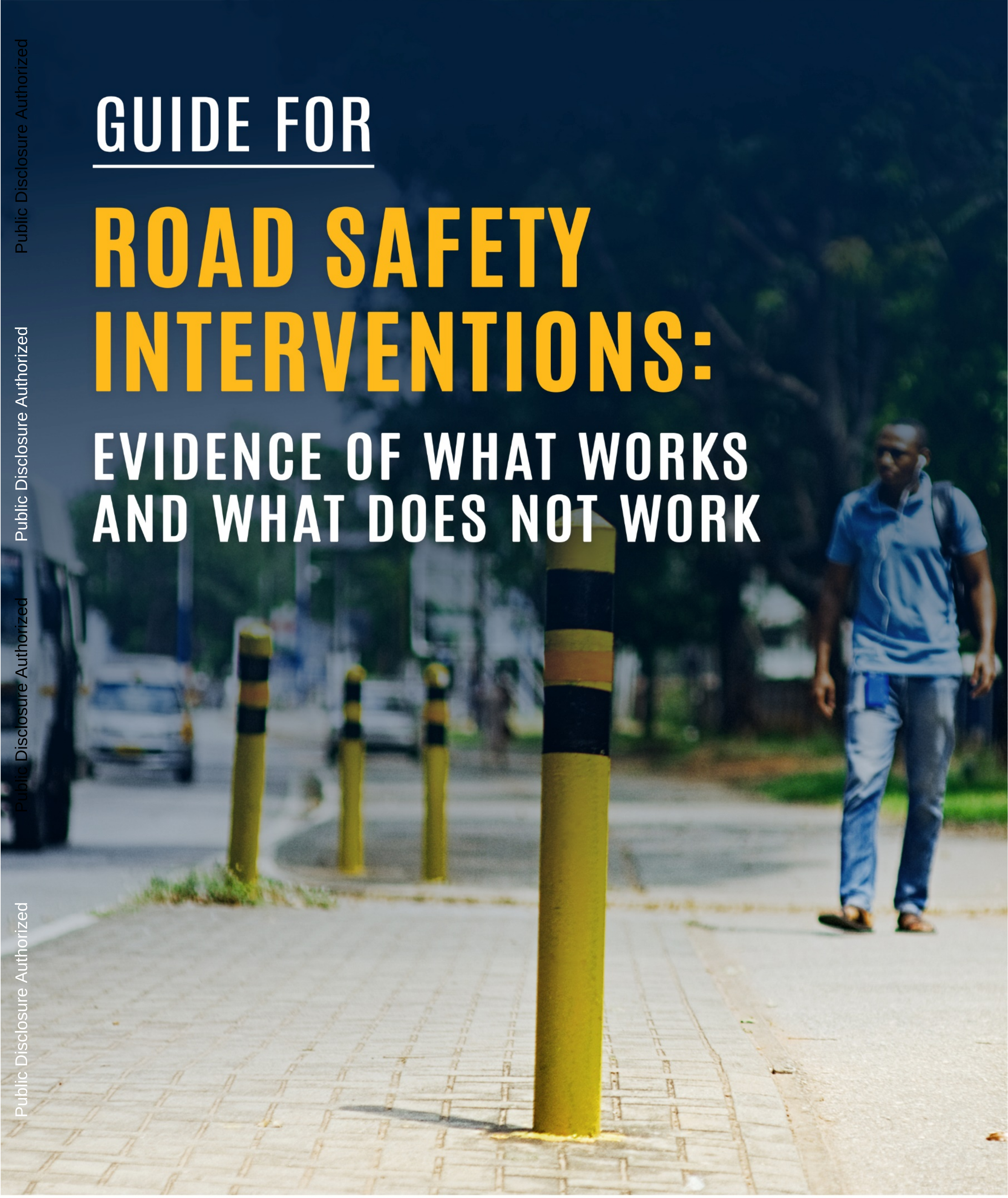
GUIDE FOR

ROAD SAFETY INTERVENTIONS:

EVIDENCE OF WHAT WORKS AND WHAT DOES NOT WORK



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EXECUTIVE SUMMARY

Road traffic crashes result in an estimated 1.35 million deaths and 50 million injuries worldwide per year with over 90 percent of these occurring in Low-Middle Income Countries (LMICs). Aside from the obvious pain and suffering this inflicts on individuals and communities, these deaths and injuries also place a large financial burden particularly on LMICs, by slowing economic growth.

The scale of the current response to this continuing crisis does not match the size of the problem. In addition, limited road safety resources are often expended on ineffective or suboptimal interventions. While road safety knowledge has improved over recent decades, there is still a need to improve decision making when selecting and applying effective evidence-based road safety interventions. Effective interventions are those that reduce fatal and serious injuries.

The Global Road Safety Facility (GRSF) has developed this evidence-based guide on "**What Works and What Does Not Work"** in road safety in response to the critical need for effective evidence-based solutions. This guide has been prepared to help readers understand that not all road safety interventions are equally effective and that what appear to be "common-sense" approaches to selecting road safety interventions will often not be the best. Although some provide benefits, others have very limited or even negative impacts, despite being commonly—and mistakenly—recommended or accepted. The guide offers a range of recommendations with a focus on interventions in LMICs, although the information may also be of relevance to all countries. The contents will be valuable to those working on road safety at policy or practitioner levels, including World Bank technical team leaders and others who seek to establish, expand, or improve road safety programs in LMICs.

The guide sets knowledge on evidence-based interventions within a "Safe System" context, providing advice on each of the Safe System pillars (road safety management, safe roads, safe speeds, safe vehicles, safe road users, and post-crash care) while recognizing that evidence-based solutions must be drawn from across pillars to produce effective road safety outcomes. At the core of this document is a summary table with an overview of beneficial and non-beneficial interventions based on sound scientific evidence. This is followed by more detailed information including case studies and references to the evidence base to support the summary.

Many safe road interventions are recommended for adoption, including integrated public transport, roadside and central barrier systems, medians, infrastructure to support appropriate operational speed for road users, roundabouts, grade separation and interventions to reduce exposure to risk at intersections, pedestrian footpaths and crossings, separated bicycle and motorcycle facilities, and traffic signs and line marking (including audio-tactile line marking). Some of these are highly effective, with up to a 70 or 80 percent reduction in fatalities and severe injuries (for example, safety barriers and roundabouts).

Various speed-related interventions also produce significant benefits, with some able to almost eliminate death and serious injury. Examples of effective speed interventions include traffic calming (including humps and chicanes), roundabouts, raised intersections and crossings, gateway treatments, lower speed limits (including 30 km/h (20 mph) zones for pedestrians) and speed cameras.

A variety of road user-based interventions have been implemented over many years, with effective examples including extensive supervised on-road practice and/or graduated licensing systems as part of the driver-licensing system, increased age for driving license eligibility, hazard perception training and testing, public education and campaigns as part of an integrated strategy (especially communicating enforcement to increase general deterrence), enforcement, penalties, alcohol interlocks, fatigue and speed monitoring, and increased helmet wearing rates.

Key vehicle-based interventions include applying minimum vehicle safety standards and vehicle ratings (through the Global New Car Assessment Program, or “NCAP”), seat belts, periodic vehicle maintenance, daytime running lights, under-run guards on trucks, Electronic Stability Control, and other advanced vehicle technologies.

Enhanced post-crash care can also produce better road safety outcomes, including systems to improve emergency response time, better emergency care, improved first aid skills for the public, and improved hospital care.

Equally important, the report also identifies clear examples where interventions are not effective. The worst of these are interventions that increase risk. These include increasing travel speed without improving quality of safety infrastructure, most forms of post-license driver and rider education and training, and many (but not all) forms of regular school-based driver education (such as those that seek to increase car-handling skills). The increase in risk is typically because such initiatives increase the level of confidence leading to an increase in risk taking. Other interventions that have no demonstrated safety benefits are to be avoided. These include license schemes through application or payment, training programs or education within schools that aim to improve road safety knowledge (including ad hoc visits by road safety experts or enthusiasts), and education campaigns conducted in isolation.

There are effective alternative interventions for each of these as described within this document, and these should be applied instead. It is extremely important that resources are not wasted on ineffective interventions on behalf of road safety but rather that evidence-based road safety interventions are employed.

There are a variety of documents available on the issue of road safety intervention effectiveness, many of which are referenced here. However, there are some key points of differences and added value in this guide, including a synthesis of the evidence on a broad range of interventions and a contrast between effective and noneffective interventions, allowing readers to compare options. Where noneffective interventions are identified, viable effective interventions are provided thereby supporting decision making. The guide also provides direct advice to those working in LMICs, drawing on key sources of information where this is available. Importantly, concise yet robust evidence is provided across each of the Safe System pillars.

There is a need to continue building the knowledge base on effective road safety interventions, particularly in LMICs where there are a number of gaps in knowledge. The contents of this guide represent a useful, up-to-date summary of current knowledge for application.

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1. INTRODUCTION

1.1 BACKGROUND

This guide has been prepared to help readers understand that not all road safety interventions are equally effective. Some provide substantial benefits, while others have very limited or even no positive impacts, but may nonetheless be mistakenly recommended or accepted. Some interventions that are still in use even have harmful effects on road safety.

Road safety knowledge has improved substantially over recent decades, but it is still a relatively new science. The evidence base on effective road safety interventions is growing, with new information being added on a regular basis. Some interventions are known to be highly effective at reducing fatal and serious crash outcomes when implemented correctly. However, the same interventions may produce only limited benefits when applied in the wrong way. Other interventions are of limited benefit regardless of how they are applied, while a small number have been proven to be harmful.

Ineffective interventions have been adopted and are still being applied for a variety of reasons. These include the mistaken belief that they will work based on "common sense" assumptions, ease of application, political acceptance, low cost, and popularity. In some cases, there is poor research evidence which provides misleading results. **It is of profound importance that resources are not wasted on these ineffective interventions on behalf of road safety but rather that strictly evidence-based road safety interventions are used in World Bank and other projects and in the choice of actions in any road safety program**.

This guide provides advice on 'What Works and What Does Not Work" in road safety, with a focus on interventions that can be used by those working in low- and middle-come countries (LMICs). While the intended audience is primarily those working in LMICs, it is likely that the information will be of relevance in all countries. The contents will be valuable to those working on road safety at the policy or practitioner level, including World Bank Technical Team Leaders and those in client countries seeking to establish or expand road safety programs.

The guide provides an introduction to the topic of road safety interventions, a summary of findings, and references for more detailed information. The document sets knowledge within a "Safe System" context and highlights the need for an evidence-based approach across Safe System components. At the core of this guide is a summary table with an overview of beneficial and nonbeneficial interventions. This is supported in an appendix with more detailed information, including case studies and reference to the evidence base to support the summary.

In this guide, effective interventions are defined as those that reduce fatal and serious injuries. The most effective interventions are those that substantially reduce or eliminate these injuries. Ineffective interventions therefore are those interventions that do not reduce these injuries. The focus of the guide is on intervention effectiveness in terms of this fatal and serious injury reduction, and not on issues such as cost, public acceptability, period of benefit (treatment or service life), or related issues. Although intervention effectiveness should be a main driving force when selecting road safety solutions, these other issues also need to be considered.[1] For example, an economic analysis comparing the costs for interventions and their likely

[1] For further details see Turner, B., Styles, T., & Jurewicz, J. (2012) Investigation of Black Spot Treatments, in Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2012, Evaluation of the National Black Spot Program Volume 3 BITRE Report 126, Canberra ACT.

benefits (or savings in crash costs) is important to ensure that interventions are cost-effective and that limited resources are invested in the most beneficial solutions. Information has not been provided on this aspect of effectiveness in this guide as this analysis is context specific (for instance, the cost of interventions may vary substantially between countries or even different road environments within a country).

There are a variety of documents available on the issue of intervention effectiveness, many of which are referenced within this document, but there are some key differences in this guide, including that it:

- Focuses both on what is effective and what is not, which is unique in the road safety context
- Provides a contrast between effective and noneffective interventions, allowing readers to make comparisons, thereby guiding decision making
- Provides information on effective interventions across all Safe System pillars of road safety and takes the Safe Systems concept into account
- Gives direct advice to those working in LMICs
- Is concise yet addresses major road safety interventions supported by a robust evidence base under each pillar.

1.2 ROAD SAFETY AND THE WORLD BANK

The World Bank's long-standing concern with global road safety has been reinvigorated through recent vital developments. There is increasing appreciation of the significant impacts of road crash fatalities and injuries on the economic growth of LMICs. Road crash fatalities and injuries cause human suffering, grief, loss, and disability. Analyses by the Global Road Safety Facility (GRSF) at the World Bank show that road crash fatalities and injuries also cost the economies of LMICs 1.7 trillion dollars and over 6.5 percent of GDP every year,[2] and thus retard the economic growth of the LMICs.[3] Crashes also drive families into poverty through the loss of family income earners due to fatality or disability.[4] [5] Thus, improving road safety directly impacts the Bank's twin goals of reducing poverty and increasing shared prosperity, as well as its focus on growing human capital. These considerations also apply for other Multilateral Development Banks. Since 2018, the World Bank Environment and Social Framework has included road safety, via Environmental and Social Standard 4 (ESS4).[6] The World Bank has also developed a Good Practice Note for the Environmental and Social Framework road safety requirements.[7]

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[2] World Bank (2019). *Guide for Road Safety Opportunities and Challenges: Low- and Middle-Income Countries Country Profiles.* Washington, DC., USA: World Bank.

[3] World Bank (2017). *The High Toll of Traffic Injuries: Unacceptable and Preventable. A World Bank Study. Advisory Services and Analytics Technical Report P155310.* Washington, DC: World Bank.

[4] Bodrum, L., Tucker, P., Sakashita, S., Kinyanjui, P., & Man, L. (2020). *The Day Our World Crumbled: The Human Impact of Inaction on Road Safety.* Global Alliance of NGOs for Road Safety

[5] Aeron-Thomas, A., Jacobs, G. D., Sexton, B., Gururaj, G., & Rahman, F. (2004). The involvement and impact of road crashes on the poor: Bangladesh and India case studies. *Transport research laboratory, published project report, PPR010.*

[6] For World Bank Environment and Social Framework resources see: https://projects.worldbank.org/en/projects-operations/environmental-and-social-framework/brief/environmental-and-social-framework-resources

[7] World Bank (2019). *Good Practice Note: Environment & Social Framework for IPF Operations Road Safety*. Washington DC.: World Bank. http://pubdocs.worldbank.org/en/648681570135612401/Good-Practice-Note-Road-Safety.pdf

1.3 SETTING THE SCENE WITHIN A SAFE SYSTEM CONTEXT

The Safe System has been adopted around the world, including by the World Bank, and has significantly changed the way road safety is managed and delivered, creating much improved road safety outcomes for many countries.[8] It is an approach where the traffic and road safety risks are addressed on a systems-wide basis. This approach recognizes that road users are human beings who inevitably make errors that may lead to a crash. The human body can only withstand a certain level of kinetic energy before a crash will result in death or serious injury. The road system should therefore be forgiving and consider this vulnerability to avoid serious injury or death in the event of a crash.[9] [10] [11]

A Safe System comprises several essential components which together reflect a holistic view of road safety. The system relies on these components working together to reduce, and eventually eliminate, fatalities and serious injury. The key components of the system include:

- Road safety management
- Safe roads and roadsides
- Safe speeds
- Safe road users
- Safe vehicles
- Effective post-crash care[12]

These components act together (that is, as a system) to produce an environment whereby fatal and serious injuries can be reduced and ultimately eliminated. Interventions must be drawn from across all of these pillars to deliver Safe System outcomes.

This note uses these Safe System components to structure a discussion concerning effective road safety interventions while recognizing that a cross-pillar approach is needed.

1.4 THE NEED FOR AN EVIDENCE-BASED APPROACH IN ROAD SAFETY

Funding to deliver road safety outcomes is limited, and this is relevant in all countries. Therefore, there is a need to invest in solutions that will provide the greatest benefit. As identified above, the objective is to reduce and eventually eliminate fatalities and serious injuries. A robust evidence base on effective interventions is required to meet this objective as quickly and efficiently as possible. There is a growing evidence base in road safety relating to effective interventions. This evidence base has been established using rigorous evaluation methodology. In many cases there is clear evidence for the benefits of some treatments. As is noted below, the benefits can be substantial, with some interventions able to almost eliminate fatalities and serious injury.

[8] Mooren, L, Grzebieta, R., Job, R.F.S. Williamson, A. (2011). Safe System – International Comparisons of this Approach. *A Safe System-making it happen: Proceedings of the Australasian College of road Safety Conference, Melbourne, September 2011*. http://acrs.org.au/wp-content/uploads/Mooren-et-al-Safe-System-%E2%80%93-Comparisons-of-this-Approach-in-Australia.pdf.

[9] Job, RFS. Re-invigorating and refining Safe System advocacy. *Journal of the Australasian College of Road Safety, Vol. 28,* No. 1, Feb 2017: 64-68.

[10] Turner, B, Breen, J & Howard, E, 2015, *Road safety manual: a manual for practitioners and decision makers on implementing safe system infrastructure*; 2nd ed, World Road Association Paris, France.

[11] Turner, B Cairney, P Jurewicz, C & McTiernan, D (2010) Recent progress in implementing the safe system approach. *Journal of the Australasian College of Road Safety, 21*, 1, 17-19.

[12] There are variants on these pillars, and sometimes on the terminology used. This list is derived from the Global Action Plan for road safety (UN Road Safety Collaboration (2011). Global Plan for the Decade of Action for Road Safety 2011-2020. World Health Organization www.Who.int/roadsafety/decade_of_action.), with the addition of a speed pillar (for the rationale for this inclusion see Wambulwa, WM. & Job, S. (2020). *Guide for road safety opportunities and challenges: Low- and middle-income country reports*. Washington, DC: Global Road Safety Facility, World Bank.

