7. DESIGN TOOLS FOR SAFE OUTCOMES

7.1. Introduction

As identified in section 1.3, existing road design guides are generally technically sound and are essential for the design process, but they will not enable designers to achieve safety outcomes on their own. Even designing strictly to existing guides will result in designs that allow death and serious injury. It is therefore very important that additional tools and processes be used to ensure that road safety objectives are met through the life cycle of a road or network. In response to knowledge on this issue, various approaches have been developed over time to help ensure safety is adequately considered throughout the life cycle of a road.

The comprehensive approach to the safe design, operation, maintenance, and use of roads is generally referred to as Road Safety Infrastructure Management. This is described in the EU standard, the EU Directive 2008/96/EC, as well as the PIARC Road Safety Manual, among other sources. The objective of road safety management is to integrate all road safety activities throughout the design and operation of an individual road or network such that a systematic approach is taken to reducing death and serious injury.

Examples of safety techniques used at each stage of the road life cycle are provided in figure 7.1, while details for these are provided in section 7.3.

Figure 7.1: Road safety techniques for different stages of the road life cycle.

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The strategies implemented in road traffic safety management can include both reactive and proactive approaches.

- A reactive approach to road safety is associated with the identification of locations experiencing safety problems (screening), problem definition (diagnosis), and the identification and implementation of countermeasures (cure) from a detailed examination of crash data. Road safety improvements are proposed in response to identified safety problems brought to light by crashes that have occurred after the road has been designed, built, and opened to the travelling public.

- A proactive approach to road safety is associated with the prevention of safety problems before they manifest themselves in the form of a pattern of crashes focusing on what is known about the impact of different situations, road features, and treatments on road safety injury or crash outcomes. The proactive approach applies this knowledge to the roadway design elements or to improvement plans on existing roads to diminish the likelihood and severity of crashes.

Years of experience in crash analyses and treatment of crash locations has improved the understanding of the road and roadside elements that contribute most to crash risk, and the amount that each of these elements contribute to that risk, making the proactive approach more generally applicable. The reactive and proactive approaches are often used in combination with the emphasis shifting from one to the other, depending on the maturity of the overall safety management processes in an organization or nation, or even in different road environments.

As an example, for a rural route with high numbers of run-off-the-road crashes, it is desirable that all potential high severity locations be treated, regardless of whether crashes have happened there yet or not (the route-based approach is described in later sections of this guide). This is in contrast to a crash-based analysis that addresses just those points on the road where crashes have previously occurred. Equally risky locations (in terms of road and roadside features) should not be ignored.

Whichever approach is used, it is necessary to identify safety deficiencies that need to be investigated to diagnose safety problems, and then identify and implement countermeasures or design improvements to remedy the deficiencies before they create serious harm to road users.

In order for these deficiencies to be addressed effectively through the design process, there must be some form of performance measure of the effectiveness of the design to achieve safety outcomes, in the same way as key performance indicators (KPIs) are applied to other design aspects.

### 7.2. Road Infrastructure Safety Performance Indicators

Road Infrastructure Safety Performance Indicators (SPIs) are any measurement that is causally related to crashes or injuries, and can be used in addition to the figures of crashes or injuries in order to indicate safety performance or understand the process that leads to crashes. Road Infrastructure SPIs aim to assess the safety hazards by infrastructure layout and design (e.g., percentage of road network not satisfying safety design standards).

The inclusion of performance indicators is common practice within major infrastructure projects. They are quantifiable measures of performance over time and provide targets for teams to aim for, milestones to gauge progress, and insights to help organizations make better decisions.

“**What gets measured gets done.**”

Managing with the use of performance indicators includes setting targets (the desired level of performance) and tracking progress against that target. Historically, specific performance indicators to reflect safety outcomes have seldom been applied in road design. At best, phrases such as “improved safety
outcomes” are used when defining project objectives, but these are not measured in any tangible way. With the development of better assessment techniques for safety in design, and even the quantification of safety impacts from design decisions, there is now the ability to better specify safety outcomes in design.

