ROAD SAFETY MANUAL
A GUIDE FOR PRACTITIONERS!

PLANNING, DESIGN & OPERATION

RISKS & ISSUE IDENTIFICATION

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World Road Association (PIARC)

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10. ASSESSING POTENTIAL RISKS AND IDENTIFYING ISSUES

KEY MESSAGES

- Assessment of risk should be undertaken for the entire road network for which the road agency is responsible. In many countries, a small percentage of roads account for a large percentage of deaths and serious injuries. At programme level, the task is to identify such routes and address these as a priority.
- There are established approaches for identifying high risk crash locations – but training of key staff is required.
- Assessment of crash data should be undertaken to identify high risk locations (where data is available). Good quality crash data is required to identify crash-based locations.
- Proactive approaches should also be adopted – especially for major road corridors – including impact assessment, road safety audit, safety inspection, and road assessment programmes.
- Where crash data is not available, these proactive approaches must be adopted while collection of crash data commences.
- Proactive approaches should be used in combination with crash data where this is available. This combination of approaches provides a full assessment of road safety risk.
10.1 INTRODUCTION

This chapter discusses methods for identifying high risk locations, and the ways that different sources of data can be analysed to assess the causes of this risk. The assessment of potential risks and identification (or ‘diagnosis’) of issues are the first steps of the risk assessment process introduced in Infrastructure Safety Management: Policies, Standards, Guidelines and Tools (Figure 10.1).

Figure 10.1 Assessing risk and identifying issues within the risk assessment process

The traditional approach used in the identification of risk is the analysis of historical crash data. This approach is still very relevant, but in recent years there has been recognition that other sources of information should also be used in the risk assessment process. This broadened proactive approach is important in all countries, but particularly in LMICs where crash data may be of poor quality. Proactive approaches are being increasingly used in HICs to supplement historical crash data. Although this chapter is structured to present separate information on each approach, it is very important that both proactive and reactive approaches be used in the assessment of risk.

The focus of this manual is on the elimination of death and serious injuries, as these are the crash types that have the greatest societal impact. However, identification of high risk locations involving death and serious injury does not just involve analysis of fatal and serious injury crash data. Other sources of information can also be used to identify likely locations where serious injury or death may occur.

The following section provides brief information on project- and programme-level approaches to risk assessment, while Crash-based Identification (‘Reactive’ Approaches) discusses crash-based methods for identifying and assessing risk. Proactive Identification provides information on the proactive approaches, including impact assessment, road safety audit and road safety inspection Combining Crash Data and Road Data brings both the reactive and proactive approaches together to discuss an integrated approach to assessing risk.
HOW DO I GET STARTED?

Guidance documents on the assessment of risk are available, and should be adopted by all countries and embedded within core business. Training in the use of the following tools should be provided:

- treatment of high crash locations (see Crash-based Identification (‘Reactive’ Approaches))
- impact assessments
- road safety audits
- safety inspections
- road assessment programmes (each is described in Proactive Identification).

As a priority, assessment should be undertaken on high risk routes and corridors (see Belize case study in Box 10.1), utilising crash data were available (Crash-based Identification (‘Reactive’ Approaches)) as well as information on safety-related road elements (e.g. through safety audit and road assessment programmes – see Proactive Identification).
10.2 PROGRAMME-LEVEL AND PROJECT-LEVEL APPROACHES

Road agencies typically allocate funding to improve high risk locations, whether based on crash history or on the potential risk. This funding may take the form of dedicated funding for high risk locations and/or be embedded in other operating budgets (for example, major projects or asset management). Most actions undertaken by a road agency have a safety impact, whether they are initiated for safety reasons or not. If consideration of safety is included in all decision-making, safety risk can be reduced, often at little or no additional cost. The assessment of risk needs to occur at the programme and project level, and the advice provided in this chapter is relevant to both.

Assessment of risk should be undertaken for the entire road network for which the road agency is responsible. Such an approach would require a network-wide assessment of risks and issues. The outcomes of such an approach would identify key crash types, trends, geographic regions or areas, deficiency types, etc., with the outcomes of this assessment informing programmes of work.

It is often the case that a small percentage of roads account for a large percentage of deaths and serious injuries. At the programme-level, the task is to identify such routes and address these. For those countries with limited resources or that lack adequate data across the whole network, such locations are the most important to assess. These locations can form the basis of a corridor demonstration project. The content from this and the following chapters can be used as a guide to the assessment of risk across networks or along corridors. The examples below provide information on the corridor approach in Belize (Box 10.1) and in New South Wales, Australia (Box 10.2)

BOX 10.1: CASE STUDY - CORRIDOR APPROACH TO RISK ASSESSMENT, BELIZE

The problem: As identified in the Case Study in Linkage with other Policies, Standards and Guidelines in General Principles of Infrastructures Safety Management, although Belize is only a small country, it recorded 70 road traffic deaths in 2009, equivalent to 21 traffic deaths per 100,000 population.