In other cases, the evidence is less clear. This may be because we have yet to fully evaluate an intervention, perhaps because it is relatively new. GRSF encourages further research to ensure interventions are evaluated, and that results of good practice are disseminated.

In some cases, it may be very difficult to determine a clear benefit, either because the intervention has had no clear impact, or because the resources required to conduct an evaluation are not available. However, many comprehensively evaluated effective interventions exist and they are to be preferred over interventions of unknown impact.

Interventions with minimal benefit are sometimes funded, even though these are not the most effective solutions we have available. However, this should only occur when necessary as part of a longer-term strategy, to achieve the required political support/acceptability for more effective actions, that is, only as an additional component along with very effective interventions. Adopting ineffective interventions without the implementation of the most effective interventions should not be the practice.

We now have clear knowledge that **some interventions that have been used to improve safety can lead to an increase in serious crashes**. What might seem like a good idea on the surface may not stand up under scientific scrutiny. This situation occurs in a variety of public policy decision making arenas, and not just in road safety. The example in Case Study 1 is from a policy area outside of road safety, but rather is from the field of criminal justice. This well-documented example shows how some policy initiatives can produce counter-intuitive outcomes. Similar examples from road safety are shown later in this report.

CASE STUDY 1- SCARED STRAIGHT PROGRAM TO DETER CRIMINAL BEHAVIOR IN YOUNG OFFENDERS

The "Scared Straight" programs involved organized visits to prisons by young offenders. The aim was to expose young offenders to real prisons and inmates in the hopes that they will be deterred (or "scared") from further criminal behavior. On the surface this seems like a useful approach. However, many evaluations of these programs have been conducted, and a robust review of the issue concluded that "not only does it fail to deter crime, but it actually leads to more offending behavior"[13]). The reasons the program was not successful are not entirely clear, but it is likely that young offenders do not believe they will be caught, or that they do not take a long-term perspective regarding consequences of their actions, or they may have less fear of prison because it is familiar.[14]

In addition, they may be influenced by their more deviant peers taking part in the program. Unfortunately, the Scared Straight program remains popular with policy makers, perhaps because it intuitively seems a good approach, it is cheap to implement, and it is politically popular as it offers a seemingly useful solution to a major problem. Importantly, the evidence is still not believed, and so more harm than good is being done through this program. Indeed, the review highlighted above also reported that the policy response to this negative finding was not to stop running the intervention, but rather to stop funding the research.

[13] Petrosino, A, Turpin-Petrosino, C, & Buchler, J 2009, "Scared Straight" and other juvenile awareness programs for preventing juvenile delinquency (Review), The Cochrane Collaboration, John Wiley & Sons.
[14] This is a well-established effect in psychology, in which simple exposure to a situation reduces fear and increases liking: Anand, P. & Sternthal, B. (1991). Perceptual fluency and affect without recognition. *Memory and Cognition, 13*, 293-300; Zajonc, R. B. (1968). Attitudinal effects of mere exposure. *Journal of Personality and Social Psychology Monographs, 9(2, Pt. 2),* 1-27.

1.5 APPLICABILITY OF EVIDENCE IN LMICS

Road safety policy in LMICs is sometimes created without consideration of the existing sound evidence base. One of the reasons for this is the view that evidence from other countries, especially High Income Countries (HICs), is not applicable in LMICs. Indeed, much of the available evidence for what works comes from HICs. Similar evidence for the efficacy of an intervention may be difficult to obtain in LMICs because crash and other relevant data are often not available or are not reliably reported.[15] This makes rigorous evaluations of interventions in LMICs challenging (where we have found examples from LMICs they are noted in the supporting evidence in Appendix A.1). Thus, the application of evidence from HICs to LMICs is sometimes dismissed. Another challenge is that findings from research and application may not be adequately disseminated to those working in LMICs, with information presented in academic journals or costly manuals. These are often produced in English which is an additional barrier to those working in LMICs where English is not always widely understood.

Although deeper analysis shows that this dismissal is often misleading, the dismissal of applicability can be seen as sound, based on visible differences between LICs and HICs: HICs often have better vehicles, more effective enforcement and more rigorous penalty processes, better roads, lower urban speed limits, and better post-crash care with well-equipped ambulances and emergency departments. In addition, each country has distinct cultural features, often combined with distinct geographical, political, and religious differences. The many existing differences are sometimes seen as a sound basis for not considering the adoption of solutions known to work in other countries, especially HICs. However, the dismissal of proven solutions from other countries may be too hasty and result in lost opportunities to save many lives and disabilities in various LMICs. There are good reasons for not dismissing the applicability of evidence without deep specific analysis. Along with all our extraordinary diversity, **in road safety we have more in common than separates us**. Our critical and relevant commonalities include:

- The universally applicable laws of physics which determine crash forces, and the effects of speed on force and allowed reaction time;
- We have fundamentally similar bodies and thus we are all vulnerable to physical force which may kill or disable us in crashes;
- We all make mistakes, and we are all vulnerable to the impairing effects of drugs, alcohol, fatigue, and distraction;
- All countries have speeds of travel that allow for physical forces which can cause deaths and disabilities in the event of a crash;
- All countries have roads that mix vehicles and vulnerable road users;
- All countries have roads that allow head-on crashes by employing only thin lines of paint or even less to separate oncoming traffic;

[15] LICs are estimated to be missing 84 percent of deaths in official country crash databases, while MICs are missing 51 percent. See: World Bank (2019). *Guide for Road Safety Opportunities and Challenges: Low- and Middle-Income Countries Country Profiles*. Washington, DC., USA: World Bank.

- We share similar psychologies: most of us are overconfident of our driving and unrealistically optimistic about our futures, generating feelings of invulnerability to serious crashes.[16] [17] [18]

Thus, despite our differences, many interventions inevitably improve road safety, including infrastructure to reduce speeds (especially where vulnerable road users are present), separating oncoming traffic with barriers, having pedestrians walk on footpaths rather than the road, and using general deterrence to discourage unsafe behavior. To achieve these interventions, all countries must provide genuine funding for road safety. Nonetheless, culture, religion, geography, and other distinctive circumstances remain vitally relevant to road safety. The art in implementing strong road safety policy and programs lies in accepting vital valid evidence from elsewhere, using that evidence to prioritize the interventions most effective in addressing local road safety challenges, yet understanding the distinctive local circumstances, and refining implementation, narratives, and communications to address these distinctive local circumstances.

Interventions must be chosen based on evidence. However, the interventions and/or the messages employed to support them in the community must be tailored to local culture and beliefs.

[16] Job, RFS (1990). The application of learning theory to driving confidence: The effect of age and the impact of random breath testing. *Accident Analysis and Prevention, 22*, 97-107.

[17] Svenson, O. (1981). Are we all less risky and more skilful than our fellow drivers? *Acta Psychologica, 47 (2*), Pages 143–148.

[18] Weinstein, ND. (1984) Why it won't happen to me: Perceptions of risk factors and susceptibility. *Health Psychology, 3(5),* 431-457.

2. SUMMARY OF WHAT WORKS AND WHAT DOES NOT WORK

2.1 INTRODUCTION

This section provides a summary on the effectiveness of interventions used in road safety. Information is provided for each of the Safe System pillars. Road safety management is a key enabler for delivery of safety interventions. The approaches used to manage road safety are less suited to empirical evaluation. Rather, the following are generally accepted good practice road safety management elements:[19]

- Adopting a Safe System approach to addressing road safety
- Undertaking a road safety management capacity review and implementing the findings
- Providing strong road safety leadership through a "lead agency"
- Establishing a road safety management framework with Key Performance Indicators (KPIs), including the requirement for data collection strategies to effectively plan and monitor road safety activity and outcomes
- Building road safety capacity across the sector
- Developing and adopting ambitious strategies and road safety targets with regular reporting on progress.

This report focuses on the remaining Safe System pillars (safe roads and roadsides, safe speeds, safe vehicles, safe road users, and post-crash care) using these as the structure for this discussion. An evidence-based approach has been developed over several decades on interventions relating to each of these pillars.

The information which follows summarizes potential effectiveness for different types of road safety interventions. Each intervention is rated in terms of effectiveness. An expected crash reduction of greater than 30 percent has been classed as "highly effective" while interventions with benefits but less than 30 percent have been rated as "effective".[20] Some interventions are rated as "not effective" because they have not shown any safety benefits in the literature. There are also several interventions that have been highlighted as leading to an increase in crashes.

Even for the highly effective interventions, it is possible that if these are not implemented based on best practice principles, the benefits may not occur, and it could even be detrimental to road safety. As one example, roundabouts when well-designed as appropriate for their local context can produce substantial benefits. However, examples exist of poor design, and in these situations the benefits will be greatly reduced (see Appendix A.1.1).

There are a small number of exceptions to the information provided, particularly in relation to road user interventions (discussed in Appendix A.1). In addition, as discussed above, poorer execution of delivery for interventions will produce substantially lower benefits, and so these

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[19] B Bliss, A, Breen, J. (2013) Road Safety Management Capacity Reviews and Safe System Projects Guidelines (Updated Edition), Global Road Safety Facility/World Bank, Washington D.C.

[20] This figure will vary depending on level of severity and target crash type (that is, pedestrians or motorized vehicles). Unless otherwise stated, this figure relates to casualty crash reduction across all road users because this is what most of the available evidence reports on. It can be difficult to compare intervention effectiveness, since some apply to changes to discreet section of roads, others to policies that apply broadly.

results generally indicate maximum potential effectiveness, although there are exceptions where benefits may be higher.

The list of interventions provided in this chapter is not exhaustive, but rather a selection of those most commonly used in LMICs is provided. The evidence base underpinning each of these assessments can be found in Appendix A.1, or by clicking on the relevant hyperlink for each intervention.

2.2 SAFE ROADS AND ROADSIDES

INTERVENTION	DESCRIPTION	POTENTIAL EFFECTIVENESS
INTEGRATED PUBLIC TRANSPORT	Provision of organized bus,[21] light rail and heavy rail services	HIGHLY EFFECTIVE
ROADSIDE BARRIER SYSTEMS	Concrete, steel and/or wire rope barrier that constrain vehicles when leaving the roadway	HIGHLY EFFECTIVE
CENTRAL BARRIER SYSTEMS	Concrete, steel and/or wire rope barrier that constrain vehicles when they leave the roadway and cross into opposing traffic	HIGHLY EFFECTIVE
MEDIANS	Segregation of vehicles traveling in opposing directions of travel, either through constructed or painted areas of separation	HIGHLY EFFECTIVE
INFRASTRUCTURE TO SUPPORT APPROPRIATE SPEED FOR ROAD USERS	See Safe Speed	HIGHLY EFFECTIVE
ROUNDABOUTS	Intersection control measure implemented in order to reduce speeds, angle of impact, and road user conflict points	HIGHLY EFFECTIVE
GRADE SEPARATION AT INTERSECTIONS	Provision of over or underpasses with on-ramps and off-ramps	HIGHLY EFFECTIVE
REDUCING RISK EXPOSURE AT INTERSECTIONS	Physically preventing cross-traffic turn movements at intersections, or closing low quality intersections and redirecting traffic to high quality facilities	HIGHLY EFFECTIVE
PEDESTRIAN FOOTPATHS	A section clear of the roadway used by pedestrians	HIGHLY EFFECTIVE
PEDESTRIAN CROSSINGS	Crossing point giving priority for pedestrians, including signalized crossings or grade separated crossings (pedestrian underpass or footbridge, pedestrian overpass).[22]	HIGHLY EFFECTIVE
SEPARATED BICYCLE FACILITIES	Bicycle path or lane that is physically separated from motorized traffic	EFFECTIVE
SEPARATED MOTORCYCLE FACILITIES	Motorcycle lanes that are separated from other traffic through lines or physical separation.	EFFECTIVE

[21] Informal mini-bus and passenger truck services do not fall within this category.
[22] Also see 'Raised Crossing' in Speed section

OTHER INTERSECTION IMPROVEMENTS	Traffic signals and provision of turning lanes	EFFECTIVE
SIGNS AND LINE MARKING	Warning, directional, and other traffic signs and line marking	EFFECTIVE
AUDIO-TACTILE LINE MARKING	Raised or milled (cut) sections of road, placed either along the road (edge, or center) or across the road, to warn road users of hazards	EFFECTIVE
IMPROVING SURFACING ON POOR QUALITY ROADS WITHOUT ADDITIONAL INFRASTRUCTURE IMPROVEMENT	Providing a high quality road surface (that is, surfacing a dirt road) on a poor quality road (that is, with poor alignment and width)[23].	NOT EFFECTIVE: INCREASED RISK

2.3 SAFE SPEEDS

INTERVENTION	DESCRIPTION	POTENTIAL EFFECTIVENESS
TRAFFIC CALMING INCLUDING HUMPS, CHICANES	Reducing speed of traffic, especially in areas of higher risk (that is, presence of vulnerable road users; poor quality infrastructure; entering a built up area on a rural road)	HIGHLY EFFECTIVE
ROUNDABOUTS	Intersection control measure implemented in order to reduce speeds, angle of impact, and road user conflict points	HIGHLY EFFECTIVE
RAISED INTERSECTIONS	Raised section of roadway on approach and/or through an intersection	HIGHLY EFFECTIVE
RAISED CROSSINGS	Raised section of roadway at a pedestrian crossing point	HIGHLY EFFECTIVE
GATEWAY TREATMENTS	Signs used with other measures (including physical or painted lane narrowing) to create a threshold or gateway between high and low speed environments	HIGHLY EFFECTIVE
LOWER SPEED LIMITS	Mandatory maximum speed limits for vehicles, most effective when these are set to provide safe mobility for all road users and supported with appropriate infrastructure design	HIGHLY EFFECTIVE
30 KM/H (20 MPH) ZONES FOR PEDESTRIANS	Road environments designed to reduce speeds to 30 km/h (20 mph) or below.	HIGHLY EFFECTIVE
SPEED CAMERAS	Mobile or fixed cameras that can detect vehicle speeds at a set point, or over a length of road	HIGHLY EFFECTIVE
INCREASING TRAVEL SPEED WITHOUT IMPROVING QUALITY OF INFRASTRUCTURE	Increasing speed of traffic without appropriate improvements in infrastructure[24]	NOT EFFECTIVE: CAN RESULT IN INCREASED RISK

[23] This will increase the speed of vehicles without supporting road users with improved infrastructure. Also see Safe Speed interventions on this topic.
[24] Examples of infrastructure improvement include provision for vulnerable road users (for example crossings and sidewalks), improved alignment and road cross sections, and access control and management.

2.4 SAFE ROAD USERS

INTERVENTION	DESCRIPTION	POTENTIAL EFFECTIVENESS
DRIVER LICENSING SYSTEMS THAT INCLUDE EXTENSIVE ON-ROAD SUPERVISED PRACTICE	Structured licensing that involves extensive supervised on-road training, and a robust examination of driver ability	EFFECTIVE
GRADUATED LICENSING SYSTEMS	Systems for novice drivers that limit the situations in which they can drive (that is, by limiting passengers; zero alcohol tolerance; restricting vehicles that can be driven)	EFFECTIVE
LICENSE THROUGH APPLICATION OR PAYMENT [25]	Systems for licensing that do not require extensive on-road training and strict testing, but rather are obtained through application (including through illegal payment)	NOT EFFECTIVE
INCREASE AGE FOR DRIVING LICENSE ELIGIBILITY	Raising the minimum age of eligibility for new drivers	EFFECTIVE
HAZARD PERCEPTION TRAINING AND TESTING	Training novice drivers to better anticipate and perceive hazards as part of rigorous driver licensing regimes	EFFECTIVE
POST-LICENSE DRIVER AND RIDER EDUCATION AND TRAINING [26] [27]	Post-license skills training for drivers or riders	NOT EFFECTIVE: SOME RESULT IN INCREASED RISK
SCHOOL-BASED EDUCATION AND TRAINING [28]	Training programs or education within the school system that teach driving skills to high-school students	NOT EFFECTIVE: SOME RESULT IN INCREASED RISK
PUBLIC EDUCATION AND CAMPAIGNS [29]	Comprehensive and on-going public education campaigns that are linked in content and timing with enforcement and penalty regimes	EFFECTIVE
ENFORCEMENT	Includes roadside enforcement of drink driving, speed enforcement (roadside or through automated cameras); seat belt and helmet wearing	EFFECTIVE
PENALTIES	Fines (best if unavoidable, and not subject to corruption) and demerit points (points-based licensing systems)	EFFECTIVE

[25] Other licensing systems should be used in favor of this option. The effects of creating driving "within the system" (rather than starting outside any system) may have benefits, along with the value of the threat of taking away driving privileges.
[26] As outlined in Appendix A.1, some skills-based training programs have been found to increase driver risk, most likely through increased confidence, leading to increases in risk taking. Improvements to licensing systems are recommended instead.
[27] Training for specialized vehicles and professional drivers (that is, certain types of trucks) is likely to be effective, but no impact evaluations have been conducted due to very small sample groups.
[28] As highlighted in Appendix A.1, this includes ad hoc educational activities, including visits by road safety experts or enthusiasts. There are exceptions to this category in rare situations where children have been trained how and where to cross the road at an appropriate age. Care should be taken to ensure that the confidence of children in their ability to cross the road on their own is not increased, or similarly, that parents are not led to believe that children are safe to cross the road on their own following such training, until a suitable age is reached. Given the poor safety provision around many schools in LMICs (as outlined in Appendix A.1), improvements to road infrastructure should be considered as a viable mechanism for improving child safety.
[29] Education campaigns that teach knowledge or skills that are not linked with enforcement and penalty regimes, or where safer alternative behaviors are not provided are not effective. Instead, public education and campaigns that are used as part of an integrated strategy that link with enforcement and penalty regimes should be used instead.