A recent survey by the World Road Association (PIARC)\(^{165}\) highlighted that there are four categories of performance indicators that are typically used to improve safety for road infrastructure projects. These are:

- The number or percentage of the network that was subject to a road safety audit or inspection (for example, South Africa has an objective based on the extent of the network assessed).
- The international Road Assessment Programme (iRAP) targets (for example, percent of travel on three-star roads or better; see below for information on targets 3 and 4 from the voluntary road safety targets relating to road infrastructure).
- Targets relating to provision of additional safe infrastructure by length of road (for example, Estonia has targets from kilometers of infrastructure installed for central and roadside barriers and centerline rumble strips).
- Provision of additional safe infrastructure as a percentage of the network (for example, Norway set targets to 2018 for the percentage of motor vehicle traffic on national roads with speeds of 70 km/h or higher with median barriers).

For many years, the conduct of a road safety audit has been specified as part of the road design process in many countries to assess road safety of a scheme from the perspective of all road users. This is especially the case for larger projects. This process requires designers to consider safety improvements without any quantifiable objective. However, with the advent of models that quantify safety outcomes, including from design, it is now possible to specify safety outcomes in a more objective manner. The models (some of which are outlined later in this section) can provide reasonably accurate accounts of likely safety outcomes in terms of fatal and serious injuries (the key crash types that need to be eliminated under the Safe System approach). These models can also be used to set a threshold level in regard to crash risks. In theory, it is possible to specify that design should not result in death or serious injury.

In recent years, a large number of models have been developed to help assess the impact of designs on road safety outcomes. Some of these have been developed for specific countries or environments, while others have more general application. Some have been devised for specific application in low- and middle-income countries (LMICs) or can be adapted or readily used in these countries. The earlier such tools can be applied in the design process the better. Changes to design are likely to be more feasible and will generally be at lower cost if they are incorporated before the design is completed.

In 2016 the UK Transport Research Laboratory (TRL) identified and reviewed 21 such models used internationally for identifying affordable and appropriate engineering-based solutions to improve road safety on rural road networks,\(^{166}\) while some of the more recent models are included in the descriptions that follow.

Alternatively (or in addition), the types of safety provisions to be included in designs for different road types can be specified. For instance, it may be that for high-speed, high-volume roads vehicles travelling in different directions must be separated by an appropriate central barrier system. Some countries are now developing safe cross sections for new roads, and as part of upgrades that embed this type of thinking, so as to provide safe infrastructure outcomes. These types of performance indicators (whether based on crash outcomes, infrastructure characteristics, or defined stereotypes) are typically set at country or

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regional/state level and should ideally be linked to road safety strategy and funding capability.

Relevant infrastructure-based performance measures have been established globally. Many governments have included road safety targets in support of the Sustainable Development Goals (SDG’s), which were adopted by all United Nations member states in 2015. This led to the development of voluntary global road safety performance targets. 167 Two of these targets relate specifically to safe road infrastructure (figure 7.2). Target 3 states that “by 2030, all new roads achieve technical standards for all road users that take into account road safety or meet a three-star rating or better.” Target 4 declares that “by 2030, more than 75 percent of travel on existing roads is on roads that meet technical standards for all road users that take into account road safety.”

The use of one or more of these types of performance indicators is highly recommended as part of national transport policies as well as at project levels during design. A recent study has identified that application of safety metrics as part of the design process can double the safety benefits (or halve the number of deaths and serious injuries), often at little or no additional cost. 168

7.3. Infrastructure Tools and Techniques

This section contains introductory information on some of the road safety infrastructure tools and techniques that can be used to assess risks and identify solutions. In general, the earlier such tools can be applied in the design process, the better. Early changes to design are likely to be more feasible and will generally be at lower cost. The tools included are those most likely to be used by road designers. Examples of the most common tools are included as well as information on some promising emerging tools. These are presented in the same order as they appear in figure 7.1.

Road safety impact assessment

Being able to explicitly estimate the impact on road safety that results from building new roads or making substantial modifications to the existing road infrastructure that alter the capacity of the road network in a certain geographic area is of crucial importance if road safety is not to unintentionally suffer from such changes. The same applies to other

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schemes and developments that have substantial effects on the pattern of road traffic. The procedure that has been designed for this purpose is known as road safety impact assessment (RSIA) (Wegman et al. 1994).

This procedure is intended to be applied at the planning stage, often proceeding to a definite design for the scheme. A safety impact assessment thus precedes and complements the eventual safety audit of any specific design for the scheme.

