agenda for Sustainable Development recognizes that road safety is a prerequisite to ensuring healthy lives, promoting well-being, and making cities inclusive, safe, resilient, and sustainable. The Decade of Action for Road Safety 2011–2020, officially proclaimed by the UN General Assembly in March 2010, had a goal to stabilize and reduce the forecasted level of road traffic deaths around the world. To continue this global focus on improving road safety, the UN General Assembly has adopted a new resolution on global road safety, proclaiming the period 2021–2030 as the Second Decade of Action for Road Safety with the goal to reduce road traffic deaths and injuries by at least 50 percent by 2030.

A substantial reduction in road deaths will only be feasible if concerted efforts are made, following the “Safe System” approach involving all elements of road safety, management, and delivery. This includes all pillars of the Safe System—starting from road safety management, safe roads and roadsides, safe speed, safe vehicles, safe road users, and post-crash care. This guide focuses on elements of safe road and roadside designs for road networks that can provide safe mobility to all road users, as well as complementary changes to improve speeds, vehicle safety, road user behaviors, and post-crash care. A balanced road design must take into account these complementary system elements to maximize safety benefits. The energy carried by a moving object is proportional to the square of its speed. A well-designed “forgiving roadside” ensures that this energy is dispersed in a crash, and as a result, less energy is transferred to the occupants.

Road infrastructure design plays a vital role in road safety outcomes. Safe infrastructure supports other road safety pillars by encouraging appropriate road user behavior (such as appropriate speed and correct lane position) and by providing a forgiving road environment if things go wrong. Poorly designed road infrastructure can give rise to dangerous road user behavior. One of the key realizations of the

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3 United Nations General Assembly Resolution A/RES/74/299 on Improving Global Road Safety.
Safe System approach is that drivers make mistakes and will continue to do so, even if we can reduce how often these occur. This road user error has long been recognized as a significant contributor to poor road safety outcomes. However, roads of any given speed can be designed to reduce the likelihood of crashes occurring, and there is very clear evidence that the severity of outcomes when crashes do occur is significantly influenced by the road design.\textsuperscript{4} Even if a crash still occurs, improved road infrastructure can save many lives and prevent debilitating injuries.

As examples of the significant benefits that can be obtained through the provision of safe road infrastructure, reductions in deaths and serious injury of up to 80 percent are possible by installing appropriate barrier systems and ensuring that these are adequately maintained, while the same benefits can be obtained from installing well designed roundabouts.\textsuperscript{5}

The Safe System approach highlights that a shared response is required to address road safety. This means that road users will continue to take responsibility for their actions, for instance by being alert and compliant with road rules. However, it is also recognized that road managers and designers have a significant responsibility to provide a road system that protects all road users. This can be achieved through appropriate designs of roads.

As an example, if a driver runs off the road and sideswipes a tree at high speed, there is a very high probability of a fatal or serious crash outcome. In this same situation, if road users were protected from the tree by a well designed and installed roadside barrier, the risks to the occupants would be significantly reduced to the extent that it is likely that only minor damage would occur to the car, but that there would be no significant injuries (assuming a reasonably safe and well-maintained vehicle). This is regardless of the cause of the crash: impairment, misjudgment of speed, fatigue, distraction, drugs, or alcohol. The same protection occurs when pedestrians and cyclists are adequately separated from motorized traffic, or when speeds are managed through traffic calming to appropriate levels given the road users present. Similarly, when vehicles travelling in opposing directions at high speeds are separated by barriers, the risk of a head-on crash occurring is greatly reduced. The provision of this safe road infrastructure relies on good decision-making by recognizing key risk factors while planning road infrastructure and incorporating appropriate design elements to address these risks. This also requires an understanding of the key crash types that result in death and serious injury. These crash types include collisions with vulnerable road users (including pedestrians and cyclists); run-off road, head-on, high-angle collisions including right-angle crashes at intersections; and rear-end crashes.

Substantial improvements to road systems are already occurring in many countries. However, efforts to improve the whole system are required, and this will take time and resources. A long-term vision is required to provide improved design to support safe road design and use following safe system principles. Many countries have set a target date of 2050 for an elimination of death and serious injury on the roads (e.g., in Europe\textsuperscript{6, 7} and Australia\textsuperscript{8}). This will require commitments of key partners involved in decision-making to provide infrastructure that works alongside improvements in vehicle safety as well as other Safe System pillars to produce such outcomes.


1.2. Safe System Guiding Principles to Safer Design

The following Safe System principles are recommended to ensure safety in sustainable road transport system design:

1. Inclusiveness: Road design needs to be for all road users—not only for motorized vehicles. The implication of this is that designers need to cater for the most vulnerable road users present. In doing so, safety will typically be improved for all road users.