ALCOHOL INTERLOCKS [30]	Alcohol interlocks test the breath of a driver for alcohol, and if present, prevent the vehicle from starting. Modern versions also require rolling repeat tests, and can distinguish human lips from a pump to minimize the risk of the system being circumvented.	EFFECTIVE
FATIGUE MONITORING [31]	Systems designed to monitor driving fatigue through in-vehicle systems that recognize signs of fatigue and provide direct warnings and interventions to prevent continued driving	EFFECTIVE
SPEED MONITORING [31]	Systems designed to monitor driving speed through in-vehicle systems and provide direct warnings and interventions to prevent continued speeding	EFFECTIVE
INCREASED SEAT BELT WEARING RATES	Measures to increase seat belt wearing rates	HIGHLY EFFECTIVE
INCREASED HELMET WEARING RATES	Wearing helmets while riding motorbikes or bicycles	HIGHLY EFFECTIVE

[30] Only effective when in place
[31] This is a relatively new intervention with innovative technology. Testing in laboratory and on-road trials indicate that this intervention is likely to be effective when in place, but reductions in crashes are yet to be determined through large-scale evaluations.

2.5 SAFE VEHICLES

INTERVENTION	DESCRIPTION	POTENTIAL EFFECTIVENESS
MINIMUM SAFETY STANDARDS	Ensuring that new and used vehicles meet minimum safety standards	EFFECTIVE
SEAT BELTS	A belt or strap to securely hold a vehicle occupant in place during a collision	HIGHLY EFFECTIVE
VEHICLE MAINTENANCE	Periodic vehicle inspection and roadside maintenance checks	EFFECTIVE
DAYTIME RUNNING LIGHTS FOR CARS AND TRUCKS	Automated use of headlights to help increase visibility of vehicles at all times of day and night	EFFECTIVE
DAYTIME RUNNING LIGHTS FOR TWO- OR THREE-WHEEL VEHICLES	Automated use of headlights to help increase visibility of vehicles at all times of day and night	EFFECTIVE
UNDER-RUN GUARDS ON TRUCKS	Devices fitted to the front and side of trucks to prevent vulnerable road users from being run over	EFFECTIVE
ELECTRONIC STABILITY CONTROL	Automatic application of braking to individual wheels by the vehicle to prevent loss of control	HIGHLY EFFECTIVE
ADVANCED VEHICLE TECHNOLOGIES INCLUDING FULLY OR PARTIALLY AUTOMATED VEHICLES	Emerging technologies that reduce or prevent vehicles from colliding with other vehicles or vulnerable road users, including lane keeping systems and autonomous emergency braking	HIGHLY EFFECTIVE

2.6 SAFE POST-CRASH CARE

INTERVENTION	DESCRIPTION	POTENTIAL EFFECTIVENESS
SYSTEMS TO IMPROVE EMERGENCY RESPONSE TIME, INCLUDING DEDICATED PHONE NUMBERS AND LOGISTICAL SUPPORT	Systems to ensure rapid emergency response including dedicated phone numbers and logistical support	EFFECTIVE
IMPROVED EMERGENCY RESPONSE CARE	Improved equipment and skills for first responders and other emergency response units	EFFECTIVE
IMPROVED FIRST AID SKILLS FOR THE PUBLIC	Improved skills for members of the public who may provide first aid when first on the scene at a crash	EFFECTIVE
IMPROVED HOSPITAL CARE	Improved equipment and skills at trauma units within hospitals	EFFECTIVE

3. CONCLUDING COMMENTS

This guide has highlighted that the knowledge base about what works in road safety is growing, and that there are some beneficial interventions that need to be adopted more widely as part of World Bank and other projects. There are many effective interventions across each of the Safe System pillars. When used in combination (particularly across pillars as part of a system), effective interventions can produce significant road safety outcomes.

Highly effective interventions (defined as those producing crash reduction benefits of 30 percent or more) are highlighted in the table below, noting that it is difficult to directly compare different intervention types:[32]

ROADS AND ROADSIDES	SPEEDS	ROAD USERS	VEHICLES	POST-CRASH CARE
Integrated public transport	**Traffic calming**	**Increased helmet wearing rates**	**Seat belts**	—
Barrier systems	**Roundabouts**	**Increased seat belt wearing rates**	**Electronic Stability control**	
Medians	**Raised intersections**		**Advanced vehicle technologies**	
Infrastructure solutions to support appropriate speeds	**Raised crossings**			
Roundabouts	**Gateway treatments**			
Grade separation	**Lower speed limits**			
Reducing risk exposure at intersections	**30 km/h (20 mph) zones for pedestrians**			
Pedestrian footpaths	**Speed cameras**			
Pedestrian crossings				

There are also a variety of supporting road safety measures across all road safety pillars that will bring crash reduction benefits. When used in combination (as is often done in delivery of safety programs[33]), these can be substantial.

Importantly, there are also some clear examples where interventions are not effective. The worst of these are those interventions that increase risk. These include:

- Increasing travel speed without improving quality of infrastructure

[32] Some interventions operate at a very local level (such as road and speed-related treatments) and may produce high crash reductions at these locations. Others operate at a population level, or over a wider geographic area (such as minimum vehicle standards or healthcare improvements) and may produce more modest crash reduction benefits as a percentage, but in aggregate produce substantial safety gains.
[33] In the case of road infrastructure treatments, it was noted by Turner & Roberts that four out of five treated crash locations used more than one intervention (see Roberts, P & Turner, B (2007), Estimating the crash reduction factor from multiple road engineering countermeasures, International Road Safety Conference, Perth, Western Australia.

- Improving surfacing on poor quality roads without additional infrastructure improvement
- Most forms of post-license driver and rider education and training
- Regular school-based driver skills training.

Alternative options that provide demonstrated safety benefits are available and should be used instead. Other interventions to be avoided that have no demonstrated safety benefits include:

- License schemes through application or payment
- Training programs or education within schools that aim to improve road safety knowledge
- Education campaigns conducted in isolation.

Alternative options are also available for each of these and should be used instead.

As already highlighted, **it is of profound importance that resources are not wasted on these ineffective interventions on behalf of road safety but rather that evidence-based road safety interventions are used in World Bank and other projects**.

It is also notable that even effective or highly effective interventions can have diminished benefits if they are not used in the right manner (for instance, some safe road interventions applied at the wrong location or not implemented correctly). When in doubt, advice should be sought on correct application of these interventions.

GRSF encourages further robust evaluations on the effectiveness of road safety interventions, particularly those used in LMICs. For further information, or to discuss any of the issues in this document, please contact the GRSF team (GRSF@workbank.org).

APPENDIX A - WHAT IS THE EVIDENCE?

This section provides the evidence base on effectiveness of different road safety interventions. The information provided is based on assessment of robust, easily accessible documents. Where available, systematic reviews or meta-analysis of existing studies have been included. Where these are not available, a selection of robust references is provided. As with the tables provided in the main report, the interventions are arranged by Safe System pillars.

A.1 SAFE ROADS AND ROADSIDES

A.1.1 INTRODUCTION

There are many different infrastructure interventions that can be applied to improve safety outcomes. Some of these can have substantial safety benefits, almost eliminating fatalities and serious injury, while others have more minor impacts.

Interventions that reduce crash severity outcomes generally are the most beneficial, producing up to 80 percent reductions in fatal and serious injury. These include roadside and central barrier systems on high speed roads, infrastructure that supports lower speed environments (especially for vulnerable road users – discussed further under Safe Speeds in Section 2.3) and roundabouts at intersections (lower impact speed and angle of impact). Interventions that reduce exposure to risk are also highly beneficial. These interventions include access control/management, separating vulnerable road users from other road users (that is, by providing a well-designed foot path which is kept clear of obstructions, commerce, and parking, and thus ensuring that the footpath is usable by pedestrians) and designs that prevent cross-traffic turning movements (banning left turn in, or left turn out movements at intersections for those driving on the right-hand side). Interventions can also reduce the likelihood of a crash occurring in the first place. This class of intervention has more varied results. Examples include signs and line-marking (lower safety benefits), traffic signals (moderate benefits), and infrastructure that supports speed reduction (high benefits; see Safe Speeds).

Infrastructure interventions can produce immediate impact and can also produce ongoing benefits. Once installed, they will continue to deliver at a similar level (although some maintenance may be required).

For all infrastructure interventions the execution of infrastructure improvements is vitally important. **Even the best interventions can potentially cause harm if selected for an inappropriate location, or if it is poorly designed, installed, and/or maintained.** The appropriate selection and application of infrastructure solutions requires expert advice. There are many examples of where well-established interventions have been used inappropriately, resulting in a reduction in benefits, or even an increase in risk. Case study 2 below provides an example for roundabouts.

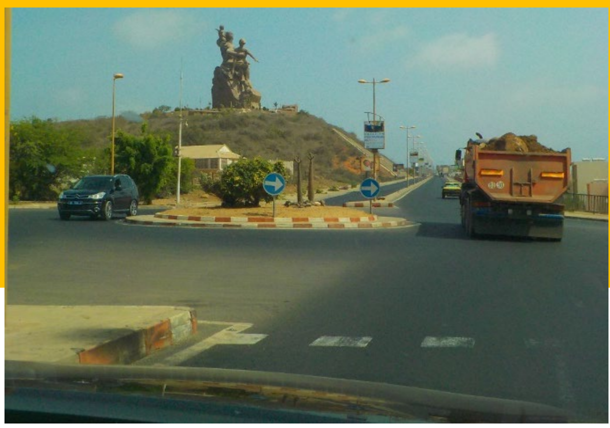
CASE STUDY 2 - ROUNDABOUTS

Well-designed roundabouts are able to deliver considerable road safety benefits, with reductions in fatalities and serious injury of between 70 percent and 80 percent. The reason for this success is that roundabouts:

- **Reduce the number of conflict points within an intersection compared with other intersection types**
- **Reduce the entry speed of vehicles as well as speeds through the roundabout, because vehicles are forced to take a meandering path rather than traveling straight through the intersection**
- **Reduce the impact angle (and therefore the impact force and severity) if a collision does occur, effectively converting more severe crossing conflicts to merging and diverging conflicts.**

However, not all roundabouts are designed to a high standard. If basic design principles are not followed, the safety benefits are not likely to be obtained. One key design flaw with some roundabout designs is that there is not enough "deflection" through the roundabout, meaning that collisions can occur at high speed and at high impact angles. To address this issue, the design process should include verifying that the fastest possible path through the roundabout is below the circulatory speed target. This is illustrated in the two images below. Similarly, in areas where there are vulnerable road users present, facilities must be provided to cater for them, otherwise risks for these road users can be increased.

Good deflection (Source: GRSF)



Poor deflection (Source: GRSF)

Infrastructure interventions also include the design of the roadway itself. Road design can have road safety impacts through newly constructed roads, but also through road upgrades. However, **designing and constructing roads according to guidelines will not necessarily produce safe outcomes.**[34] This is because guidelines are not a recipe book, but rather provide broad design principles as well as technical detail. Considerable expertise is required to safely design, that is, avoiding adoption of minimum design standards, and inconsistency in road design.

[34] Austroads (2019), *Guide to Road Safety Part 6: Road Safety Audit*, AGRS06-19, Austroads, Sydney, Australia.

Even when designed to the best required standard in most countries, many road users will still be killed or seriously injured because the designs do not deliver a Safe System. On this issue, the Australian Guide to Road Design[35] states that:

"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."

Because of the complexities of road design, additional tools have been developed to help identify safety risk and maximize the safety potential through design. These tools include Road Safety Audit/ Inspection and Impact Assessment, Road Infrastructure Safety Assessments (including the International Road Assessment Programme (iRAP) and the Road Safety Screening and Appraisal Tool (RSSAT) and Safe System Assessment).[36] In addition, greater attention is being paid to the application of relevant safety metrics in project planning and design, ensuring an outcomes-based focus that maximizes safety benefits.

This section provides a brief summary on the effectiveness of some key safe road interventions supported by research evidence. There are a number of other resources available on the effectiveness of infrastructure solutions, often with statistically robust information. Examples include:

- The iRAP Road Safety Toolkit (http://toolkit.irap.org/), which provides information tailored to low and middle income countries (LMICs) and includes a tool to assess the impacts of road designs.
- Austroads guidance (e.g. https://www.onlinepublications.austroads.com.au/items/AP-R422-12) from Australia
- The CMF clearinghouse (http://www.cmfclearinghouse.org/) from the USA

A.1.2 INTEGRATED PUBLIC TRANSPORT

There is strong evidence to indicate that moving road users on to safer forms of transport produces positive safety outcomes as does general reductions in traffic in cities. Provision of well-designed (safe) integrated public transport is one effective way to achieve this. This can have the effect of moving road users from modes of travel that can be higher risk (such as motorcycles and informal public transport services such as mini-buses and shared taxis – see Figure A.1) to safer mass transit options (Figure A.2).

[35] Austroads (2015), *Guide to Road Design Part 1*, AGRD01-15, Austroads, Sydney, Australia).
[36] Turner, B, Howard, E & Breen, J (2015), *Road safety manual: a manual for practitioners and decision makers on implementing safe system infrastructure*. PIARC, Paris, Available from https://roadsafety.piarc.org/en.

Figure A.1: Informal Mutatu bus Service, Kenya. (Source: John Barrell)

Figure A.2: BRT, Lagos. (Source: Lagos Metropolitan Area Transport Authority - LAMATA)

Duduta et al (2013)[37] suggests that well designed public transit is the safest mode of urban travel, and this is supported by a number of studies they cite. They identified a more than 50 per cent reduction in fatalities from the TransMilenio Bus Rapid Transit (BRT) system in Bogotá; a 46 per cent reduction in crashes in Guadalajara (Mexico) from the Macrobús BRT; and a 55 per cent reduction in fatalities from the Janmarg BRT system in Ahmedabad. This represents the combined benefit of a large package of safety improvements that were all implemented concurrently with the BRT system deployment. It is very difficult to isolate the effects that were specific to BRT infrastructure. The authors note that it should not be assumed that every BRT will have a positive impact, and the safety benefit will be very dependent on safety provision as part of design. This typically involves installation of safe road infrastructure, so this treatment could equally be included under that pillar. Without adequate road infrastructure (for instance, safe crossing facilities for pedestrians moving to and from the public transport) the benefits will be greatly reduced, and in some cases overall risk may even increase.

A.1.3 ROADSIDE BARRIER SYSTEMS

Barriers are used to shield errant vehicles from hazards. They can be used along the median (central barriers) to prohibit movement of traffic across the median or on the roadsides to shield vehicles from roadside hazards as shown in Figure A.3.

Figure A.3: Roadside barriers in Nepal (Source: GRSF)

[37] Duduta, N, Adriazola-Steil, C & Hidalgo, D (2013), Saving lives with Sustainable Transport Traffic safety impacts of sustainable transport policies, World Resources Institute, Washington DC.

They are designed to redirect an impacting vehicle and in some cases to dissipate crash forces in a controlled manner thus reducing the severity of crashes involving out-of-control vehicles.

Barriers broadly fall under three categories: flexible barriers (for example, wire-rope safety barriers), semi-rigid barriers (for example, steel beam) and rigid barriers (for example, concrete). Each type of barrier has various benefits and constraints that make them suitable for some locations, but unsuitable for others. Barriers must also be properly installed, and use appropriate end treatments. Guidance should be sought on these issues.

The benefits from installing appropriate barrier systems and ensuring that these are adequately maintained can be substantial with benefits of up to 80 percent reductions in severe crash outcomes.[38] [39] [40]

A.1.4 CENTRAL BARRIER SYSTEMS

See Roadside Barrier Systems.

A.1.5 MEDIANS

Medians provide a degree of segregation between vehicles moving in opposite directions and are effective at reducing head-on collision, particularly in high speed environments. They can be constructed (raised medians as in Figure A.4) through provision of curbing, or can be provided through wide centerline markings (Figure A.5, and often in association with audio-tactile line marking – see Section A.1.16).

Figure A.4: Constructed median on high speed road (Source: B P Deepu, EPS)

Figure A.5: Painted median/central hatching. (Source: iRAP)

They can also be used in urban areas, including to help pedestrians stagger their crossing movement (especially when used in association with formal crossings). Care needs to be taken when painted medians are installed that they are not used by vehicles as passing or additional lanes. This behavior can be discouraged through use of flexible posts or intermittent traffic islands.

Constructed medians tend to produce a greater safety benefit than painted medians with around a 50 percent reduction in crashes compared to around a 15 percent reduction.[41]

[38] Woolley, J, Stokes, C, Turner, B & Jurewicz, C (2018), *Towards Safe System Infrastructure: A Compendium of Current Knowledge.* Austroads, Sydney, NSW.
[39] Ray, M, Silvestri, C, Conron, C & Mongiardini, M (2009), '*Experience with cable median barriers in the United States: design standards, policies, and performance*', Journal of Transportation Engineering, vol. 135, no. 10, pp. 711-20.
[40] Carlsson, A 2009, *Evaluation of 2+1 roads with wire rope barrier: final report*, VTI report 636A, Swedish National Road and Transport Research Institute, Linkoeping, Sweden.
[41] Turner, B, Steinmetz, L, Lim, A & Walsh, K (2012) Effectiveness of road safety engineering treatments, AP-R422-12, Austroads, Sydney, NSW.

Recent trials involving wide painted centerlines and audio-tactile markings have produced promising initial results, with reductions approaching those seen from constructed medians.

A.1.6 INFRASTRUCTURE TO SUPPORT APPROPRIATE SPEED FOR ROAD USERS

For evidence on this issue please see the Safe Speed content (Appendix A.2).