A scenario method is used to carry out an RSIA. The starting point is the existing road network, the current pattern of traffic on that network, and the level of reported road injury collisions within the area. Current traffic patterns include usage for all users—motorized and nonmotorized—although nonmotorized travel data are notoriously difficult to access at the same level as motorized data. It is helpful, though not essential, to have all this information represented in a digital form within a geographic information system (GIS).

The information needed relates to a road network which is made up of roads of several types that have different road safety characteristics. Each road consists of junctions and stretches of road between the junctions, with associated traffic volumes for each user group, and the number of collisions and casualties.

Alternative scenarios to this current situation are the possible changes being studied in respect to the physical infrastructure and the associated traffic volumes in the road network in the future. If, for example, a new road is to be added to the existing network, the traffic and transport models can be used to estimate what this will mean for the traffic volumes throughout the network in the future.

The central step is to interpret these changes in terms of the impacts they will have on the numbers of crashes and casualties. To accomplish this, what are needed are quantitative indicators of risk (such as casualty rates per million vehicle-km) for each type of road and user, supplemented, if possible, by corresponding indicators for each main type of junction. One way of obtaining such indicators is to estimate them at a national level and adjust them if necessary, using data for the area in question. In addition, thought should be given to any expected changes over time in the level of risk for each type of road or junction. These kinds of information enable safety impacts to be estimated for the duration of the road’s life cycle.

If the various data are accessible from a computer, calculations of safety impacts for a range of scenarios and comparisons between impacts of different scenarios can be made quite readily. The procedure can be adapted to help identify what changes are needed in a given scenario in order to bring the safety impact within some target range.

When implementing this scenario technique, it is important to bear in mind the quality of the information being used. It is also important for the information to be accessible in such a way that calculations for a range of scenarios can be elaborated at relatively modest costs within a short period of time. For this purpose, the traffic and transport models should be set up in such a way that an RSIA module to apply the relevant indicators of risk for future years can be readily linked with them. This requires a higher proportionate investment in safety features in LMIC designs to achieve these comprehensive improvements.

Adopting this sort of methodology of risk assessment allows consideration to be made of future land use changes and the potential for the land use changes to encroach on the road corridor and change the consequent function and safety risk. Additionally, it allows for opportunities to influence road user behavior by introducing cycle ways and footways to encourage sustainable travel modes—many of which are initially lacking in LMICs and need the additional consideration to develop comprehensive networks.

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Road safety audit

Road safety audits have been applied to road design projects for several decades and are a well-established approach in high-income countries (HICs) as well as LMICs. A large number of experts have been trained in the application of this approach, and there is broad industry understanding of the benefits from applying such audits.

The road safety audit (RSA) process involves independent teams of experts assessing designs at one or more stages of project development through a formal process to identify safety-related risks. The sooner that an audit is undertaken in the design process, the greater and easier the safety benefits are to achieve. Road safety audits are not a check of compliance against design standards (as identified in section 1.3, compliance with such standards does not guarantee a safe design). These teams of experts review designs and make assessments on safety impacts for all road users based on experience. Road safety issues are documented, and a priority for addressing these issues is typically given. It is expected that designers would address each of these issues wherever practicable.

Given the broad international adoption of road safety audits, a large number of guidance documents exist on how to conduct audits, including from the UK, Australia, the US, Africa, Asia, and the World Road Association (PIARC). The process outlined in each of these documents is broadly similar.

Assessments of the benefits of road safety audits have identified that the process produces positive outcomes and often for very low costs. For example, benefits of recommendations made through the audit process in a study from Australia found that 75 percent of recommendations implemented had benefits that far outweighed costs by a factor of 10 to 1. The costs for undertaking audits form only a small additional cost, estimated at around 4 percent of total design cost (noting that the design cost is only a small component of overall project costs when compared to construction), while the costs for implementing the recommended changes were also often low (65 percent of recommendations had a cost < US$1,000).

Although road safety audits can lead to substantial road safety benefits, this will only occur if audits are conducted correctly by an experienced team. Audits, especially extensive ones, can also lead to a large number of recommendations which can be difficult for designers to address. However, audit recommendations could be classified under different priorities based on the potential safety risk and the cost of treatment to address them. This prioritization is a decision for the design team, as the audit only deals with safety considerations. Finally, the biggest barrier to successful audit outcomes is that recommendations are often not addressed, and so a strong process is required to ensure that this stage occurs, including that decisions by the design team in response to audits are well documented.