2. Road functionality: Roads serve two functions: “access and mobility” or “movement and place.” Roads serve two primary functions or “roles”: to facilitate the movement (mobility) of people and goods and to act as places (access) for people. For safe design the “actual function,” not the “intended function” should be identified. In cases where mono-functionality cannot be realized in the short term, efforts should be made to provide adequate safety through safe speeds, starting with provision for the most vulnerable road users.

3. Clarity: Design should meet road users’ expectations and be free from any surprise to road users. In case of practical limitations, clear delineation (e.g., markings and signs), adequate sight distance (e.g., decision sight distance), and/or speed management should be used to provide safety for all road users. In addition, variations in key design parameters along the road have an impact on traffic flow and safety. Such transitions should be supported by safe speed reductions, for example, traffic calming. This is applicable in case of variation in cross-section design near bridges/ culverts, for roads passing through villages and towns, at-grade crossing facilities for vulnerable road users, and so forth.

4. Homogeneity: Design should limit differences in vehicle speed, direction of travel, mass, and size. The design should ensure that vehicles (road users) travelling at different speeds are not able to interact (e.g., fast moving cars and vulnerable road users); that those travelling in different directions are not able to collide, especially at higher speeds, (for example in head-on conflicts), and that road users of different mass or size do not mix (for instance, trucks and vulnerable road users). Where it is not possible to provide designs that ensure separation, speeds need to be low. The implication of this principle includes that:

   • Design should ensure the safe segregation of vulnerable road users from motorized traffic where operating speeds need to be above 30 kph, i.e., conforming to Safe System speed.
   • Designs should ensure, whenever possible, physical separation between bi-directional traffic in situations where speeds are above human tolerance levels (e.g., 70 kph for motorized vehicles that have modern safety features) and more so when visibility is restricted.

5. Safe Speed: Design should support Safe System speeds. The determinant of “safe design” is the safety of the most vulnerable or least protected road user and their tolerance to impact forces during a collision. This survivability is largely dictated by the impact speed for different road users. Hence, similar to “design vehicle,” the concept of “design road user” should be adopted to ensure safety, especially when considering the speed environment.

6. Forgiving roads and roadsides: Roads and roadsides should be forgiving, i.e., free from hazards. In higher speed environments roads and roadsides should be free from permanent as well as temporarily fixed objects, such as rigid structures, trees, stopped/parked vehicles, etc., and should be protected if vehicle departure is non-recoverable.

7. Minimized exposure: Design needs to minimize exposure to risk for all users. This can be achieved at the planning stage by providing good quality,
safe infrastructure that encourages modal shifts (e.g., from motorcycles to mass transit systems in cities). Exposure to risk can also be managed through the provision of safe infrastructure elements. As an example, intersections can be designed to remove or eliminate exposure by banning turning movements across multiple lanes of traffic.

8. System design: Road design should be done in a way to support other elements of the Safe System. For example, it may be possible to build post-crash response into the design (e.g., providing shoulders to park disabled vehicles or access of emergency vehicles, providing for safe enforcement activity).

1.3. The Role of Road Design Guides

It is vitally important to understand that guidelines provide broad design principles in both urban and rural settings, as well as technical details, but do not provide full details on design for every situation. These principles and technical details need to be adhered to in order to achieve required outcomes, including a provision for safety. However, every solution is a unique combination of standard elements that requires expert knowledge and local understanding to apply correctly. The Australian Guide to Road Design states the following:

“Every road project is a unique undertaking and can never be precisely repeated. There are no ‘off the shelf’ solutions that will fully address all situations encountered, and the rigid and unthinking application of charts, tables, and figures is unlikely to lead to a successful design outcome. Good design requires creative input based on experience and a sound understanding of the principles. However, every situation is different, and therefore design requirements will also differ.”

This applies to all elements of design, and particularly to safety. The Australian guidance elaborates further on this issue by stating that “designing and constructing roads according to guidelines will not necessarily produce safe outcomes.” Based on the outcomes of design and our knowledge of safety performance, this has unfortunately proven to be true in many situations. Safe road design is not like following a recipe, but rather considerable expertise is required to safely design roads for all road users. Because of the complexities of road design, additional checks and tools have been developed to help identify safety risk, and maximize the safety potential through design. These tools include road safety audit/inspection, road infrastructure safety assessments (including international Road Assessment Program (iRAP)), and a Safe System assessment. In addition, greater attention is being paid to the application of relevant safety metrics in project planning and design. These issues and tools are discussed in chapter 7.