A.1.7 ROUNDABOUTS

A roundabout is a one-directional roadway around a circular central island. Vehicles entering a roundabout are typically controlled and required to "give-way" to vehicles already in the roundabout. The speed of vehicles is reduced on the approach (through provision of islands or raised pavements) and/or through the roundabout itself (through the geometry of the central island). The angles of interaction between vehicles within the roundabout are reduced due to the geometry of the roundabout resulting in lower severity outcomes when vehicles do collide. Conflict points are also reduced. Additional features can be provided to allow safe navigation of roundabouts by pedestrians (including splitter islands on approach and raised pedestrian crossing points). Roundabouts with multiple lanes and higher speeds are less safe for motorcyclists and bicyclists.

Well-designed roundabouts can provide considerable safety benefits, with reductions of up to 80 percent in severe crashes. [42] [43]

A.1.8 GRADE SEPARATION AT INTERSECTIONS

Grade separation involves the provision of an overpass or interchange that allows traffic to continue to flow without the need to stop or interact at intersections. Separating conflicting vehicle movements using grade separation is one of the most effective ways to improve safety outcomes at an intersection. Grade separation is typically used as part of freeway/motorway systems where there are large traffic flows to justify the high cost. Evaluations typically indicate that injury crashes are halved with installation of grade separation.[44] Grade separation needs to be well designed, with acceleration and deceleration lanes in higher speed environments. Vulnerable road users need to be provided with alternative facilities at these higher speed locations.

A.1.9 REDUCING RISK EXPOSURE AT INTERSECTIONS

Along with measures to reduce speed and impact angles, reducing exposure to risk is one of the methods to help achieve substantial safety improvements at intersections. This can include full closure of intersections, although there is a requirement that good quality alternative options be available for this strategy to be effective. Full closure can virtually eliminate severe crash risk (noting that some risk will remain through traffic displacement). In addition, partial closure of intersections can also be highly effective (Figure A.6). This might include providing a median through an intersection to eliminate cross-traffic turning movements (such as, when driving on the right hand side of the road, prohibiting left turns into and out of side roads). There is typically a need to provide alternative high quality turning facilities. Banning turning

[42] NCHRP (2019), Development of Roundabout Crash Prediction Models and Methods. National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, DC.
[43] BITRE 2012, Evaluation of the National Black Spot Program Volume 1, Bureau of Infrastructure, Transport and Regional Economics, Canberra, Australia.
[44] AASHTO (2010), Highway safety manual, 1st edn, American Association of State Highway and Transportation Officials, Washington, DC, USA.

movements has resulted in substantial road safety benefits, with reductions of between 30 and 45 percent of injuries having been noted.[45] [46]

Figure A.6: Narrow median preventing turn movements at intersection. (Source: FHWA)

A.1.10 PEDESTRIAN FOOTPATHS

Pedestrian footpaths are an area adjacent to the roadway for use by pedestrians. They are used in urban areas (Figure A.7) as well as in rural areas where pedestrians are present. In urban areas they are typically raised, separating pedestrians from motorized traffic with curbing.

Figure A.7: Pedestrian footpath (Source: Turner & Smith, 2013[47])

In higher speed environments they may be separated from traffic lanes (such as with barriers or through space) although in some circumstances a graded shoulder may provide adequate

[45] Le. T.Q., F. Gross, and T. Harmon. (2018). Safety Effects of Turning Movement Restrictions at Stop-Controlled Intersections. 97th Annual Meeting of the Transportation Research Board, Paper No. 18-03753, Washington, D.C.
[46] Turner, B, Steinmetz, L, Lim, A & Walsh, K (2012) Effectiveness of road safety engineering treatments, AP-R422-12, Austroads, Sydney, NSW.
[47] Turner, B. & Smith, G. (2013), Safe System infrastructure: implementation issues in low and middle income countries, ARR383, ARRB Group Ltd, Vermont South, Australia.

protection. To be effective, footpaths must be of adequate width, well maintained, and free from obstructions, including parked vehicles, signs, traders, and so forth.

Footpaths are included as standard infrastructure in many countries as it is accepted wisdom that they produce improvements for pedestrian. The evidence indicates benefits of up to 60 percent reductions for pedestrians from the installation of footpaths.[48] [49] [50]

A.1.11 PEDESTRIAN CROSSINGS

A variety of pedestrian crossing types can be applied at intersections or at other locations where there is demand. Crossing types include low cost measures such as marked priority crossings ("zebra crossings"), signal-controlled crossings, raised crossings (an area of elevated pavement surface, preferably with pedestrian priority), or pedestrian under- or over-passes. Marked priority crossings ("zebra crossings") often have limited impact in LMICs, and may even increase risk if not installed at appropriate locations and with adequate features (for instance, higher speed environments with multiple lanes in situations where there is poor sight distance, or where compliance is poor). Similarly, under- and over-passes, especially in urban settings that dramatically increase the distance and effort of pedestrians to cross a road, or that result in personal security issues, may provide little benefit.

Other facilities to assist pedestrians when crossing include road narrowing, refuge islands, and slow speed environments (Figure A.8). Improving visibility including through better sight distance and lighting can also have benefits.

Figure A.8: Pedestrian crossing incorporating speed reduction devices.
(Source: Lusakatimes, 2019)

There is little reliable information on benefits of pedestrian crossings in LMICs, but there is extensive information from HICs. There the benefits range from around a 40 percent reduction in pedestrian injuries from installation of a refuge island,[51] up to around 70 percent reductions

[48] iRAP 2010, Road safety toolkit http://toolkit.irap.org/default.asp?page=treatment&id=20
[49] Elvik, R, Høye, A, Vaa, T & Sørensen, M 2009, The handbook of road safety measures, 2nd edn, Emerald Publishing Group, Bingley, UK.
[50] Jensen, SU 1999, 'Pedestrian safety in Denmark', Transportation Research Record, no. 1674, pp. 61-9.
[51] Campbell, BJ, Zegeer, CV, Huang, HH & Cynecki, MJ 2004, A review of pedestrian safety research in the United States and abroad, report FHWARD-03-042, Federal Highway Administration Virginia, USA

from use of raised pedestrian crossings and low speed environments.[52] [53] [54] [55] Interventions that rely solely on motorized vehicle compliance to produce benefits (such as priority crossing without speed control) are very unlikely to have substantial benefits where compliance levels are low.

A.1.12 SEPARATED BICYCLE FACILITIES

Bicyclists are vulnerable road users and so it is important to provide adequate facilities so that they can use roads safely. This is particularly the case when motorized vehicles speeds are in excess of 30 km/h. Collisions above this speed often result in very serious injuries or even death. Facilities include off-road paths, on-road lanes (preferably separated from both passing vehicles and parked vehicles), and dedicated facilities at intersections (signalized crossings, protected intersections, areas of high contrast road surfacing, off-road bypass facilities, and bicycle storage boxes).

Evaluations on the effectiveness of such facilities can be difficult, because the design may be of variable quality, or because improved provision often results in a dramatic increase in bicycle numbers and so crash numbers may appear to increase in some instances.[56] This is an issue that can also occur for other road user types with the provision of higher quality roads. Reductions of around 15 percent in cyclist injuries have been noted from the use of cycle lanes adjacent to traffic,[57] [58] while higher benefits have been seen with more comprehensive interventions, such as bicycle boulevards.[59]

A.1.13 SEPARATED MOTORCYCLE FACILITIES

Motorcycle riders are very vulnerable road users given their lack of physical protection and often high travel speed. Serious injuries and death are common when larger vehicles collide with this road user group, especially at speeds higher than 30 km/h. The proportion of motorcycle riders is high in many countries, and in these environments, separate lanes are sometimes provided to reduce exposure between these vulnerable road users and larger vehicles. These lanes can be provided on or adjacent to existing roads with segregation provided by painted lines or (preferably) through physical separation such as physical barriers. In some cases, exclusive lanes are provided for motorcycles (Figure A.9) and these provided an added advantage with reduced interaction at intersections with other vehicles.

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[52] Hiller, P, Makwasha, T & Turner, B (2016), Achieving safe system speeds on urban arterial roads: compendium of good practice, AP-R514-16, Austroads, Sydney, NSW.
[53] Candappa, N, Stephan, K, Fotheringham, N, Lenné, MG & Corben, B 2013, ‘Raised crosswalks on entrance to the roundabout: a case study on effectiveness of treatment on pedestrian safety and convenience’, Traffic Injury Prevention, vol. 15, no. 1, pp. 631-9.
[54] Jensen, SU 1999, ‘Pedestrian safety in Denmark’, Transportation Research Record, no. 1674, pp. 61-9.
[55] Retting, RA, Ferguson, SA & McCartt, AT 2003, ‘A review of evidence-based traffic engineering measures designed to reduce pedestrian-motor vehicle crashes’, American Journal of Public Health, vol. 93, no. 9, pp. 1456–63.
[56] Total crash numbers may in reality have decreased in some instances as the improved facilities may have drawn cyclists from parallel, more dangerous routes.
[57] Chen, L., Chen, C., Srinivasan, R., McKnight, C. E., Ewing, R., and Roe, M., (2012). "Evaluating the Safety Effects of Bicycle Lanes in New York City," American Journal of Public Health, Vol. 102, No. 6.
[58] Abdel-Aty, M.A., C. Lee, J. Park, J.Wang, M. Abuzwidah, and S. Al-Arifi. (2014) "Validation and Application of Highway Safety Manual (Part D) in Florida." Florida Department of Transportation. Tallahassee, Florida.
[59] Minikel, E. (2011) "Cyclist Safety on Bicycle Boulevards and Parallel Arterial Routes in Berkeley, California." Presented at the 90th Meeting of the Transportation Research Board, Washington, D.C.

Figure A.9: Exclusive motorcycle facility (Source: Turner & Smith 2013[47])

Although the use of separated motorcycle facilities is relatively limited, there has been a steady increase in use over recent years. For example, there are approximately 135km of exclusive lanes and 110 km of non-exclusive lanes in Malaysia on expressways and major federal roads.[60] Evaluations of motorcycle lanes can be difficult for much the same reason as bicycle lanes (including issue of changed exposure and variable design), and because applications to date have been limited. However, results for evaluations of exclusive lanes indicate the number of traffic crashes has decreased by almost 40 percent, and fatalities by 80 percent.[61]

A.1.14 OTHER INTERSECTION IMPROVEMENTS

In addition to those improvements already mentioned above (including speed reduction, roundabouts, grade separation, and reductions in exposure) a variety of other improvements can be made at intersections to provide safety benefits. These includes low cost (and typically lower benefit) interventions such as warning signs and introduction of priority signs (Give Way/Yield and Stop signs), through to more substantive infrastructure improvement with higher costs, but also typically higher benefits (these include improved facilities such as turning lanes and channelization, and improved intersection visibility). One of the more commonly-used interventions is traffic signals. When well designed (including provision of fully controlled turns) and when used in moderate speed environments (including provision of speed-reducing features to reduce speeds to survival impact levels of 50 km/h or less), these can produce quite reasonable benefits. Reduction in injury crashes of around 30 percent are typical for basic traffic signal installations where there is good compliance, but higher benefits can be achieved with addition of controlled turns and speed reduction.[49 44 46] Other more innovative intersection designs are being tested in various countries with some showing great potential.[38]

A.1.15 SIGNS AND LINE MARKING

There are a range of signs and line marking as well as other options that can provide advanced warning of hazards and provide guidance to road users about their required position on the road. These are particularly useful where there is reduced visibility (including at night, see

[60] Alvin Poi W H, Shabadin, A, Jamil, H, Roslan, A and Hamidun, R (2019) Motorcycle lane: how to judge if that is necessary, *IOP Conf. Series: Materials Science and Engineering 512.*
[61] Radin Sohadi R U, Mackay M and Hills B 2000 Multivariate analysis of motorcycle accidents and the effects of exclusive motorcycle lanes in Malaysia *Journal of Crash Prevention and Injury Control 2(1)* 11–17

Figure A.10) or when approaching bends or curves in the road. Options are relatively low cost, and although they can also produce valuable safety benefits, these are typically less than those from more substantive infrastructure and speed-related solutions. Reductions in injury crashes range from around 5 percent for guideposts and raised reflectorized pavement markers up to around 25 percent for chevron alignment markers, provision of center and edgeline markings, and warning signs.[49 44 46] When various delineation treatments are used in combination at high-risk locations and as part of mass action, route-based programs, higher benefits may be achieved.[62]

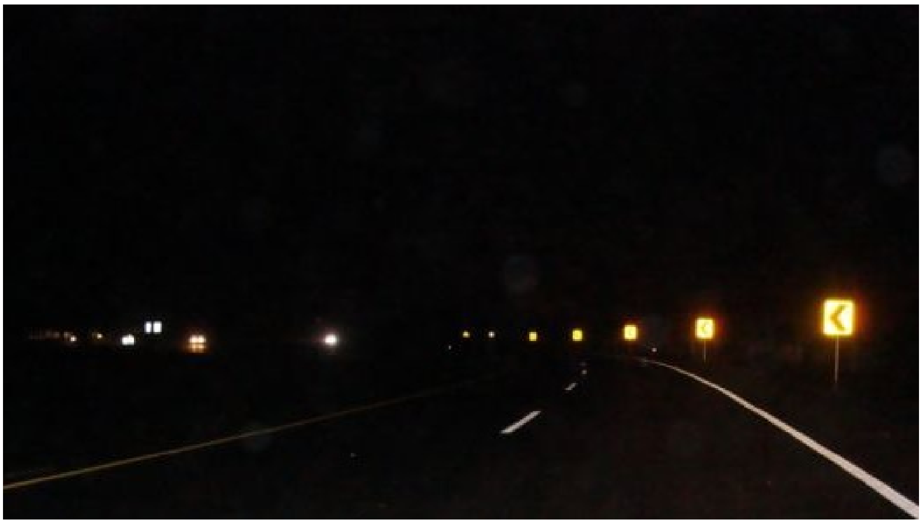

Figure A.10: Example of signs and/or line marking Retroreflective chevron signs providing visibility at night. (Source: iRAP)

A.1.16 AUDIO-TACTILE LINE MARKING

Various forms of rumble strips or audio tactile line marking have emerged in recent years. These are either raised sections (often in thermoplastic) or milled (cut) into the road surface. They can be placed along the road (longitudinally) either on the road edge (on or adjacent to the edgeline) as in Figure A.11, or in the center of the road, or they can be used across the road (transverse markings) as shown in Figure A.12. When driven over, these devices alert motorists via vibration and sound. In the case of longitudinal markings, they warn motorists that they are leaving their traffic lane (often due to inattention or fatigue). When used across the road they can inform motorists that there is a hazard ahead. These interventions reduce crashes by around 20-30 percent.[49 63]

[62] Jurewicz, C., Chau, T., Mihailidis, P. & Bui, B. (2014). From Research to Practice – Development of Rural Mass Curve Treatment Program. Proceedings of the 2014 Australasian Road Safety Research, Policing & Education Conference.
[63] Bahar, G, Masliah, M, Wolff, R & Park, P 2007, Desktop reference for crash reduction factors, report FHWA-SA-07-015, Federal Highway Administration, Washington DC, USA.

Figure A.11: Example of longitudinal ATLM (Source: Secretariat CAREC 2018. CAREC Road Safety Engineering Manual 2: Safer Road Works)

Figure A.12: Example of transverse ATLM Transverse rumble strips in Vietnam. (Source: World Bank)

A.1.17 IMPROVING SURFACING ON POOR QUALITY ROADS WITHOUT ADDITIONAL INFRASTRUCTURE IMPROVEMENT

An assumption is often made that when paving a road (that is, from dirt or unsurfaced roads to concrete or aggregate surfacing) or improving the current road surface, safety benefits will ensue. However**, increases in risk can occur, especially if other improvements (specifically for safety) are not made at the same time**. This is particularly true in LMICs where the quality of the road before resurfacing can be very poor, leading to very low speeds.[64] Road surface improvements can lead to substantially higher traffic speeds, and if other measures are not taken to improve safety for vulnerable road users (for example, provision of footpaths, traffic calming) or for motorists (including improvements at intersections and curves, roadside management, improved sight distance, and so forth) crashes are likely to increase. Given the knowledge base on the increase in crash risk for any given road with increases in speed [65] [66] [67] (also see the following section on speed interventions), it is expected that such improvements will result in large increases in risk, even when taking into account improvements in road surface friction, vehicle stability, and other possible benefits. Further details can be found in Case Study 3 below.

[64] One study with a limited sample in India found that speeds dropped by 30-40 km/h for inter-urban roads when roughness increased substantially – see Ch.Ravi Sekhar, J.Nataraju, S.Velmurugan, Pradeep Kumar and K.Sitaramanjaneyulu (2016). Free Flow Speed Analysis of Two Lane Inter Urban Highways. Transportation Research Procedia 17, 664 – 673.

[65] GRSP (Global Road Safety Partnership) (2008). Speed management: a road safety manual for decision makers and practitioners. Geneva, Global Road Safety Partnership. Available at: http://whqlibdoc.who.int/publications/2008/9782940395040_eng.pdf

[66] Elvik, R (2009), The power model of the relationship between speed and road safety: update and new analyses, TOI report 1034/2009, Institute of Transport Economics, Oslo, Norway.

[67] Elvik, R (2013), 'A re-parameterisation of the power model of the relationship between the speed of traffic and the number of accidents and accident victims', Accident Analysis & Prevention, vol. 50, pp. 854–60.