Efficiency assessment

Budgets for transport in general and for road safety in particular should be spent as optimally as possible. Efficiency assessment (EA) tools (e.g., cost-benefit analyses) determine the effects for society of a given investment, for instance in road safety, in order to prioritize investment alternatives.

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170 http://www.standardsforhighways.co.uk/dmrb/search/710d4c33-0032-4dfb-8303-17aff1ce804b.
A full cost benefit analysis is an extremely demanding task to perform properly. It requires all significant monetized costs and benefits to be assessed, typically over a scheme’s lifetime. It should include annual maintenance costs, all environmental and social impacts, and all costs need to be moved into a single base year value, and GDP growth across the assessment period needs to be taken into account. It is an in-depth process that can require significant effort and so may not be suited to smaller schemes.

The simplest method for carrying out EA is called cost effectiveness (CE). In CE the cost that needs to be expended for each crash saved in alternative and competing schemes is estimated to help with the prioritization of investments. The approach is commonly applied to the treatment of small improvements or high-risk sites and assesses the whole program of design alternatives that are to be applied rather than assessing the cost effectiveness of an individual scheme.

The main parameters required are:

- The number of crashes per year over a fixed period of years; generally for three to five years,
- The estimated effectiveness of each scheme as an expected reduction in crashes after implementation, and
- The total estimated cost of the proposed schemes.

This gives a value which represents the cost required to save a single crash for each proposed scheme. The potential schemes can be ranked by the calculated CEs in descending order, and those schemes with the smallest values should be implemented preferentially.

A First Year Rate of Returns (FYRR) is commonly used for appraising low-cost schemes. In this method crash costings are required in addition to the parameters required to do a CE. The approach requires the treatment cost to be calculated, the average crash cost, and an estimate of savings.

The simplest FYRR will be estimated as:

$$\text{FYRR} = \left(\frac{100 \times \text{annual casualty saving} \times \text{casualty cost}}{\text{scheme cost}}\right)$$

The largest variable is the estimated effectiveness which relies on a robust understanding of the effectiveness of safety interventions.

The effectiveness of any safety interventions that are implemented relies heavily on the appropriate application of those measures to treat a specific problem. This can only be determined through a thorough understanding of the underlying factors determined from intensive examination of crash data and thorough monitoring of each implemented measure. Internationally, this is one activity that is not undertaken as diligently as it should be. Therefore, any potential savings claimed for particular treatments must be taken with extreme caution unless robust evidence of their effectiveness in truly comparable situations is available. Without monitoring and evaluation, much of the claimed benefit could be the result of statistical variation from purely random events.

**Road Safety Screening and Appraisal Tool**

The World Bank and GRSF have developed a Road Safety Screening and Appraisal Tool (RSSAT) that assesses the road safety impact of projects, both in relative terms (comparing risks with and without project) as well as absolute risk terms. The user-friendly RSSAT produces a metric called Project Safety Impact (PSI), which is the ratio of road traffic fatalities with project to without project. It also assigns a road safety risk level for the existing situation as well as the project scenario based on the number of fatalities, and finally it presents the monetized road safety costs/benefits over the analysis period of the project. The PSI is generated by taking account of crash reduction benefits from physical attributes, the operating speed, and traffic volumes (including for nonmotorized traffic) as shown in figure 7.3. The RSSAT can be used early during project preparation to test various road
design scenarios and make an early informed decision on the safest cross-section design.

The current version of the RSSAT (v1) is only based on road design features, speed, and traffic flow composition. However, with additional effort this tool can be extended to include other road safety interventions related to road user risk factors (e.g., seat belt use, enforcement compliance, etc.), vehicle safety, and so on. The RSSAT is meant to be used for projects involving maintenance, rehabilitation, or reconstruction/upgrade of existing roads, including lane expansion or change from gravel to paved surface. The RSSAT can be applied for roads that are classified as rural roads, inter-urban highways, access-controlled expressways, and urban roads, including arterials. It is not intended to be used for the construction of new roads (e.g., greenfield projects) nor for mass rapid transit projects (Bus Rapid Transit (BRT), Light Rail Transit (LRT) or Mass Rapid Transit (MRT)).