Road design guides have always considered road safety. Issues such as sight distance and design speed dictate much of the design process, and these are based fundamentally on trying to achieve safe outcomes for road users. However, roads are still designed and constructed with inherent risks that result in death and serious injury. This lack of safety may be because there is a “trade-off” between safety and efficiency or mobility due to project constraints such as cost, inconsistency in road design, or simply lack of consideration for vulnerable road users, especially in LMICs (see section 2.3 for a discussion on differing vehicle and road user types in this context). However, in many countries this outcome is no longer seen as acceptable. It is no longer acceptable to design or upgrade roads with inherent safety flaws that carry with them unacceptable levels of risk of death or serious injury. We must ensure that designs follow Safe System principles, and as far as practical eliminate death and serious injury.

Safety-related design information often falls into

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the later stages of design guidance documents. For example, decisions about what type of intersection design to use or availability of a right-of-way are made at the start of the design process. Road designers may either have limited ability to alter this decision, or feel like they cannot. They do their best to design the safest version of what they have been asked to produce. However, there are significant safety implications based on this earlier decision-making process. As an example, roundabouts in higher speed environments typically have much better safety performance than traffic signals. This highlights that planning and policy decisions often have a big impact on design choices and outcomes. However, it also highlights the need for designers to understand the implications of design decisions, and to challenge these decisions where better outcomes are possible.

Knowledge is also improving on safe road design, with new solutions emerging on a regular basis, and in some cases, the basic road design tenets are evolving. As one example, the knowledge base on intersection design is changing, with improved design options such as using platforms to raise intersections to help manage speeds and improve safety (see section 6.4). Because of this evolving knowledge, guidance needs to be continually updated. It is important to understand that guidance updates often take many years, and so current editions of design guides and national standards do not necessarily reflect up-to-date good practices. As an example, globally, the vast majority of existing design guides do not yet reflect the new thinking relating to roadside safety. This guide aims to be as up to date as possible at the time of preparation.

Guidance produced for and in LMICs is often adapted from high-income country’s (HICs) best practices. This is because HICs were often the first to produce such guidance, and much of the underlying research on design has been conducted in these countries. In some cases, attempts have been made to reflect local conditions when translating these guides to LMIC use. However, there are significant gaps in knowledge on some issues relating to the design and use of roads in LMICs. As one obvious example, the traffic mix is often quite different, perhaps involving a much higher proportion of motorcycles and other vulnerable road users, and a mix of slower-moving vehicles. Even if the design standards do reflect good practice, they are often applied to the upgrading of existing roads, which can bring challenges. This may lead to the adoption of deviations from design standards to avoid land acquisition or retain an existing alignment; any deviation from the standards should be accompanied by measures to mitigate resulting safety hazards, although this is not always the case (see section 2.4). Similarly, there are often deficiencies in vehicle standards and maintenance. There is also sometimes different unsafe road user behaviors due to lack of enforcement of otherwise common traffic laws and lack of infrastructure. Because of these gaps, there may be deficiencies in the design advice that aligns with the road environment of an LMIC and its users. This may require greater understanding and a need to develop the content of current guidance. This needs to occur in a structured, evidence-based manner (see section 2.6).

In summary, road design guides are technically sound, but they may not meet all objectives around informing designers how to deliver the unique combination of elements in road design and road safety solutions. Most of the constraints identified above are recognized and often documented in the design guides themselves. However, these constraints are often overlooked by practitioners, leading to stringent application without reference to the local context (an issue discussed further in section 2.4). In many instances, this also leads to poor road safety outcomes. Because of the complexities of road design, additional tools have been developed to help identify safety risk and maximize the safety potential through design (see chapter 7). This guide has been designed to address these gaps, including highlighting the safety-related issues that need to be considered when designing roads, as well as the tools and approaches that are needed to ensure safety.
1.4. About This Guide

This guide has been produced by the Global Road Safety Facility (GRSF), which is hosted by the World Bank. A summary of the GRSF program is contained in box 1.1. This document has primarily been produced for those working in the development and implementation of road improvements and safety features in LMICs, although information will also be of interest to those working in HICs. It provides direct guidance on safety-related issues for designs in both urban and rural settings based on experience and a knowledge of LMIC activity from around the world. Thus, this guide should be used by task team leaders of the World Bank and other Multilateral Development Banks (MDBs) to inform LMIC clients on safety issues in design, as well road designers and practitioners involved in road development projects, researchers and academics. The list of common risk factors provided here can be the starting point, and respective design elements should be carefully followed to incorporate safety into road design.