CASE STUDY 3 - SURFACE IMPROVEMENTS

Tanzania received funding to upgrade the 140 km Mafinga to Igawa Road which had deteriorated drastically due to pavement aging. However, following a spate of serious crashes, the World Bank requested that iRAP undertake a rapid road safety assessment of the upgraded corridor. An investigation identified various hazards. This included that although 30km/h speed limit signs are present throughout the road, estimated operating speeds are often above 80km/h, well above the speeds before the upgrade occurred. On many sections of the road pedestrians are present, as shown in the example below. These pedestrians are now exposed to high levels of risk given this increase in speed.

Among other actions, it was recommended that sidewalks be installed on approximately 7km of roads in villages and urban areas and that pedestrian crossings and traffic calming be installed. Work will be completed later in 2020, but already many of these recommendations have already been addressed. This will produce significant benefits to this vulnerable road user group.

A.2 SAFE SPEED

A.2.1 INTRODUCTION

There is a direct, causal link between speed and safety outcomes. Indeed, there are no other risk factors that have such a substantial and pervasive impact on safety as speed. Speed has an impact on both the likelihood of a crash occurring, and severity of the outcome when crashes do occur.

There is very strong evidence about the impact of changes in speed on crash risk.[68] [69] [70] Figure A.13 provides information on change in speed for rural roads and freeways. This highlights that the more severe crash types (especially fatal crashes) increase the most with a change in speed. Conversely, the more severe crash types improve the most with a reduction in speed.

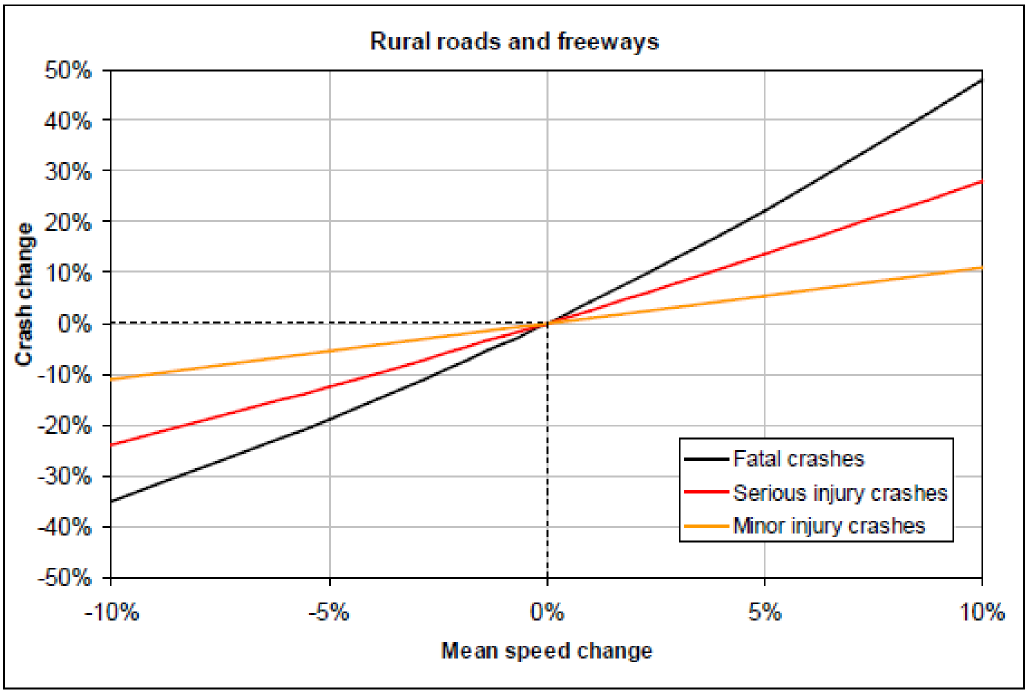

Figure A.13: Relationship between change in speed and change in crash risk. Source: Elvik 2009[66]

In many instances increasing vehicle speeds is an important economic objective. **Economic improvement can only be achieved if there is a subsequent improvement in the safety of the road itself to prevent the increased costs of crashes countering the economic benefits of reduced travel time.** Indeed, freeways and motorways are our fastest, but also typically our safest, roads. These roads can maintain safe mobility through the high quality of the infrastructure that is provided. This includes proper roadside and median protection (for example, through barrier systems), protecting road users at intersections through provision of grade separation and on- and off-ramps, and ensuring that vulnerable road users are

[68] GRSP (Global Road Safety Partnership) (2008). Speed management: a road safety manual for decision-makers and practitioners. Geneva, Global Road Safety Partnership. Available at: http://whqlibdoc.who.int/publications/2008/9782940395040_eng.pdf
[69] Elvik, R (2009), The power model of the relationship between speed and road safety: update and new analyses, TOI report 1034/2009, Institute of Transport Economics, Oslo, Norway.
[70] Elvik, R (2013), 'A re-parameterisation of the power model of the relationship between the speed of traffic and the number of accidents and accident victims', Accident Analysis & Prevention, vol. 50, pp. 854–60.

separated from faster moving traffic. In situations where there is no form of access control or these other safe infrastructure measures, severe crashes will undoubtedly increase if speeds increase. This highlights the need for a clear functional road classification and the provision of infrastructure to meet the needs and speeds of relevant road users.

It is often thought that increased speeds will have a subsequent economic benefit. The relationship between vehicle speed and other economic objectives is demonstrated in Figure A.14.

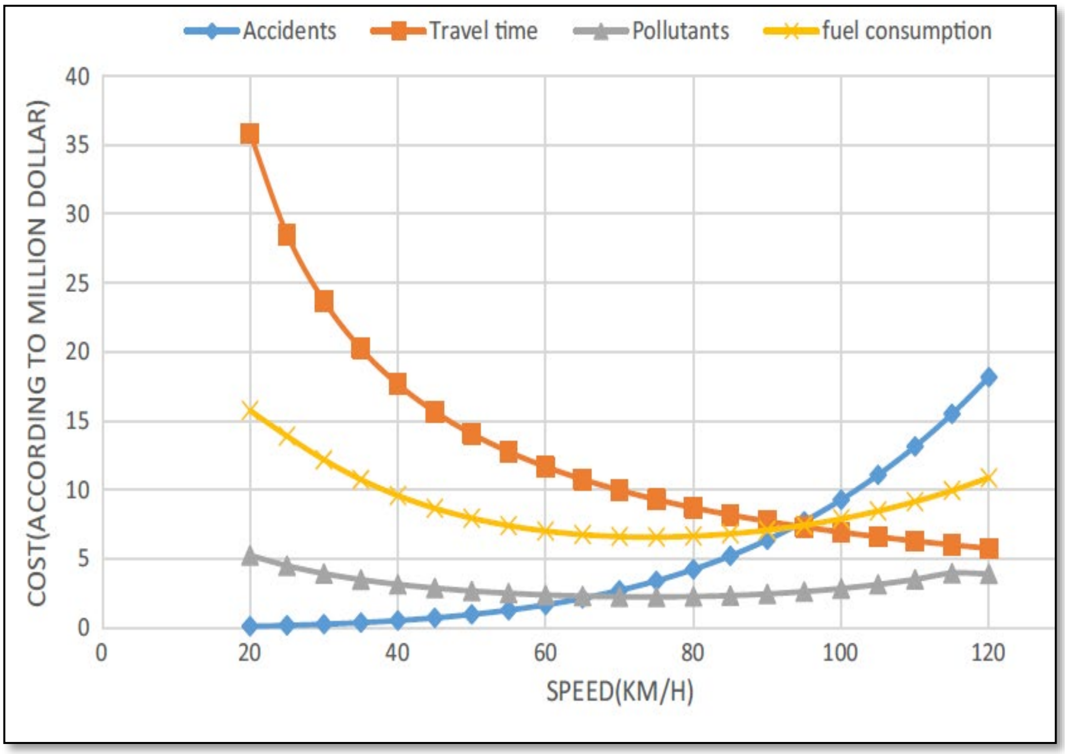

Figure A.14: Increases in speed have large impacts on multiple components of travel cost. Source: Hosseinlou et al., 2015)[71]

With the increase in speeds, travel time is reduced (although generally not as much as many think due to issues such as congestion, presence of intersections, and so forth), but at the same time, costs for fuel consumption, pollutants, and road crashes increase. The optimal speed of vehicles when including these broader societal objectives is generally less than many people think.

Various guides exist highlighting the links between speed and safety outcomes, as well as effective methods for managing speeds. Examples include:

- GRSP (Global Road Safety Partnership) guide to speed management: a road safety manual for decision-makers and practitioners (http://whqlibdoc.who.int/publications/2008/9782940395040_eng.pdf)
- FHWA Speed Management Toolkit (https://safety.fhwa.dot.gov/speedmgt/ref_mats/docs/speedmanagementtoolkit_final.pdf)
- Austroads Rural Speed Compendium (https://austroads.com.au/publications/road-safety/ap-r449-14)

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[71] Hosseinlou, MD., Kheyrabadi, SA., Zolfaghari, A. (2015). Determining optimal speed limits in traffic networks. *International Association of Traffic and Safety Sciences*, 39(1):36-41.

- Austroads Urban Speed Compendium (https://austroads.com.au/publications/road-safety/ap-r514-16).

Appropriate speeds need to be constantly reviewed, particularly in areas where there is changing land use and an increasing presence of vulnerable road users. As an example, in many LMICs, cities and even rural townships are expanding along highway corridors that were designed to cater for high-speed intercity traffic. These corridors need to be reviewed and appropriate speed management and infrastructure provisions put in place. Ultimately many of these locations need to be rebuilt as urban streets.

Details on some specific speed-related interventions can be found in the remainder of this section.

A.2.2 TRAFFIC CALMING INCLUDING HUMPS, CHICANES

Various road infrastructure devices can be used to effectively manage the speed of vehicles. Humps (Figure A.15) and platforms refer to raised sections of pavement, with various forms of speed humps and platforms available for different road types and speed environments. Chicanes provide another mechanism for slowing vehicles through horizontal deflection (or movement) of vehicles. Again, the designs can vary depending on the degree of speed control desired, as well as the operating environment. These interventions can be used at high risk locations (such as areas where pedestrians and other vulnerable road users need to cross) or as part of an integrated area-wide traffic calming scheme.

Figure A.15: Traffic calming/Speed Hump (Source: NACTO)

Well-designed traffic calming can produce substantial safety benefits. Reductions of around 35 percent for all injury crashes are typical, but much higher benefits are likely for pedestrians and other vulnerable road users (around a 70 percent reduction in fatal and serious pedestrian injury).[49 50 55 72]

[72] Makwasha, T & Turner, B (2017), 'Safety of raised platforms on urban roads', Journal of the Australasian College of Road Safety, vol. 28, pp. 20-7.

A.2.3 ROUNDABOUTS

Roundabouts have been included here as well as within the section on Safe Roads due to their substantial impact on speed reduction when designed and installed correctly. For further details, please see the content in Section A.1.7.

A.2.4 RAISED INTERSECTIONS

Raised intersections (also known as raised junctions or plateaus) are raised sections of pavement with ramps designed to reduce speeds to required levels (typically 50 km/h in the absence of vulnerable road users, and lower where they are present). The whole intersection can be raised or alternatively, raised sections can be placed in advance of the intersection (sometimes referred to as raised stop bars).

Benefits of around 40 percent reductions in injury crashes are likely with this intervention[52 72] with higher benefits likely for vulnerable road users.

A.2.5 RAISED CROSSINGS

Raised pedestrian crossings are flat-top speed humps that also provide priority to pedestrians rather than motorists. They typically consist of a raised platform with a marked pedestrian crossing on top (Figure A.16). A central refuge and narrowing may also be provided, particularly on wider roads. Additional humps may be used in advance of the crossing to further reduce vehicle speeds. The raised crossing slows vehicles and also increases the visibility of pedestrians due to the increased height.

Figure A.16: Raised pedestrian crossing (Source: GRSF)

This treatment can result in substantial safety improvements for both motorized road users and pedestrians (65 percent and 75 percent respectively.[52 53 46 72]

A.2.6 GATEWAY TREATMENTS

Gateway treatments (also called entry treatments or thresholds) are used to mark the transition points between a higher speed environment to a lower speed environment. They are particularly useful when approaching a town or village. Speed reductions are achieved through the use of speed signs (these may be larger than normal) and road narrowing (either through constructed islands or through painted markings). In some cases, raised pavements are used (Figure A.17), or colored or textured pavements used instead.

Figure A.17: Gateway treatment between a high speed and low speed environment (Source: World Bank)

These interventions can be cheap to install, but produce substantial benefits in regards to severe crash outcomes. They are particularly useful for reducing fatal and serious injuries to vulnerable road users. Reductions of around 40 percent of fatal and serious injuries are possible.[73] [74] [75]

A.2.7 LOWER SPEED LIMITS

This intervention involves lowering the posted speed limits using static signs towards safer levels. This is a widely applied speed management measure aimed at producing lower vehicle speeds, and crash and injury severity reductions. Speed limits should be set based on the most vulnerable road users present and as part of an integrated strategy that addresses safe mobility. Depending on other road and traffic elements (including the surrounding land use, traffic mix, and volumes) the reduced speed might need to be supported by other infrastructure solutions to provide "self-explaining roads" and to help ensure that motorized road users understand speeds and thereby improve compliance.

[73] Makwasha, T. and Turner, B. (2013). Evaluating the use of rural-urban gateway treatments in New Zealand. Journal of the Australasian College of Road Safety, 24(4):14-20.
[74] Forbes, G (2011), Speed reduction techniques for rural high-to-low speed transitions, NCHRP SHP 412, Transportation Research Board, Washington, DC, USA.
[75] Wheeler, A, Taylor, M & Payne, A 1993, The effectiveness of village 'gateways' in Devon and Gloucestershire, project report no. 35, Transport Research Laboratory, Crowthorne, UK.

The safety benefits from a change in the speed limit will depend on the magnitude of change and the level of compliance. A 10 km/h reduction in a speed limit could be expected to produce around a 15 percent reduction in injury crashes, and up to around a 40 percent reduction in pedestrian fatal and serious injuries, but in the right circumstances, benefits can be greater than these.[49] [50] [57]

A.2.8 30 KM/H (20 MPH) ZONES FOR PEDESTRIANS

Many of the solutions highlighted in this section can be used in combination to create low speed environments (Figure A.18) which provide a greater degree of safety for vulnerable road users, including pedestrians. As indicated above, pedestrians have a reasonably good chance of surviving when struck by vehicles at or below 30 km/h, but above this speed, the chances of survival reduce dramatically. Reduction in serious injuries to pedestrians can be very high with this treatment (in excess of 70 percent[49] [54] [55]) and there will also be high benefits for other road users in these environments.

Figure A.18: Example of 30 km/h residential zone in Korea. (Source: KOTI)

A.2.9 SPEED CAMERAS

Speed cameras are devices that are mounted on the side of the road, above the road, or in vehicles to detect speeding vehicles. They may be fixed (at a set location) or mobile (Figure A.19). In some situations, two or more cameras are used to detect average speed of vehicles. Speed cameras differ from traditional speed enforcement in that photographs of the vehicle and license plate are taken, and a citation is mailed to the vehicle owner. This eliminates the need for a police officer to intercept the speeder. To work effectively, automated cameras require license plates to be clearly displayed on vehicles and need to have a robust administrative system to issue fines. Guidance is available on establishing speed camera programs.[76]

[76] Job, S., Cliff, D, Fleiter, J.J., Flieger, M., & Harman, B. (2020). Guide for Determining Readiness for Speed Cameras and Other Automated Enforcement. Global Road Safety Facility and the Global Road Safety Partnership, Geneva, Switzerland.

The introduction of speed cameras combined with the promotion of enforcement activity is very effective safety intervention. For example, evaluation of the first 28 speed cameras introduced in the state of New South Wales, Australia, revealed a 71 percent reduction in speeding, which delivered an 89 percent reduction in deaths at the treated locations.[77] Other studies show consistent though somewhat smaller reductions in trauma.[78] Reduced speeds also deliver large reductions in fatalities and injuries for pedestrians.[79]

Figure A.19: Roadside mobile speed camera
(Source: commons.wikimedia.org/wiki/File:Radarvelocidade20022007-1.jpg)

A.2.10 INCREASING TRAVEL SPEED WITHOUT IMPROVING QUALITY OF INFRASTRUCTURE

As identified at the start of this section, when speeds increase and there are no subsequent improvements in infrastructure to support this higher speed and to protect vulnerable road users, crash risk will increase. As identified in the previous section (Section A.1.17) this can occur when road surface improvements are made on poor quality existing road alignments and/or where vulnerable road users are present. **It is clear from the evidence that increases in speed without subsequent improvement in infrastructure has harmful impacts.**

[77] Job, RFS & Sakashita, S. (2016). Management of speed: The low-cost, rapidly implementable effective road safety action to deliver the 2020 road safety targets. Journal of the Australasian College of Road Safety, May 2016, 65-70.
[78] Wilson, C; Willis, C, Hendrikz, J, Le Brocque, R, Bellamy, N (2010). "Speed cameras for the prevention of road traffic injuries and deaths" The Cochrane Library (10): CD004607.
[79] World Health Organization (WHO) (2013). Pedestrian Safety: A road safety manual for decision-makers and practitioners. WHO: Geneva.

A.3 SAFE ROAD USERS

A.3.1 INTRODUCTION

Changing road user behavior has been the focus of activity for road safety practitioners for many decades. Given that many crashes are in some way caused by road user error, it would seem obvious that improving behavior would be the first option for improving road safety. However, changing behavior to produce safety benefits still brings significant challenges and sometimes only very limited benefits. More effective solutions to address road user issues can often be found in other Safe System pillars. For example, it is possible to engineer roads to provide very direct visual cues to road users on the appropriate speed, or even to constrain speeds through physical measures. This is typically more effective than telling drivers about the risks of higher speeds and telling them they should slow down. Similarly, vehicle technologies play an increasing role in safely managing driver behavior through various warning systems, partial automation (for example automatic emergency braking), and vehicle management systems (for example seatbelt reminders systems and alcohol interlocks).