**Star rating for design (SR4D)**

The iRAP methodology (described below) can be used to help assess the safety of road designs and to identify ways to improve this design before roads are constructed or upgraded. One of the ways that this can be performed is by using the SR4D web app developed by iRAP with funding support from the GRSF.

The process can be applied by any suitably trained engineer or road safety practitioner and is easily incorporated into the road design process. SR4D provides an objective “star rating” for each road user type (pedestrian, vehicle occupant, motorcyclist, and cyclist) based on different road design elements that are drawn from proposed designs and coded by users. Key design elements are selected with a click from a menu of options.
Figure 7.4: Intersection selection options for SR4D.

For example, figure 7.4 shows various options for intersection type, quality, and intersecting road volume. Once design elements are selected, the tool uses the iRAP method to generate a risk score or star rating, an approach that provides repeatable qualification of road user risk. In addition to the star ratings, the method can also be used to produce statistics on various safety-related road attributes (such as percentage of road or design with good quality pedestrian crossings); estimates of the numbers of fatalities and serious injuries associated with the designs, including identification of locations where numbers are likely to be highest and lowest; and Safer Roads Investment Plans (SRIP) that list safety countermeasures that could be viably added to the design to improve safety within a specified budget. Star ratings can be used to set an objective “pass mark” for designs, and their use is consistent with broader performance targets that can be set as part of a wider strategy as described in the previous section above.

Safe System Assessment Framework

The Safe System Assessment Framework (SSAF) is a tool that assesses project designs to determine the likelihood of fatal and serious injury outcomes. The tool is mainly concerned with the safe road and safe speed pillars of the Safe System, but usefully also provides prompts for designers to consider relating to the other pillars (road user, vehicle, and post-crash care) that they may influence to help achieve safe designs. An assessment can be made of projects (or project elements) to determine the impact on fatal and serious outcomes from design decisions. It also helps identify changes that might be applied to bring designs into closer alignment with Safe System outcomes.

The framework breaks designs down into basic elements, comprising the key crash and road user types that result in fatal and serious injury outcomes. These crash types are:
Run-off-the-road,
Head-on,
Intersection,
Rear-end and other,
Pedestrian,
Cyclist, and
Motorcycle.

Each of these crash types is assessed based on different components of risk, which are

- Exposure,
- Likelihood, and
- Severity.

An estimate is made of the contribution for each of these risk types against each of the key crash types. A subjective scale between 0 and 4 is applied, with 0 indicating that there is minimal contribution, and 4 indicating a high impact on poor safety outcomes.

**Figure 7.5:** Safe System Assessment Framework matrix.

<table>
<thead>
<tr>
<th></th>
<th>Run-off-road</th>
<th>Head-on</th>
<th>Intersection</th>
<th>Other</th>
<th>Pedestrian</th>
<th>Cyclist</th>
<th>Motorcyclist</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure</strong></td>
<td>AADT, length of road segment</td>
<td>AADT, length of road segment</td>
<td>AADT for each approach; intersection size</td>
<td>AADT; length of road segment</td>
<td>AADT; pedestrian numbers; crossing width; length of road segment</td>
<td>AADT; cyclist numbers; pedestrians</td>
<td>AADT; motorcycle numbers; length of road segment</td>
</tr>
<tr>
<td><strong>Likelihood</strong></td>
<td>Speed; geometry; shoulders; barriers; hazard offset; guidance and delineation</td>
<td>Geometry; separation; guidance and delineation</td>
<td>Type of control; speed; design; visibility; conflict points</td>
<td>Speed; sight distance; number of lanes; surface friction</td>
<td>Design of facilities; separation; number of conflicting directions; speed</td>
<td>Design of facilities; separation; speed</td>
<td>Design of facilities; separation; speed</td>
</tr>
<tr>
<td><strong>Severity</strong></td>
<td>Speed; roadside features and design (e.g. flexible barriers)</td>
<td>Speed</td>
<td>Impact angles; speed</td>
<td>Speed</td>
<td>Speed</td>
<td>Speed</td>
<td>Speed</td>
</tr>
</tbody>
</table>

Source: Austroads.