The solution: A multi-sector approach was taken to assessing road safety in Belize. Part of that project involved infrastructure improvements for a demonstration corridor. The initial process for this infrastructure improvement component involved:

- a video-based road survey of the road and roadside features across the major highway network (around 600 km in total);
- an assessment of safety along this network using the Road Assessment Programme protocols, including star rating. This involved assessments at 100 m intervals of more than 30 attributes that were known to make severe injury crashes more common;
- development of a Safer Roads Investment Plan, which provided a series of ‘bank ready’ options to allocate resources to countermeasures.

Specific investment options were recommended to the project stakeholders, with the ultimate decision on an appropriate investment level determined by the road authority staff in Belize. Improvements on an 80 km demonstration corridor between Belize City and Belmopan were agreed. Safety improvements included:

- The widening of shoulders to provide a recovery area for vehicles that begin to run-off-the-road and a safe location for disabled vehicles to stop out of the traffic flow. This included the restoration of 11.25 km of narrow lanes to their original 11-foot (3.4 m) width, which over the years had deteriorated and...
Road fatalities and injuries were modelled for the demonstration corridor, with and without the recommended improvements. An economic evaluation compared the incremental costs and benefits of these two alternatives. The results of the incremental analysis indicated that for the level of investment proposed, 470 fatalities and serious injuries could be avoided over the 20-year analysis period. This is equivalent to a reduction of 20% in the number of injuries and fatalities over a 20-year period.

Using very conservative crash cost values, the estimated net present value (NPV) of the project is US$6.1m, and the economic rate of return (ERR) is 28.8%. The ERR is well above the Caribbean Development Bank’s cut-off rate of 12.0%, which highlights the significant economic benefits that can be had from road safety investments.

The economic analysis focused on the quantifiable costs and benefits related to the safety infrastructure improvements on the demonstration corridor, as these can be estimated with greater reliability and robustness. However, the institutional strengthening and capacity building components are also expected to have a significant impact on road safety throughout the country. Tangible benefits are also expected from proposed road education, awareness and communication activities.

The outcome: This project is still being evaluated, but early indications are positive.

Source: Belize Ministry of Public Works and Caribbean Development Bank

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**BOX 10.2: CASE STUDY – CORRIDOR APPROACH IN NEW SOUTH WALES, AUSTRALIA**

The problem: Road safety infrastructure improvements on their own were not producing strong results in terms of fatal and serious injury reductions.

The solution: New South Wales developed road safety reviews of major roads as a dedicated corridor approach to the analysis and selection of engineering works (and some behaviour change programmes) to improve road safety. Road safety reviews are different from engineering audits and blackspot programmes. They focus on a single corridor, analysis of fatal crashes, and a physical review of the entire highway by a multidisciplinary road safety team (that includes expertise in engineering, road design, behavioural science/psychology, statistics, and policing). The review process does not focus on where the road does not meet standards, but rather it focuses on analysis of fatal crash locations. The review team considers the highway as a whole and addresses the question of how to avoid injury occurring, rather than how to avoid the crash occurring. Further details of this approach can be found in de Roos et al. (2008).

The outcomes: The road safety gains achieved have been strong, as indicated in the figure below. On the Pacific Highway (of over 600 km), comparing crashes in the years before to the years after the...
selected works showed a 45% reduction in deaths and strong reductions in injuries. The same process on the Princes Highway (over 400 km) resulted in an 83% reduction in deaths on the highway and strong reductions in injuries. These reviews yielded an average benefit cost ratio of over 12:1 for the works, well above the benefit cost ratios achieved with traditional blackspot programmes or engineering audits in the state.

![Figure 10.2 Reduction in fatal crashes following the implementation of a program of road safety works on the Princes and Pacific highways - Source: Dr Soames Job, Global Road Safety Solutions.](image)

At a project level, the steps outlined in this chapter are equally relevant. They highlight how to identify risk at more specific locations (e.g. intersections, routes or areas) and diagnose risk at these locations. Crash-based (reactive) and more proactive approaches are relevant to both programme- and project-level approaches. In each case (whether programme or project level) the same steps are involved in assessing risks and identifying casual issues.
10.3 CRASH-BASED IDENTIFICATION ('REACTIVE' APPROACHES)

This section focuses on crash-based identification of high risk locations, a process that is known as accident investigation, or the treatment of 'blackspots'. The term 'sites with potential for safety improvement' is also used, as the approach involves selecting locations that have high potential for reductions in crashes through the introduction of targeted safety improvements. The approach relies on crash analyses to first identify safety problems before a solution is sought. These are often called 'reactive' methods because a response is only initiated after crashes have occurred. A fuller account of this approach is provided in the PIARC document Road Accident Investigation Guidelines for Road Engineers (PIARC, 2013).