The often limited impact of some road user interventions is not surprising given the current knowledge of safety science. The well-established "Hierarchy of Control", which stems from the industrial health and safety field, highlights measures to minimize or eliminate exposure to hazards[80] and is shown in Figure A.20.

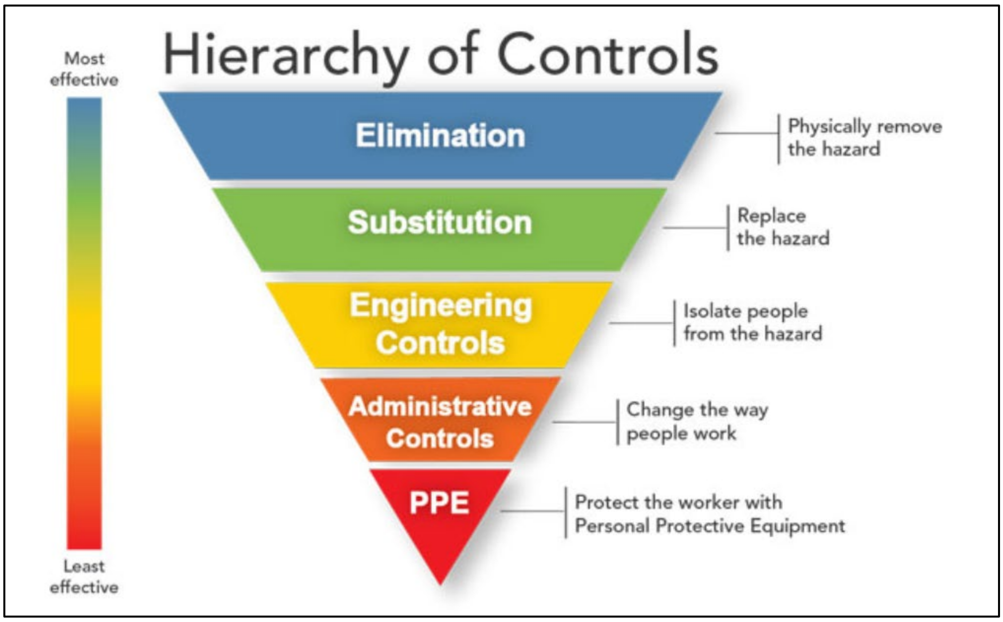

Figure A.20: Hierarchy of Controls. (Source CDC 2020[81])

Based on this approach, the most effective interventions are those that eliminate the hazard, followed by substitution of the hazard, and then engineering controls (which may include seat belts and airbags in the road safety context). Behavioral interventions which generally fall under administrative controls are at the lower-end of the effectiveness scale since they require constant supervision and vigilant enforcement, supported by continuous training as new people enter the system. At a population level, such interventions often involve a large amount

[80] For a discussion on the Hierarchy of Control from a Safe System perspective, please see McTiernen, D & Rensen, A (2016), The Safe System Hierarchy of Control Framework for Local Roads, Proceedings of the 2016 Australasian Road Safety Conference, Canberra, Australia.
[81] Center for Disease Control (2020) - Hierarchy of Controls - NIOSH Workplace Safety and Health Topic. www.cdc.gov. Retrieved June 3rd 2020

of resources to reach the desired number of people to make a measurable impact. Instead, the greatest successes typically come when we can eliminate a hazard entirely (for example, by putting motorized traffic and pedestrians on non-overlapping, non-conflicting paths).

As noted previously, improving road user behavior is a key element of the Safe System approach, and there are important actions that need to be taken to improve road safety through this mechanism. Methods used for improving road user behavior include implementation of driver licensing, training, education, enforcement, monitoring (for example, through vehicle telematics) and road safety campaigns. As shown in the summary table in Section 2, although there is some clear evidence that road user behavior can be improved, **there are several popular road user interventions which have been found to be ineffective or even harmful for reducing fatal and serious injuries**. The remainder of this section provides an overview of the evidence base on effectiveness of safe road user interventions.

A.3.2 DRIVER LICENSING SYSTEMS THAT INCLUDE EXTENSIVE ON-ROAD SUPERVISED PRACTICE

Driver licensing systems that ensure novice drivers are required to undertake many hours of supervised on-road driving has proven to be effective.[82] [83] While safety benefits are shown, the reason for them is not certain. Benefits may arise from learning safer habits, such as adhering to speed limits and wearing a safety belt, and from better scanning and anticipation of other road users, but also because the age of driving is increased (see Section A.3.5 for evidence on the importance of this issue). A number of countries have moved to systems where this extensive on-road supervision is required, often as part of a Graduated Licensing System (or GLS, see Section A.3.3). Given that this on-road experience is typically coupled with other elements of GLS, it is hard to determine the impact of this element alone.

There are limited indications that structured pre-license training can produce a safety benefit. One review[84] reported on research from Denmark that found structured training by a qualified driving instructor and involving classroom instruction, car control skills, defensive driving, and hazard perception (see Section A.3.6) can produce safer drivers, in this case a reduction in multi-car collisions, but not single vehicle collisions, in the first year of driving. However, this study was based on self-reports of crash involvement and suffered from a limited methodology. It was noted in the review[84] that studies on this topic typically suffer from methodological limitations.[85] The review clearly highlighted that training may be associated with poorer on-road safety outcomes if this results in reduced hours of supervised training or accelerated attainment of license. In summary, license systems involving extensive on-road supervised training as part of a GLS are the preferred form of licensing system.

[82] Gregersen, N. P., Nyberg, A., & Berg, H. Y. (2003). Accident involvement among learner drivers—an analysis of the consequences of supervised practice. Accident Analysis & Prevention, 35(5), 725-730.
[83] Catchpole, J, Makwasha, T, Newstead, S, Imberger, K & Healy, D (2017). Impact of Victoria's Enhanced GLS on Novice Driver Crash Involvement. Proceedings of the 2017 Australasian Road Safety Conference, Perth, Australia.
[84] Beanland, V, Natassia, G, Salmon, P & Lenne, M. (2013), Is there a case for driver training? A review of the efficacy of pre- and post-licence driver training, Safety Science, 51, 127–137.
[85]Studies of this type would ideally involve "randomization" of subjects into different groups, but typically this does not occur. Randomization means that those completing training are randomly allocated into this group, while others are randomly allocated into a group that is not trained, or receives some other alternative. This minimizes potential biases (such as self-selection bias) meaning that differences in performance between groups can be attributed to differences in training.

A.3.3 GRADUATED LICENSING SYSTEMS

GLS typically combines extensive supervised on-road training with a phased approach to driving. Initially drivers are restricted in how they can drive (for example, with initial limitations on passenger numbers; zero alcohol tolerance; restricting vehicles that can be driven). GLS coupled with supervised on-road driver training has been found to be effective with a 20 to 30 percent reduction in novice driver fatal and serious injury.[83 86]

A.3.4 LICENSE THROUGH APPLICATION OR PAYMENT

In contrast, driver licensing systems that do not include extensive on-road supervised training and GLS will therefore be less effective. Many countries do not include these components within their driver licensing systems. Systems that rely on **a simple application process, or situations where more rigorous licensing regimes can be subverted through payment, are not likely to be effective and should be avoided** and other alternatives provided in this section should be used. However, having a robust licensing system is likely to bring some road safety benefits as this provides a mechanism to monitor driver violations (such as speeding) and therefore provides an incentive for road users to comply with regulations. In many countries, licenses can be suspended or canceled if drivers exceed certain conditions (also see Section A.3.11 on penalties).

A.3.5 INCREASE AGE FOR DRIVING LICENSE ELIGIBILITY

A link between driver age, experience, and crash risk has been firmly established. Drivers in their first year are three to four times as likely to have a crash compared to a more experienced driver.[87] This risk peaks in the first few months of driving and decreases rapidly after about 6-8 months of driving experience.[88] Part of this high risk is related to lack of skills and experience and driving in higher risk situations, but there is clear evidence that driver's cognitive maturity also plays a significant part. Studies on younger versus older novice drivers indicate that the younger drivers have greater crash risk than their older counterparts.[89] Therefore, one way to reduce injuries and deaths is to delay the age at which young people are eligible to obtain a license. This is likely to be one of the mechanisms by which GLS systems work given that they delay the onset of driving (along with other elements). Evidence also suggests that increasing driving age will also have a beneficial impact on safety outcomes.[90] Increasing driving age by 1 year is likely to produce a 5-10 percent reduction in the crash rate for the first year of Driving.[49]

A.3.6 HAZARD PERCEPTION TRAINING AND TESTING

Hazard perception refers to a road user's ability to anticipate potentially dangerous situations on the road ahead. This skill typically takes many years of experience to acquire. Hazard perception skill can be measured using computer-based hazard-perception tests, and similarly, hazard perception training can be provided, typically as part of comprehensive novice driver licensing regimes. Hazard perception testing and training appear to have the

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[86] Hartling L, Wiebe N, Russell K, Petruk J, Spinola C & Klassen TP (2004) Graduated licensing for reducing motor vehicle crashes among young drivers, Cochrane Database of Systematic Reviews.
[87] Palamara P, Legge M & Stevenson M (2002) The relationship between years of licensing, traffic offences and crash involvement: Implications for driver licensing in Western Australia. Developing Safer Drivers and Riders: Conference Proceedings, Brisbane QLD.
[88] Mayhew DR, Simpson HM & Pak A (2003) Changes in collision rates among novice drivers during the first months of driving. Accident Analysis & Prevention, 35, 683-691.
[89]Curry AE, Metzger KB, Williams AF, Tefft BC4, (2017), Comparison of older and younger novice driver crash rates: Informing the need for extended Graduated Driver Licensing restrictions, Accident Analysis & Prevention 108, 66-73.
[90] Williams, (2009). Licensing age and teenage driver crashes: A review of the evidence. Traffic Injury Prevention, 10(1), 9-15.

capability to reduce crash risk. For example, the inclusion of a hazard-perception test in the UK driver licensing process has been estimated to reduce drivers' high speed road crash rates by about 10 percent in the year following their test.[91]

A.3.7 POST-LICENSE DRIVER AND RIDER EDUCATION AND TRAINING

Once drivers and riders have received their licenses (preferably through a robust system as outlined above) there are often demands to build on the basic skills obtained through various types of education and training. Despite faith in this post-license education and training, **general passenger car driver training is proven repeatedly to be ineffective, or even harmful, for road safety**. The highly credible Cochrane Library has published rigorous reviews of the evidence which have shown no safety benefits of driver training. The review of post-license driver training evaluations concluded that there is: "…. no evidence that post-license driver education is effective in preventing road traffic injuries or crashes. …. Because of the large number of participants included in the meta-analysis (close to 300,000 for some outcomes) we can exclude, with reasonable precision, the possibility of even modest benefits."[92] The analysis of the evidence also found that: "No one form of education … was found to be substantially more effective than another, nor was a significant difference found between advanced driver education and remedial driver education."[92] More recent reviews have demonstrated increases in crash rates from vehicle handling skills-based training such as skid training. Although this result might seem counter-intuitive, the simplest way to understand this is that any benefits that might arise through training are greatly out-weighed by the over-confidence imparted in those involved in these courses. This is illustrated in the example in Case Study 3 below.

[91] Horswill, M. S. (2016). Hazard Perception in Driving. Current Directions in Psychological Science, 25(6), 425–430

[92] Ker K, Roberts IG, Collier T, Beyer FR, Bunn F, Frost C. Post-licence driver education for the prevention of road traffic crashes. Cochrane Database of Systematic Reviews 2003, Issue 3. Art. No.: CD003734. DOI: 10.1002/14651858.CD003734.

CASE STUDY 3 - SKID TRAINING

Skid control (or "skid pan") training is intended to teach drivers how to control their vehicle if they encounter slippery road surface conditions, including on wet roads and from snow, ice, oil, or debris. Slippery surface conditions are artificially created in an off-road setting. The training often promises "advanced driving skills" to help tackle these dangerous conditions, and intuitively, acquiring such experience seems to make sense. However, there is considerable evidence that such training contributes to increased crash risk. This negative outcome has been replicated from numerous studies, including those conducted in Europe, North America, Australia, and New Zealand.

One of the main reasons that such training is not effective is that any benefits obtained through improved knowledge or skills are out-weighed by a greater risk from over-confidence following such training. Driver skills training is shown to increase confidence[93] [94] (making existing general over-confidence worse[93]) and increased confidence is associated with increased risk taking.[95]

(Source: wwww.driveandstayalive.com)

In some LMICs, post-license training may be seen as a way to make up for poor licensing systems (see Section A.3.4) where drivers and riders commence on-road activity without any of the required skills or experience. It is unlikely that a small number of post-license training sessions would provide the required experience for safe road use, and as the evidence from elsewhere shows, there is a very real chance that this will result in increased risk. Even if such training and education was shown to have benefits (which it has not), these types of interventions fall at the bottom of the hierarchy of control (see Section A.3.1). Immense resource would be required to train an adequate number of road users to have any beneficial impact, and continued training is likely to be required. It is highly recommended that new road

[93] Job, RFS (1990). The application of learning theory to driving confidence: The effect of age and the impact of random breath testing. Accident Analysis and Prevention, 22, 97-107; DeJoy, D. M. (1989). The optimism bias and traffic accident risk perception. Accident Analysis & Prevention 21(4): 333-340.
[94] Katila, A, Keskinen,O Hatakka,M. Laapotti S. (2004). Does increased confidence among novice drivers imply a decrease in safety? The effects of skid training on slippery road accidents. Accident Analysis & Prevention, 36 (4), 543–550; Gregersen, N. P. (1996). Young drivers' overestimation of their own skill: An experiment on the relation between training strategy and skill. Accident Analysis & Prevention 28 (2), 243-250.; Ker, K., I. Roberts, T. Collier, F. Beyer, F. Bunn and C. Frost (2005). Post-licence driver education for the prevention of road traffic crashes: a systematic review of randomised controlled trials. Accident Analysis & Prevention 37(2): 305-313.
[95] Weinstein, Neil D. (1988). The precaution adoption process. Health Psychology, Vol 7(4), 355-386;
Prabhakar, T., Lee, S.H.V., & Job, RFS (1996). Risk Taking, optimism bias and risk utility in young drivers. L. St. John (Ed.), Proceedings of the Road Safety Research and Enforcement Conference. (pp.61-68). Sydney, NSW: Roads & Traffic Authority of NSW.

users go through a strict procedure of obtaining a license through a robust system (such as GLS) as outlined above.

There are a few quite specific areas of exception where driver training has been found to be effective through evaluations. There is research on commercial and occupational drivers which shows positive impacts from stand-alone training programs.[96] There are studies which show links between training and reductions in risky driving behavior,[97] and others that show positive impacts from transit bus driver training programs, particularly defensive driving training, but evaluations also recognize that several other factors can influence training outcomes,[98] particularly an organization's safety culture.

Post-license motorcycle rider training has produced no demonstrated road safety gains, with benefits absent in systematic reviews of the evidence[99] and in a more recent well-controlled evaluation of post-license training.[100] In regard to the research evidence, there are no known exceptions to this.

A.3.8 SCHOOL-BASED EDUCATION AND TRAINING

Many attempts have been made to improve road safety outcomes for school-aged children through education and training. Based on changes in safe behavior, teaching children how and where to cross the road safely appears to provide benefits.[101] However, this should only be applied to children of a suitable age so as not to encourage more independent (unsupervised) road crossing by younger children. Regular refresher training is also important. Even then, the hope that these changes in behavior will produce real safety benefits remains unproven.[102] As highlighted elsewhere, even if such training does provide a benefit, a huge amount of resource is required to adequately train a large enough number of children to produce a safety impact. Asides from the financial constraints, there are also logistical ones, and there are often significant issues including lack of skilled trainers when attempting to provide such training on a large scale.[103]

Section A.3.9 indicates that there are likely to be benefits of public education campaigns that are combined with enforcement activity. There may also be broader benefits of education campaigns to raise awareness of road safety issues thereby increasing acceptance of other societal changes to improve safety, such as legislation to support enforcement or improved knowledge on purchase of safe vehicles. This may include broad education aimed at school-aged children. Indeed, it is sometimes stated that road safety education is a lifelong learning process.[104] However, educational activities performed on an ad hoc basis do not fall into this category. The OECD reports that **ad hoc activities including visits from road safety experts and enthusiasts will be relatively unsuccessful** despite their popular appeal.[104]

[96] Gregersen, Nils Petter, Brendt Brehmer, and Bertil Moren. 1996. "Road Safety Improvement in Large Companies. An Experimental Comparison of Different Measures." Accident Analysis and Prevention 28 (3): 297-306.
[97] Dorn, Lisa, and David Barker. 2005. "The effects of driver training on simulated driving performance." Accident Analysis and Prevention 63-69.
[98] TCRP. 1996. Bus Occupant Safety- A Synthesis of Transit Practice. Washington DC: Transportation Research Board.
[99] Kardamanidis, K., Martiniuk, A., Ivers, R. Q., Stevenson, M. R., & Thistlethwaite, K. (2010). Motorcycle rider training for the prevention of road traffic crashes. The Cochrane Library
[100] Ivers, R. Q., Sakashita, C., Senserrick, T., Elkington, J., Lo, S., Boufous, S., & de Rome, L. (2016). Does an on-road motorcycle coaching program reduce crashes in novice riders? A randomised control trial. Accident Analysis & Prevention, 86, 40-46.
[101] Oxley J, Congiu M, Whelan M, D'Elio A, Charlton J. (2008). Teaching young children to cross roads safely. Ann Adv Automot Med., 52, 215-23.
[102] Duperrex, O., Roberts, I., & Bunn, F. (2002). Safety education of pedestrians for injury prevention. The Cochrane Library.
[103] Hammond, J., Cherrett, T., & Waterson, B. (2014) The Development of Child Pedestrian Training in the United Kingdom 2002–2011: A National Survey of Local Authorities, *Journal of Transportation Safety & Security, 6:2*, 117-129
[104] OECD (2004) Keeping children safe in traffic, OECD, Paris.