Road Safety Inspection

A road safety inspection (RSI) is a systematic review of the safety provision on an existing road, in particular in relation to the provision and hazards associated with traffic signs, roadside features, environmental risk factors, and road surface condition. RSIs are based on similar approaches as Road Safety Audits (RSAs). The key difference between RSIs and RSAs is that RSAs are carried out on new or rehabilitation schemes where design teams are in place and RSIs are undertaken on existing roads where no proposals are yet in place for improvement. An RSI is a proactive approach that involves a systematic review of an existing road by driving and walking to identify hazardous conditions, faults, and deficiencies in the road environment that may lead to road user injury.

High-risk sites

Identification and treatment of high-risk sites use crash and road usage data to understand road safety issues. Depending on the quality and details recorded in crash data, several different types of analyses may be undertaken, each with a differing level of granularity:

- Specific site analysis is undertaken to identify locations across the network where a concentration of crashes have occurred. These are then investigated in detail to understand the nature of the crashes, and a site visit is undertaken. A remedial treatment program is then designed and implemented.
- Corridor/route analysis is undertaken to identify stretches of roads that perform badly. These can then be investigated, inspected, and a treatment program developed.
- Area analysis is undertaken to understand the types of crashes occurring in an area which may be more widespread than for a single site or route.

Once identification has been undertaken, sites can be prioritized to maximize casualty reduction for the available budget.

Network Safety Ranking

Network Safety Ranking (NSR) is a method defined in Article 5 of EU Directive 2008/96/EC for identifying, analyzing, and classifying parts of the existing road network according to their potential for safety development and crash cost savings. NSR looks at an existing road network to identify potential safety problems and is thus a possibility for safety development.\textsuperscript{179} NSR is based on crash data and draws extensively on a calculation of different parameters, like crashes per km, number of crashes per vehicle km, or crash cost rates.

Depending on the parameters used, additional data, such as traffic or infrastructure data might be necessary. Different sections of a road network can be ranked and prioritized according to the criteria that “investments in road safety will have the greatest impact.” It can also lead to further steps like conducting an RSI before costlier (e.g., infrastructural) measures are applied.

A general definition or procedure of how to segment a road network does not exist. Usually one section should have homogenous characteristics, e.g., in terms of geometric design, density of traffic, road users, or adjacent environment. Junctions may have to be considered separately. Which type of indicator is chosen for ranking has to be decided in each case and may also depend on the data available.

Road Assessment Programmes

These involve the collection of road characteristics data which are then used to quantify risk, identify safety deficits, or determine how well the road environment protects the user from death or serious injury when a crash occurs. There are a number of such programs globally, each of which falls under the broad banner

of the international Road Assessment Programme (iRAP).\(^{180}\)

Star ratings are calculated based on road design and other elements that impact safety outcomes. Star Rating Scores are an indication of the relative risk of death and serious injury for an individual road user, and are based on factors such as crash likelihood, severity, operating speed, and traffic flow. A risk score is generated using an algorithm, and this in turn is based on an international evidence base on crash risk.

A star rating of 1 indicates that the road is of poor quality, while a rating of 5 means that the road is of high quality from a safety perspective with a low chance of death or serious injury to road users. Star ratings for different types of road users (vehicle occupants, pedestrians, cyclists, and motorcyclists) are also generated.

Policy objectives have been set in a number of countries relating to this star rating, including for Sweden, the Netherlands, Malaysia, New Zealand, China, Chile, Australia, and the United Kingdom. As an example, as part of the National Road Safety Action Plan 2018–2020, the Australian government included an action to improve the star ratings across the whole road network, with the aim to achieve 3-star AusRAP ratings or better for 80 percent of travel on state roads, including a minimum of 90 percent of travel on national highways. In order to support these national policy objectives, project designs can be assessed to determine the star rating of individual designs. The iRAP star rating for designs tool (SR4D, see above) has been developed for this task.

Specific design proposals are then developed that can reduce the risk of future injury and collisions. A number of tools are available to assist in the evaluation of risk and potential effectiveness of treatments, including the iRAP software tool VIDA.

**Further Reading**


African Development Bank. 2014. Road Safety Manuals for Africa:

1. New Roads and Schemes Road Safety Audit
2. Existing Roads—Proactive Approaches
3. Existing Roads—Reactive Approaches

\(^{180}\) www.irap.org.
8. KEY REFERENCE DOCUMENTS