As indicated above and in Proactive Identification, reliance solely on crash data can produce situations where only a small proportion of crashes can potentially be addressed. For this reason, it is recommended that a combination of crash data and other sources of information be used to assess and treat risk.

Reactive approaches typically include the following steps:

- identifying the crash location;
- diagnosing the problem for each crash location identified;
- selecting the appropriate countermeasures that match the problems identified;
- designing the treatment;
- justifying the expenditure;
- implementing the treatment;
- monitoring or assessing its effectiveness.

This chapter focuses on the first two points – identification and diagnosis. Consideration will also be given to how crash data is used and its limitations. The other steps will be covered in Intervention Selection And Prioritisation and Monitoring and Evaluation of Road Safety. A reliable crash database is a key tool in this process of identifying and analysing crash locations (see Hospital Data in Establishing and Maintaining Crash Data Systems). Other tools also exist, for example the Network Screening and Diagnosis tools in Safety Analyst (see Box 9.7).

USING CRASH DATA

In order to treat the occurrence of crashes, crash data is needed to provide necessary information to road authorities. Further information on the collection and use of crash data can be found in Effective Management And Use Of Safety Data. Issues relating to the need for good quality data are also discussed in that chapter. To ensure adequate data quality, the data should be accurate, complex (i.e. includes all features), available (i.e. accessible to all users), and uniform (i.e. adheres to standard definitions) (PIARC, 2013).

The primary data source for crash reduction initiatives, especially those undertaken by road engineers, is typically police crash reports. This data should provide crucial information, which at a minimum should include the crash severity and the number of each injury severity type (i.e. fatal, serious, minor, etc.). Other important information to collect includes (PIARC 2013):

- crash identification number;
- information about the crash site (e.g. an accurate location);
- the occurrence of events that resulted in the crash (e.g. the crash type);
• information on those involved (gender, age, road user type, whether alcohol was involved, use of seatbelts, etc.);
• weather and lighting conditions;
• vehicles involved;
• time of day, day of week, and date.

Crash type is of particular importance, as it provides the basis for some crash location selection criteria (as discussed in the following section). Normally, crash types are divided into groups of crashes with common attributes, such as all crashes involving vehicles colliding head-on, or all crashes involving pedestrians. Further examples of crash types are shown in Identifying Crash Locations in Crash-based Identification (‘Reactive’ Approaches).

There are a number of limitations to crash data that should be understood before it is used for analysis, including that crashes may be under-reported; there may be missing information or errors in the data; data can be subjective; and there may be delays in making data available. Refer to Effective Management And Use Of Safety Data for more detail on collecting, analysing and integrating crash data, as well as data types, data quality and under-reporting.

IDENTIFYING CRASH LOCATIONS

A crash location can be an individual site (such as an intersection or bend in the road), a length of road, an area of the road network, or a collection of locations across the network that display the same crash characteristics. In order to identify crash locations, access to a comprehensive database is required to
provide sufficient information about the exact locations and circumstances of crashes that have occurred. Once all crash sites have been located, there needs to be selection criteria so that only worthy sites are selected for further analysis and treatment.

The following sections provide an overview of the approaches that can be used in identifying crash locations. Detailed guidance on the identification of high risk locations has been developed in many countries. In addition to the PIARC (2013) manual, further information can be gathered from many sources, including AASHTO (2010), Austroads (2009a), and RoSPA (2007). The African Development Bank (2014a) has recently released guidance that is specifically intended for use in LMICs.

### DEFINING LOCATIONS

It is important to consider what the boundaries of a crash location are. There needs to be a defined cut-off point, such as between crashes that occur at an intersection and crashes that are considered ‘mid-block’. It may be necessary to look beyond these defined boundaries when analysing crash data. For example, crashes within 10 metres on the approach roads to an intersection may be considered as located at the intersection; however, it may be of value to look beyond this boundary for other crashes that may be related to an intersection (e.g. 100 metres). The crash location is also generally identified as the point at which an impact occurred. However, this may only be the end point of a sequence of events. Factors relating to the cause of the crash may have started earlier on the roadway.

Crash locations can sometimes be poorly or inaccurately defined, and it is important to consider this when comparing crash sites. There are a number of different methods used to determine the location of a crash. In built-up areas, the common practice is to measure the distance from the nearest intersection, junction or landmark. However, in rural areas and also in some countries in general, names may not exist for all roads, and junctions may be few and far between. Where the supporting technology is available, Global Positioning Systems (GPS) can be used to gather latitude and longitude coordinates. Other common systems are the Linear Referencing System and Link-Node System. These too rely on road names or reliable kilometre post markers along roads. See Effective Management And Use Of Safety Data and WHO (2010) for more detail on defining crash locations.