Indeed, despite the value of education and training in other aspects of life, a comprehensive review of many scientific **evaluations of school-based driver training demonstrated clearly negative results.**[105] The study concludes that the results “provide no evidence that driver education reduces road crash involvement and suggest that it may lead to a modest but potentially important increase in the proportion of teenagers involved in traffic crashes.”[105] Similar conclusions have been reached in more recent studies.[106] [107] No sound evidence exists for road safety benefits arising from school-based driver training. Any possible benefits are overcome by increased driver over-confidence and possibly the earlier age of beginning to drive. There is direct evidence for the benefit of starting to drive at an older age, with effects of age on risk independent of driving experience.[108] This relates to fundamental brain development. No exceptions are identified.

While studies show the education on road safety in schools does improve knowledge,[109] there is no evidence that this knowledge changes the safety level of on-road behavior. Again, **there is a risk that increased knowledge increases confidence and risk-taking**.

As indicated above, even if there were benefits from school-based training, it would require immense resource (funding and skilled trainers) to produce any significant safety benefit in terms of crash reduction.

Figures indicate that 88 percent of pedestrian travel (for all age groups) occurs on roads that are unsafe.[110] This situation also occurs on roads surrounding schools in many LMICs, meaning that a viable solution for improving the safety of children is to increase the quality of road infrastructure to embed safety features. A large proportion of child injuries in LMICs occur while children are walking. Globally, the figure is 38 percent, and this is often the result of children walking where there is a mixture of vehicle types, often at higher speeds.[111] When mixed with poor sidewalks, crossings, and other safety features, the result is high numbers of child deaths and serious injuries.

Given the lack of evidence for positive safety outcomes through school based education and training, it is recommended that better approaches to improving road safety outcomes for school-aged children should be used, including investment in road infrastructure improvements around schools.

A.3.9 PUBLIC EDUCATION AND CAMPAIGNS

Public education and awareness programs have been shown to deliver extremely mixed results, but there is a growing evidence base on what actually works in regard to these campaigns. The key finding is that the effectiveness of campaigns on their own in terms of direct safety benefits is likely to be small.[112] However, there are specific situations where campaigns can be effective, especially when combined with other measures. Without

[105] Roberts IG, Kwan I. (2001). School-based driver education for the prevention of traffic crashes. Cochrane Database of Systematic Reviews 2001, Issue 3
[106] Poulter, D. & Mckenna, F (2010), Evaluating the effectiveness of a road safety education intervention for pre-drivers: An application of the theory of planned behavior, British Journal of Educational Psychology, 80, 2, 163-181.
[107] Glendon, A., McNally, B., Jarvis, A., Chalmers, S., Salisbury, R. (2014), Evaluating a novice driver and pre-driver road safety intervention, Accident Analysis & Prevention, 64, 100-110.
[108] Casey, B.J., Jones, R. M. and Hare, T. A. (2008), The Adolescent Brain. Annals of the New York Academy of Sciences, 1124: 111–126. doi: 10.1196/annals.1440.010; Johnson, S. B. and V. C. Jones (2011). Adolescent development and risk of injury: using developmental science to improve interventions. Injury Prevention 17(1): 50-5491; Oxley J, Congiu M, Whelan M, D'Elio A, Charlton J. (2008). Teaching young children to cross roads safely. Ann Adv Automot Med., 52, 215-23.
[109] Meehan, G. (2009). School student recognition of in-school road safety education. Proceedings of the Australasian Road Safety Research Policing Education Conference, 2009, Sydney, New South Wales, Australia, 2009. Sydney: NSW Roads & Traffic Authority
[110] WHO (2018) Global Status Report on Road Safety 2018, World Health Organization, Geneva.
[111] WHO (2015), Ten strategies for keeping children safe on the road, World Health Organization, Geneva.
[112] Hoekstra, T and Wegman, F (2011). Improving the effectiveness of road safety campaigns: Current and new practices. IATSS Research 34 (2011) 80–86

enforcement, a mass media campaign has virtually no direct effect in terms of reducing the number of crashes, but in combination, these measures can lead to a reduction in crashes.[112]

As one clear example, seatbelt use in the state of New South Wales, Australia, only increased slightly from baselines to over 20 percent by strong advertising of the risks of injury and death. However, good advertising of impending enforcement of seatbelt use resulted in a sudden increase in usage rate to over 95 percent, which with further refinement of enforcement and promotion increased to over 99 percent. The fear of a fine is clearly more effective.[113] Similarly, despite extensive education and campaigning on the dangers of drink-driving, an alarming 42 percent of deaths involved drink-driving. Yet with the introduction of a strong campaign warning about impending extensive random breath testing, driving-driving deaths dropped dramatically.[114] The drop in drink-driving deaths even preceded the beginning of the random breath testing enforcement, demonstrating the impact of the advance warning communications campaign. Campaigns work best when alternative behaviors are provided.[112] For example, in a drink driving campaign (to reduce driving while intoxicated) it would be useful to highlight alternative forms of transport or the importance of selecting a designated sober driver instead of driving under the influence of alcohol.

In addition, educational interventions may operate through an indirect route by changing road users' perceptions about risks of an activity.[115] For example, an intervention that made the target audience more aware of the dangers of speeding may not directly change behavior, but rather may increase awareness of the problem to a level whereby the introduction of a speed camera enforcement program is possible. That camera program would ultimately have an impact on driver behavior. Similarly, education at a very local level about a new road safety intervention (for example, roundabouts when these have not been widely used) may help improve the understanding and use for that intervention and also the acceptability of this if a clear benefit is highlighted.

A key reason for the limited effectiveness of campaigns on their own is that it is often assumed that providing information on risks will change driver behavior either through greater knowledge and/or fear of likely outcomes. However, drivers are subject to established habits, biases, situational factors, misjudgments of personal risk (including optimism bias), and sometimes, irrational behavior. It is very difficult to change behavior through campaigns (especially those based on crash risk) given these factors. In addition, such messages are often soon forgotten. Moreover, as identified in previous sections, these types of interventions generally fall at the lower end of the effectiveness scale within the hierarchy of control and require constant reminders as well as enforcement to be effective (as demonstrated by the evidence within this section).

A.3.10 ENFORCEMENT

Enforcement is a key element for reducing fatal and serious injuries. When implemented well, enforcement and the threat of sanctions (such as fines and potential loss of license) act to deter road users from participating in adverse behavior. Deterrence theory highlights that individuals will avoid offending if they fear the perceived consequences of the behavior, especially if the consequences of conducting in this behavior are seen as outweighing the

[113] Job, RFS (1988). Effective and ineffective use of fear in health promotion campaigns. American Journal of Public Health, 78, 163-167.
[114] Job, RFS, Prabhakar, T., & Lee, S.H.V. (1997). The long term benefits of random breath testing in NSW (Australia): Deterrence and social disapproval of drink-driving. In C. Mercier-Guyon (Ed.), *Proceedings of the 14th. International Conference on Alcohol, Drugs and Traffic Safety, Annecy, 1997*. (pp. 841-848), France: CERMT.
[115] McKenna, F. P. (2007). The Perceived Legitimacy of intervention. A Key Feature for Road Safety prepared for the American Automobile Association Foundation for Traffic Safety.

likely benefits.[116] [117] This deterrence therefore requires an awareness of illegal behaviors; a belief that there is a probability of detection; and a belief that the consequences of detection will be negative.[116] For this reason, enforcement is most effective when combined with campaigns highlighting risks and consequences of being caught (see Section A.3.9).

Deterrence can be general or specific. General deterrence assumes that the general motoring public who have not experienced sanctions before will be deterred from offending by the threat of punishment, as a result of awareness of others being punished for offending, or through being warned through media campaigns of impending penalties for offending.[116] [117] Therefore, for general deterrence, the target is the general population of motorists. Specific deterrence relates to offenders who have already experienced sanctions, and assumes these road users will be dissuaded from committing the same offense in future through fear of incurring further sanctions.

There are a range of road safety enforcement measures that have been shown to improve road user behavior. Implementation of intensive police programs—focused on: (i) speed; (ii) impaired driving (alcohol[118]); and, (ii) seat belt usage—is associated with average reductions varying between 20 and 30 per cent of road crashes with injuries.[119] Helmet wearing produces clear safety benefits, and enforcement of helmet wearing laws substantially increases helmet wearing rates.[120] Safety cameras, driving license suspension, and a zero blood-alcohol content (BAC) limit for young drivers are very cost-effective measures.[121] As identified above, enforcement can be combined with campaigns to increase impact.

Such enforcement has traditionally been undertaken by police, but recently a stronger role has been taken by fleet managers and even insurance companies. This has occurred with the advent of in-vehicle monitoring devices, particularly for speed compliance. The effectiveness of these systems is currently being evaluated.

A.3.11 PENALTIES

Enforcement regimes need to be linked to penalties, and these must be certain and unavoidable. When coupled with legislative change, enforcement, and broader campaigns, penalties can be an effective method for reducing road trauma.[122] [123]

There is clear evidence that greater certainty of punishment is associated with lower offense rates. Similarly, more extensive use of penalties is more effective than scarce or sporadic use.[124] One study of six countries[125] found that fewer traffic violations are committed by drivers

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[116] Elliott, B (2003), Deterrence Theory Revisited, Road Safety Research, Policing and Education Conference - From Research to Action: Conference Proceedings .Sydney: NSW Roads and Traffic Authority

[117] Davey, J. D., & Freeman, J. E. (2011). Improving Road Safety through Deterrence-Based Initiatives: A review of research. Sultan Qaboos University medical journal, 11(1), 29–37.

[118] Enforcement of drug driving has commenced in several countries, but evidence on the effectiveness of this is currently not available. There are multiple differences between drug-driving and drink-driving which mean that the simple extrapolation from the success of drink-driving enforcement to drug-driving enforcement may be misleading. These include, the many forms of drug to be tested, differences in habitual users of illicit drugs versus legal alcohol consumption, the lack of sound dose-response curves for drug impairments, and the higher cost of drug testing, which prevents pervasive testing with large numbers of tests as deployed in drink-driving enforcement.

[119] Dupont B., Blais E. (2015) Assessing the Capability of Intensive Police Programmes to Prevent Severe Road Accidents: A Systematic Review. British Journal of Criminology 45(6).

[120] WHO 2006, Helmets: a road safety manual for decision-makers and practitioners. World Health Organization, Geneva.

[121] Elvik, R, Høye, A, Vaa, T & Sørensen, M 2009, The handbook of road safety measures, 2nd edn, Emerald Publishing Group, Bingley, UK.

[122] Lefio A, Bachelet VC, Jiménez-Paneque R, Gomolán P, Rivas K. (2018). A systematic review of the effectiveness of interventions to reduce motor vehicle crashes and their injuries among the general and working populations. Rev Panam Salud Publica. 2018;42:e60

[123] Staton C, Vissoci J, Gong E, Toomey N, Wafula R, Abdelgadir J, et al (2016). Road traffic injury prevention initiatives: a systematic review and metasummary of effectiveness in low- and middle-income countries. PLoS One. 2016; 11(1): e0144971.

[124] Elliott, B. (2003) An Analysis of Risk and Deterrence; Background for LTSA Review of Administrative Penalties in New Zealand, Land Transport Safety Authority.

[125] Özkan, T, Lajunen, T, Chliaoutakis, JE, Parker, D & Summala, H 2006, 'Cross-cultural differences in driving behaviours: a comparison of six countries', Transportation Research Part F: Traffic Psychology and Behaviour, vol. 9, no. 3, pp. 227-42

in countries with strong enforcement compared with drivers in countries with relaxed enforcement because of their awareness of the consequences of these violations.

For some offense types, penalties should be graduated based on severity of activity, with higher penalties for greater levels of violation or for repeated behavior. For example, consideration should be given toward loss of license and vehicle impoundment for high-speed offenders or for repeat offenders. Individuals will be less likely to commit an offense or to reoffend if the perceived punishment for that offense is severe[126].

Penalties should be issued as quickly as possible, and there is evidence that if the punishment is administered immediately after the offence is committed, then the offender will be less likely to reoffend.[124] [127] Delays in the issuing of a fine can often lead to denial of the offense, inaccuracy of memory recall, and the potential to continue to offend. With modern technology (including SMS messaging), it is likely that infringements could be issued quickly using means other than postal mail.

A.3.12 ALCOHOL INTERLOCKS

Alcohol interlocks (Figure A.21) require drivers to provide a sample of breath before the vehicle can start, and may require repeat samples throughout a journey. If alcohol is detected, then vehicles are prevented from starting. Modern systems reduce the chances of sober passengers fooling the system by providing samples instead of drivers. Systems are also being tested that provide passive detection of driver alcohol content. Interlock devices are often installed in vehicles where drivers have been caught driving with a blood alcohol level above the legal limit.

A number of evaluations have found that alcohol interlock devices are an effective tool to prevent drink driving based on re-arrest rates, but these same studies also identify that once removed, the benefits mostly disappear. Several studies have found that use of interlock devices have benefits for crash reduction although the exact amount of benefit is difficult to determine due to small sample sizes.[128] [129]

Figure A.21: Alcohol interlock device. (Source: NHTSA)

[126] Von Hirsch, A, Bottoms, A, Burney, E & Wikstrom, P 1999, Criminal deterrence and sentence severity: an analysis of recent research, Hart Publishing, Portland, OR, USA.
[127] Homel, R 1988, Policing and punishing the drinking driver: a study of specific and general deterrence, Springer-Verlag, New York, NY, USA.
[128] Elder, RW, Voas, R, Beirness, D, Shults RA Sleet, DA, Nichols, J, Compton, R (2011). Effectiveness of Ignition Interlocks for Preventing Alcohol-Impaired Driving and Alcohol-Related Crashes: A Community Guide Systematic Review. American Journal of Preventive Medicine 40(3):362-76.
[129] Nieuwkamp, R., Martensen, H., Meesmann, U (2017), Alcohol interlock, European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Retrieved from www.roadsafety-dss.eu on 20 April 2020.

A.3.13 FATIGUE MONITORING

Fatigue is likely to contribute significantly to the number of fatal and serious injuries. Research from HICs indicate that more than 20 percent of all crashes are likely to be as a result of fatigue.[130] [131] Fatigue can be caused by driving long distances, but can also occur from driving after insufficient sleep, even after short distances. Effective measures to reduce fatigue are therefore likely to provide road safety benefits. These include ensuring drivers have adequate sleep before they drive and providing opportunities to rest along routes.

In-vehicle technologies have also been developed that can detect fatigued drivers from the driver's current state and physiological or physical changes (for example, through eye and eyelid movements, yawning) and/or through driver performance (for example, vehicle lateral position and driver headway). A variety of technologies show potential in detecting driver fatigue, but large scale robust evaluations in real-world settings are required to determine actual crash reductions.

A.3.14 SPEED MONITORING

Speed monitoring systems detect when drivers are traveling above the posted speed limit. These systems provide feedback to drivers, and may also send alerts back to fleet managers (in the case of business and commercial drivers) or parents (in the case of novice drivers). In some cases, devices are fitted that "govern" or limit vehicles so that they can only travel within the existing speed limit. Trials have also been conducted of recidivist speeders, with monitoring and alerts provided to enforcement agencies. Speed monitoring devices have been found to be effective while in use and monitored during short duration trials,[132] although the longer term impacts on safety outcomes are not yet known.

A.3.15 INCREASED SEAT BELT WEARING RATES

See Section A.4.3.

A.3.16 INCREASED HELMET WEARING RATES

The proportion of motorcycle riders tends to be higher in many LMICs compared with HICs, and this is reflected in crash outcomes. In India, 27 percent of road deaths involve motorized two-wheelers, while this figure is around 60 percent in Malaysia and up to 90 percent in Thailand.[133] Head injuries are a common cause of fatalities and serious injury among this user group. Helmets help protect against such injuries and have been shown to produce significant safety benefits. The World Health Organization (WHO) reports that wearing a motorcycle helmet decreases the risk and severity of injuries by around 70 percent, and decreases the likelihood of death by up to around 40 percent[133] Recent U.S. research also points to the strong benefits from motorcycle helmet use through the existence and enforcement of helmet laws.[134]

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[130] Horne, JA & Reyner, LA (1995), 'Driver sleepiness', Journal of Sleep Research, vol.4, special issue no.2, pp.23-9.
[131] Ryan, GA, Cercarelli, LR & Mullan, N (1998), Road safety in the rural and remote regions of Western Australia, report RR64, Road Accident Prevention Research Unit, University of Western Australia, Nedlands, WA.
[132] De Leonardis, D., Huey, R., and Robinson, E. (2014), Investigation of the Use and Feasibility of Speed Warning Systems. National Highway Traffic Safety Administration, Washington DC.
[133] World Health Organisation, (2006), Helmets: a road safety manual for decision-makers and practitioners. Geneva. <http://whqlibdoc.who.int/publications/2006/9241562994_eng.pdf>
[134] Olsen, C. S., Thomas, A. M., Singleton, M., Gaichas, A. M., Smith, T. J., Smith, G. A., ... & Kerns, T. (2016). Motorcycle helmet effectiveness in reducing head, face and brain injuries by state and helmet law. Injury epidemiology, 3(1), 8

[135] [136] Similarly, bicycle helmets have been found to have substantial safety benefits. A number of systematic reviews on the effectiveness of bicycle helmets have identified benefits of between 50 and 88 percent reductions in head and brain injury.[137] [138] [139]

A.4 SAFE VEHICLES

A.4.1 INTRODUCTION

Vehicle safety improvements have led to significant changes in safety outcomes over the last few decades. These improvements were initially introduced to passenger vehicles, but are now migrating to heavy vehicles and even motorcycles. Beneficial vehicle improvements include active and passive safety devices. Active safety includes those systems that prevent a crash occurring in the first place, while passive features reduce the level of injury when a crash occurs. Systems include seat belts, air bags, crumple zones, stability control, and autonomous emergency braking (preventing rear-end, but also vulnerable road user collision). All of these features should be encouraged given the safety benefits they produce. This includes the need to adopt these features in vehicle standards, and in fleet purchasing policy.