The guide will also be useful for those who want to embed good practice and address safety in their design. Therefore, the information in this guide will be relevant to those working on World Bank–funded projects, but also client countries as well as others involved in road-related activity. It should be used in tandem with local design guidance, and may be useful to draw attention in identifying where safety challenges may arise in a design or simply help identify gaps in the existing guidance. From that perspective, it may also be useful to those in LMICs who are about to update local guidance, or who are trying to adapt guidance from other countries to local conditions.

This guide does not provide detailed information on how to design. The information in this guide will not allow a designer to design a roundabout, a roadside barrier, or a high-speed rural curve. This document does provide external references for this type of advice. Rather, the document will help identify safety-related issues that need attention through design of a roundabout, a roadside barrier, or a high-speed rural curve or similar facilities. It also provides information on tools that should be used as part of the design process to ensure that safety is embedded within projects and policies.

It is not intended that the document will be read from cover to cover, but more that it will be used as a reference for all aspects of the design process to ensure that the safety of road users is at the forefront of design considerations. Suitable dimensions for specific treatments will also rely on appropriate local standards—which may need to be revised to provide adequate safety benefits.

Chapter 2 of this guide addresses some broad road design principles that relate to achieving safe road outcomes. The main content of this report falls within chapters 2 to 6. Within each chapter, various design issues are presented. A description is provided for each of these along with evidence-based information on safety-related issues. Solutions that are applicable in LMICs are provided, along with case studies illustrating these issues and solutions and key references for further reading. Chapter 2 focuses on planning and design, while chapter 4 focuses on vulnerable road user design, including for pedestrians, cyclists, and motorcyclists. Chapter 5 assesses designs related to cross section and alignment, and chapter 6 provides this information for intersections. Chapter 7 provides information on some design-related tools to help achieve safe outcomes.

Chapters 4 to 6 cover the design aspects of various user groups and infrastructure elements. The research cited throughout the sections is primarily based on work in HICs. Where available, specific LMIC research has been cited. However, it must be emphasized that the safety impact of many design features has not been validated in LMICs. It is hoped that this would encourage individual countries and organizations working in LMICs to develop this validation for specific situations, otherwise the same assumptions on untested transferability of measures will continue.
As noted in section 1.1, the provision of this safe road infrastructure relies on good decision-making by recognizing key risk factors while planning road infrastructure and incorporating appropriate design elements to address these risks. To provide a guidance, key risk factors related to road design for each road type are identified in Table 1.1. It is expected that careful considerations will be given while planning and designing infrastructure in such a road environment. These risk factors are further discussed along with their solutions in later sections, as indicated in the table.