Improvements to vehicle safety should form the basis of inspections systems, including for vehicles in use (private and commercial, and including motorcycles) and for the importation of new and used vehicles. The public and commercial sectors play an increasingly important role and can have substantial impacts through vehicle-purchasing specifications.

These individual safety features are captured as part of vehicle star rating (New Car Assessment Programmes, or NCAP, and used car assessment programs). Vehicles with a five star rating are the safest, and research has shown that this is reflected in real-world crash outcomes. A study based on the European NCAP data[140] found that 5-star cars had a 25 percent lower chance of fatal or serious injury compared to 2-star cars, while the chance of death was around 70 percent lower. Similar information from Australia indicates that there is twice the chance of being killed or seriously injured in a 3-star rated car compared to a 5-star rated car.

Safety is also a key issue for heavy vehicles, including those carrying freight and passengers. Additional features may be required for these vehicles, including under-run protection and blind spot mitigation. As identified above, advanced technologies are now beginning to benefit not just passenger vehicles, but also heavy vehicles. Maintenance is required to ensure vehicles remain safe, particularly in LMICs. Enforcement of mass and loading regulations is also very important. A degree of general deterrence should be created through enforcement to encourage appropriate loading and operation.

[135] Peng, Y., Vaidya, N., Finnie, R., Reynolds, J., Dumitru, C., Njie, G., ... & Sleet, D. A. (2017). Universal motorcycle helmet laws to reduce injuries: a community guide systematic review. American journal of preventive medicine, 52(6), 820-832.
[136] Lee, J. M. (2018). Mandatory helmet legislation as a policy tool for reducing motorcycle fatalities: Pinpointing the efficacy of universal helmet laws. Accident Analysis & Prevention, 111, 173-183.
[137] Attewell RG, Glase K, McFadden M. (2001), Bicycle helmet efficacy: A meta-analysis. Accident Analysis Prevention, 33:345–52.
[138] Thompson DC, Rivara FP, Thompson R. (2000). Helmets for preventing head and facial injuries in bicyclists. Cochrane Database Syst Rev 2000:CD001855.
[139] Olivier, J and Creighton, P (2017), Bicycle injuries and helmet use: a systematic review and meta-analysis, International Journal of Epidemiology, 46(1),278–292.
[140] Kullgren, A, Lie, A & Tingvall, C 2010, Comparison Between Euro NCAP Test Results and Real-World Crash Data. Traffic Injury Prevention, 11:587–593.

A.4.2 MINIMUM SAFETY STANDARDS

Vehicle design has the potential to decrease the number of crashes and crash severity by addressing the behavioral and physical limitations of road users and other traffic components. Vehicle safety involves four broad aspects,[2] First, through vehicle control mechanisms such as braking and steering. Second, innovations like autonomous braking, electronic stability control, Intelligent Speed Adaptation (ISA) helping the vehicle to avoid crush actively without driver action. Third, passive protection including seat belts and anchorages, “crumple zones”, airbags, and pedestrian protection mechanisms which provide better safety to occupants and pedestrians. Finally, emergency notification systems alert rescue services in case of crash involvement. “Active” safety technology (AST) generally acts by preventing the crash and lessening the severity, while “passive” safety technology (PST) reduces the effects of the crash.[141] Failure to maintain these systems may lead to crashes and may also increase the severity of the crashes and increased fatalities.[142] In case of developing countries, minimum safety requirements are still often overlooked even though the growth of motorization is four times than in developed countries.[143] Unfortunately, in some developing countries vehicles with the lowest safety standard are the best-sellers in the market.[144] It is estimated that vehicle defects may increase road crashes by up to 50 percent.[145] [146] [147] [148]

The United Nations (UN) Decade of Action for Road Safety identified that all countries need to address the minimum arrangements for vehicles, including seat belts and anchorages, occupant protection in frontal/side/lateral collision, pedestrian protection, and electronic stability control (ESC).[149]

A study in Latin America identified that basic improvements in vehicle design could reduce fatalities by up to around 30 percent.[150]

A.4.3 SEAT BELTS

Seat belt are one of the most effective safety interventions and can result in significant numbers of saved lives and reduced injuries if properly installed and used. Seat belts absorb energy during the crash impact and distribute it, including to stronger body parts of the vehicle occupants. They restrict users from impacting internal vehicle components, reduce the risk of being ejected from vehicles, and also reduce the risk of impacts from fellow passengers. Four types of seat belt are recommended: three-point lap and diagonal seat belt; two-point lap seat belt; single diagonal belt; and full harness.[151] The first two types are used in heavy vehicles (trucks and buses).

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[141] Isa, M.H.M., Kassim, K.A.A., Jawi, Z.M. and Deros, B.M., 2015. Promotion of active safety technologies in automobile safety ratings.
[142] Herbert, H. K., Hyder, A. A., Butchart, A., & Norton, R. (2011). *GlobalHealth: Injuries and Violence*. Infectious Disease Clinics of North America 25(3): 653–68.
[143] International Organization of Motor Vehicle Manufacturers, OICA (2015) Motorization Rate 2015 – Worldwide. Retrieved August 14, 2019 from http://www.oica.net/category/vehicles-in-use/
[144] Mock, C. N., Nugent, R., Kobusingye, O., & Smith, K. R. (Eds.). (2017).Disease Control Priorities, (Volume 7): Injury Prevention and EnvironmentalHealth. The World Bank.
[145] van Schoor, O., van Niekerk J. L.., & Grobbelaar, B. (2001). Mechanical failures as a contributing cause to motor vehicle accidents — South Africa, Accident Analysis & Prevention 33:pp. 713-721.
[146] Tanaboriboon, Y., Kronprasert, N., Khompratya, T., Suanpaga, V., Chanwannnakul, T., & Taneerananon P. (2005). An evaluation of the effectiveness of the private vehicle inspection process in Thailand, Journal of Eastern Asia Society for Transportation Studies 6:pp. 3482-3496.
[147] Boada, B. L., Boada, M. J. L., Ramirez, M., & Diaz, V. (2014). Study of van roadworthiness considering their maintenance and periodic inspection. The Spanish case. Transportation letters, 6(4), 173-184.
[148] Rechnitzer, G., Haworth, N., & Kowadlo, N. (2000). The effect of vehicle roadworthiness on crash incidence and severity. Monash University Accident Research Centre. Report nº 164. Retrieved August 15, 2019 from https://pdfs.semanticscholar.org/61de/d41a48afe8c2fed592010e7a48126c02c339.pdf
[149] UN. (2011). UN Decade of action for road safety 2011-2020.
[150] Bhalla, K., Gleason, K., 2020. Effect of Improvements in Vehicle Safety Design on Road Traffic Deaths, Injuries, and Public Health Burden in the Latin American Region: A Modelling Study
[151] WHO (2009), Seat-belts and child restraints: a road safety manual for decision-makers and practitioners, World Health Organisation, Geneva.

Seat belts reduce fatalities by 40-50 percent in the case of front car seat occupants and 25 percent for those in rear seats.[49] In the case of truck drivers, the fatality reduction is 27-77 percent.[152] Benefit-cost ratio could be as high as 31.7 for seatbelts.[49]

For younger children, child seats can be used to provide additional protection. WHO (2009)[151] reports significant benefits from use of child restraints, although this varied by type of installation and age of child. As an example, for a child up to 4 years of age there was a 50 percent lower risk of injury in a forward-facing child restraint, and an 80 percent lower chance in a rear-facing seat.

The fitting of seat belts and child restraints is obviously very important based on this evidence. However, it is equally important to ensure the use of these devices. This can be achieved through laws to make the use of these devices compulsory. It is recommended that any new law be accompanied by extensive public campaign and awareness programs prior to the change as well as appropriate levels of enforcement following the passing of the law.[151] There is strong evidence to show that a comprehensive program involving legislative change, education, and publicity campaigns to raise awareness, and sustained enforcement, produce significant increases in wearing rates with subsequent safety benefits.[151]

A.4.4 VEHICLE MAINTENANCE

Research in high income countries suggests that vehicle defects cause only a small proportion of road crashes (between 3 percent and 5 percent of crashes[153]). However, in LMICs the figures are generally much higher because the vehicle fleet is likely to be older, there may be less stringent vehicle standards, and vehicles may be less well maintained. This is likely for passenger vehicles as well as heavy vehicles which are used to move freight and passengers. Estimates are that vehicle defects might be a contributor to up to 50 percent of crashes in LMICs.[154] [155] It is therefore expected that systems to improve vehicle maintenance – particularly in LMICs – will produce road safety benefits. Methods include periodic vehicle inspection regimes and roadside maintenance checks (noting that these need to be conducted in a safe manner, preferably in an off-road setting with adequate safety facilities in place, including for vehicles leaving and entering the roadway). These inspections must be thorough, and penalties issued for transgressions must be unavoidable. Strong inspection schemes can lead to a decrease in road crash rates of up to 8 percent in HICs,[156] although benefits are likely to be greater in LMICs given the higher contribution of poorly maintained vehicles to crashes.

A.4.5 DAYTIME RUNNING LIGHTS FOR CARS AND TRUCKS

Daytime running lights (DRL) start when the engine runs. These have been widely used in countries where there is less light in daytime especially in winter, but are now increasingly being used in other locations. DRLs increase the visibility of vehicles during daytime so that other road users can see the vehicle more easily, resulting in enhanced reaction times. DRLs

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consume less energy than normal headlights. DRLs are relatively dim in comparison to headlights and so should not be used as an alternative to brighten the road ahead at night.

Evidence shows that using DRL may reduce multi-vehicle crashes by a small but significant amount (around 6 percent).[49] Crashes involving vulnerable road users can also be reduced. Experience from Nordic countries shows that mandatory use of DRL could increase the using rate up to around 85–90 percent.[49]

A.4.6 DAYTIME RUNNING LIGHTS FOR TWO- OR THREE-WHEEL VEHICLES

Two- and three-wheelers form a significant proportion of traffic in LMICs. In comparison to other vehicles such as cars and trucks, they are less visible, especially in heavy and complex traffic conditions. Also, lack of crash protection and difficulties to detect and assess their approaching speed make the two-and three-wheelers more crash prone. DRLs are an effective solution to increase visibility.

A small but significant reduction in crashes (7 percent[49]) has been reported when using DRLs by two-wheelers with a positive benefit-cost ratio.

A.4.7 UNDER-RUN GUARDS ON TRUCKS

Under-run guards on trucks or trailers prevents cars or other traffic from falling, sliding, or driving below the truck or trailer and being run over by the rear wheels (Figure A.22).

Figure A.22: Side under-run guards on truck.
(Source: www.drivingtests.co.nz/resources/what-is-side-underrun-protection-on-a-truck-or-trailer/)

Due to height and size differences with other traffic, trucks or trailers can cause severe crash outcomes. To protect more vulnerable road users and reduce damage to immoveable road side objects, side under-run protection devices (or lateral protection devices) can be helpful. Similarly, rear under-run protection devices (RUPD) prevent cars and other traffic from similar damage beneath the rear of trucks. In both cases, this high-strength structure absorbs collision energy and gives protection to other road users. The surfaces of the protective device should be smooth and potential overlapping edges should face rearwards or downwards.

One estimate suggests that these devices can reduce fatalities by up to 29 percent with a benefit-cost ratio of 3.9:1[49].

A.4.8 ELECTRONIC STABILITY CONTROL

Electronic stability control (ESC) is one of the most important vehicle safety innovations, offering significant safety benefits. ESC is a comprehensive system that detects any loss of control and applies the needed braking pressure to specific wheels to keep the vehicle on the intended path. Anti-lock braking systems (ABS) and Traction control are the integral part of this system.

ESC can reduce fatal crashes by up to 67 percent[157] [158] and produce up to an 88 percent[159] reduction in loss of control situations. Moreover, ABS shows fatality reduction for vulnerable road users[160] including fewer motorcycle deaths (21 percent) and pedestrian deaths (8.5 percent).

A.4.9 ADVANCED VEHICLE TECHNOLOGIES INCLUDING FULLY OR PARTIALLY AUTOMATED VEHICLES

Vehicle technologies are improving rapidly with a big shift to systems that provide partial vehicle automation, particularly in HICs. Technologies that allow fully automated control are also in development. The introduction of these modern technologies will improve safety through reducing driver-related risk factors. Various levels of automation exist and these are generally classified in five levels ranging from level zero with no automation to level four where a vehicle will drive itself without human assistance.[161] These technologies may include advanced crash warning systems, adaptive cruise control (ACC), lane keeping and lane departure systems, self-parking technology, and other technologies.[162]

Research suggests that autonomous vehicles (AVs) have the potential to significantly reduce the number of crashes caused by the drivers through the gradual removal of human control.[163] Although estimates vary greatly, at the maximum end of predictions it has been argued that self-driving cars will reduce 90 percent of crashes because driver error contributes to more than 90 percent of crashes.[164] In a simulation-based study, it was observed that AVs reduce the number of conflicts by 20 percent to 65 percent for signalized intersections, whereas in the case of roundabouts, the number of conflicts is reduced by 29 percent to 64 percent.[165] There are several major challenges to be addressed in order to achieve these promised levels of safety, including issues of road user acceptance of technologies, and situations where vehicle control needs to be passed back quickly to a human operator. Similarly, AV

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software/systems can malfunction, with even a single flaw leading to crashes.[166] Hence, it is necessary to better understand the road safety aspects of this technology in different road and traffic settings. In the meantime, some of these individual emerging technologies are likely to produce significant safety benefits in the short to medium term. Autonomous driving and some of the advanced safety features may be quite a way off in some countries, particularly in LMICs. This is because some of the systems rely on road infrastructure to effectively operate. For example, lane keeping systems require high quality line markings. It is also likely that issues such as lower capacity for vehicle inspection and maintenance for these advance vehicles will inhibit effective uptake of these technologies.

[166] Anderson, J.M., Nidhi, K., Stanley, K.D., Sorensen, P., Samaras, C. and Oluwatola, O.A., (2014). Autonomous vehicle technology: A guide for policymakers. Rand Corporation.

A.5 POST-CRASH CARE

A.5.1 INTRODUCTION

Fatal and serious outcomes are directly related to how injuries resulting from road traffic crashes are handled immediately after the incident occurs, as well as on-going care and rehabilitation. Other means for improving the effectiveness of post-crash response care include the training of first responders (including community members) and emergency medical services staff, and provision of adequate equipment for emergency response units and trauma units within hospitals. Training needs to be comprehensive and follow best practice principles.

A.5.2 SYSTEMS TO IMPROVE EMERGENCY RESPONSE TIME, INCLUDING DEDICATED PHONE NUMBERS AND LOGISTICAL SUPPORT

Around half of all road traffic deaths occur almost immediately following a crash.[167] [168] [169] [170] Poor post-crash care including slow response times means victims may needlessly die at the scene or during the first few hours following the injury.

A key concept in post-crash care is "the Golden Hour" and the "Platinum 30 Minutes". These both highlight the importance of the immediate period following injury where there is the highest likelihood that prompt medical treatment will prevent death as well as potential for long term disability. Therefore, providing faster response times for first medical responders will bring safety benefits. Systems to improve the response time include establishing a national call number, better logistical coordination of response, and improved telecommunications.[171]

A.5.3 IMPROVED EMERGENCY RESPONSE CARE

Emergency Medical Service (EMS) systems are vital to reducing fatalities and injury severity. This begins with the activation of the emergency care systems, and includes care at the scene, transport, and facility-based emergency care.[172] The WHO highlights the need for well-equipped ambulances with trained staff to assist with uninterrupted transfer of crash victims.[173] They also highlight the need for immediate and long-term rehabilitation to limit the impact of injury.

A systematic review of prehospital trauma systems in developing countries concluded that proper implementation of prehospital care can reduce fatalities by 25 percent. [174]

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A.5.4 IMPROVED FIRST AID SKILLS FOR THE PUBLIC

Providing first aid training to the community is a useful first step in developing EMS systems where there is a lack of formal prehospital facilities.[175] [176] This training increases knowledge, skills, and willingness to attend to victims as a first responder. If the crash victim receives this early care in the first few minutes following a crash, fatalities or crash severity can be reduced.[177] [178] Experience in LMICs supports this finding.[179] [180] In addition, training the public on making emergency calls can be beneficial, with one study identifying a BCR of 19[181] from this initiative.

A.5.5 IMPROVED HOSPITAL CARE

Inadequate trauma care infrastructure has an important detrimental role in death and disability.[182] There is evidence that many crash victims die during treatment due to inadequate facilities[183] [184] as well as suboptimal care.[185] If patients can be placed at an appropriate trauma center directly, survival rates are likely to improve.[186] A properly equipped trauma care center with appropriate infrastructure, trained personnel, and adequate equipment and supplies is vital to increasing the survival of crash victims.[187] [188] To obtain the best safety outcomes, health facilities which treat trauma patients should have a dedicated, well equipped accident and emergency (A&E) unit.[185]

There is evidence that the treatment of road crash trauma is more effective in a dedicated trauma center compared with other traditional hospital settings.[189] [190]

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