Table 1.1: Typical road design risk factors

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Motorways</th>
<th>High-speed inter-urban roads</th>
<th>Urban, residential, and village roads</th>
<th>Go to section:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Inadequate sight distance or line of sight is obstructed with unplanned roadside construction</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3.3: Sight distance</td>
</tr>
<tr>
<td>2. Missing, insufficient, or incorrect safety barrier installations (both roadside and centerline)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5.8: Barriers</td>
</tr>
<tr>
<td>3. Poor combinations of horizontal and vertical alignment, in particular “hidden dips”</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5.3: Horizontal curvature, 5.5: Vertical curvature and gradient</td>
</tr>
<tr>
<td>4. Presence of rigid objects by the roadside posing hazards</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>5.7: Roadsides</td>
</tr>
<tr>
<td>5. Insufficient drainage leading to water logging or deep open drainage ditches posing risk</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>5.11: Drainage</td>
</tr>
<tr>
<td>6. Cross-section with wide, hard shoulders which are (wrongly) regularly used for overtaking</td>
<td>X</td>
<td></td>
<td></td>
<td>5.2: Shoulder width and type</td>
</tr>
<tr>
<td>7. Inconsistent radius sequence of consecutive curves, e.g., sharp curve after a sequence of significantly more gentle curves, erroneous compound curves with high variability of ratio of the radius, broken back curves, etc.</td>
<td>X</td>
<td></td>
<td></td>
<td>5.3: Horizontal curvature</td>
</tr>
<tr>
<td>8. Unsafe routing and insufficient protection of pedestrians, cyclists, and motorcyclists along the road and intersections, including missing/insufficiently separated pedestrian and cyclist facilities from high-speed traffic and missing/insufficient crossing facilities</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4: Vulnerable Road User Infrastructure Design</td>
</tr>
<tr>
<td>9. Inadequate skid resistance</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5.10: Road surfacing</td>
</tr>
<tr>
<td>10. Lack of climbing lanes in steep upward grades on two-lane roads</td>
<td>X</td>
<td></td>
<td></td>
<td>5.6: Passing lanes</td>
</tr>
<tr>
<td>11. Insufficient superelevation on bends leading to high risk of lateral shift or overturning</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5.4: Superelevation and cross slope</td>
</tr>
<tr>
<td>12. Lack of strong and stable verges</td>
<td>X</td>
<td></td>
<td></td>
<td>5.2: Shoulder width and type</td>
</tr>
<tr>
<td>13. Signal controls that do not consider the needs of all road users, including excessive delays for pedestrians and cyclists</td>
<td>X</td>
<td>X</td>
<td></td>
<td>6.2: Signalized intersections</td>
</tr>
<tr>
<td></td>
<td>Lack of protection for left-turning movements in right-driving traffic, and right-turning movements in left-driving traffic</td>
<td></td>
<td></td>
<td>6. Intersections, 5.13. Road signs, 5.14. Line marking</td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
<td>---</td>
</tr>
<tr>
<td>14.</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Inappropriate road widths and cross-sections in built-up areas, e.g., wide road/lane widths at the expense of facilities for vulnerable road users</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>16.</td>
<td>Narrow lanes on high-speed roads, curves, and turning lanes</td>
<td>X</td>
<td>X</td>
<td>5.1: Road width</td>
</tr>
<tr>
<td>17.</td>
<td>Inappropriate parking and loading facilities</td>
<td>X</td>
<td>X</td>
<td>5.7: Roadsides</td>
</tr>
<tr>
<td>18.</td>
<td>Missing/ineffective traffic calming measures</td>
<td>X</td>
<td>X</td>
<td>3.2: Speed management and traffic calming</td>
</tr>
<tr>
<td>19.</td>
<td>Lack of visual contact between motorists and pedestrians/cyclists</td>
<td></td>
<td>X</td>
<td>3.3: Sight distance</td>
</tr>
<tr>
<td>20.</td>
<td>Poor recognition of intersections and rights of way due to a lack of guiding features, e.g., channelization, markings, and signs</td>
<td></td>
<td>X</td>
<td>6.5: Channelization, 5.13: Road signs, 5.14: Line marking</td>
</tr>
<tr>
<td>21.</td>
<td>Inadequate signage and pavement markings</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
The World Bank has the twin goals of ending extreme poverty and promoting shared prosperity. As part of these overarching objectives, World Bank is working to promote sustainable mobility around the world. Under the combined effects of globalization, population growth, rapid urbanization, economic development, and technological progress, country needs are growing exponentially, making sustainable transport a vital part of the global development agenda. Improvements in road safety are a core part of delivering sustainable transport solutions. The World Bank and GRSF recognize the significant impacts of road crash fatalities and injuries on economic growth for LMICs and the role of crashes in driving families into poverty resulting from the loss of the family income earner due to a fatality or disability. Thus, road crashes directly impact the World Bank's twin goals.

GRSF has been hosted at the World Bank since its inception in 2006 and has the objective of helping to address the growing crisis of road crash deaths and injuries in LMICs. GRSF delivers funding and knowledge development through research, knowledge transfer, advocacy, and technical assistance to scale up and improve road safety delivery in LMICs.

Road safety is embedded in World Bank activity as part of the Environmental and Social Framework (ESF) through the Environmental and Social Standard 4 (ESS4). The ESF, which took effect in October 2018, requires that road safety is considered in projects and addressed wherever it is relevant. A Good Practice Note has been prepared to guide the implementation of the road safety requirements of the ESF. The requirements now include a road safety indicator for relevant projects to monitor the road safety components of projects. GRSF has developed the Road Safety Screening and Appraisal Tool (RSSAT) (also see section 7.3) that allows assessment of the road safety impacts of planned projects early in project development. This allows for refinement of projects to improve road safety delivery before the project is well advanced and road safety interventions are more challenging to include. The Transport Global Practice has implemented a policy requiring the use of RSSAT on roads and urban mobility projects, including the attainment of minimum safety standards. GRSF is planning to develop RSSAT as a web-based tool and share it publicly, please refer to the GRSF website (https://www.roadsafetyfacility.org/).

In addition, GRSF has been promoting good practice in design through training in LMICs and embeds this good practice in projects around the world. Furthermore, GRSF has partnered with iRAP to develop the Star Rating for Designs tool, which is available for use at no charge. This tool was developed to enable a star rating to be easily incorporated into the road design process. Further details on these tools and ways that they can be used to embed road safety into design can be found in chapter 7.