Over time, especially in HICs, there has been a movement to the assessment of more extensive areas, including route-based approaches. The term ‘Network Safety Management’ is used in Europe to encompass an approach that assesses extended routes, typically between 2 and 10 km (Schermers et al., 2011). These segments have higher than expected numbers and severity of crashes when compared to other similar segments. Various tools have been developed to help with this process, and some of the key approaches are discussed below.

### DECIDING ON A TIME PERIOD

Typically, a three- to five year period is selected to provide a large enough sample of data, whilst minimising the chance of changes to the road network. In some LMICs, high risk locations and crash patterns within a location may start to form after just one to two years. Once a strong pattern has been established, especially where fatal and serious injury crashes are occurring, it is more important that treatments are implemented earlier rather than waiting up to five years for more data. When selecting the time period, it is important to use whole years to avoid cyclic or seasonal variations in the crash and traffic data. It is also important to be aware of any changes in database definitions that may have occurred in that time.

### CRITERIA FOR SELECTING LOCATIONS TO INVESTIGATE FOR TREATMENT

There is generally not enough funding to treat all identified crash locations. Selection criteria are therefore required for prioritising crash locations for further investigation and treatment. It is strongly recommended...
that fatal and serious injury crash types be used for the selection of sites, as per the Safe System approach (see The Safe System Approach). However, minor injury crashes should not be ignored as they may be indicative of a potential fatal or serious injury crash in the future. The selection process varies depending on the aim of the project and the types of actions that may be considered, and include:

- site action – treating a specific site or short length of road that has a concentration of crashes;
- route action – investigating crashes along a section of road, looking for common crash characteristics along the route, but also individual problematic sites;
- area action – investigating crashes throughout an area, where the main issues to be addressed may be on a broader scale, such as traffic management and network problems (e.g. pedestrian safety may be a recurring theme);
- mass action – this looks for common crash characteristics over a larger area, such as delineation problems or vehicles running off the road.

There are several existing methods to identify crash locations, using measurements such as crash frequency, crash rate and crash severity. More detailed information on this issue can be found in AASHTO (2010) and Austroads (2009). These help in the identification of high risk crash locations, particularly those of higher severity. It is important to note, however, that although blackspots should be targeted for treatment, they may only make up a small proportion of the network that is responsible for deaths and serious injuries. In these instances, additional proactive responses may also be required (see Proactive Identification).

For most of the methods described below, crash locations should be selected based on the same definitions for location (e.g. the same radius or route length, where this is applicable) and the same time period in order to allow for a direct comparison. However, for some methods, the data can be normalised to allow direct comparison (e.g. converted to crashes per kilometre; crashes per year).

At the most basic level, the presentation of crash locations on a map can provide information on crash clusters. In the absence of a more sophisticated crash database system, this provides a quick indication of crash locations by frequency. Figure 10.3 shows an example of crash locations overlaid on a map for an urban area. In this figure the larger the circle, the higher the number of crashes. Maps are a powerful way to present information to key stakeholders, including technical staff, policy makers, senior managers, members of the public and politicians. As they are easy to understand by all of these stakeholders they can be a strong advocacy tool.
A ranked listing by crash frequency (i.e. highest crash numbers to lowest) can form the basis of an initial list of crash locations for further assessment. Usually a threshold level is selected, with sites above this threshold being assessed. The threshold is often set arbitrarily (e.g. five crashes per year), although it is preferable to take into account the available budget and/or a threshold involving crashes of a particular type (e.g. three pedestrian injuries per year).

Given the aim of road safety management is to minimise death and serious injury crashes, it is preferable to select sites for investigation based on crash severity. A common method of identifying high risk locations to take account of severity is to prioritise sites through a crash cost analysis. An effective method often used is called the Equivalent Property Damage Only (EPDO) Index, where crashes are weighted according to their severity. For instance, fatal crashes are assigned the highest cost/weighting per crash and property-damage-only (PDO) crashes (or minor crashes if PDO crash data is not collected) are assigned the lowest cost/weighting per crash. Although this is a relatively simple criterion to implement, it provides a basis for creating a shortlist of sites to be investigated further. As with the simple crash frequency-based approach, sites are ranked from highest cost to lowest cost, and a threshold is set for investigation.

A similar and yet more sophisticated method is the Relative Severity Index (RSI). Standard crash costs are assigned to crashes by crash type and road environment, as shown in the example in Table 10.1.
<table>
<thead>
<tr>
<th>Crash costs for Victoria (AU$)</th>
<th>One-vehicle</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian hit crossing road</td>
<td></td>
<td>166,300</td>
<td>183,800</td>
</tr>
<tr>
<td>Hit permanent obstruction</td>
<td></td>
<td>162,400</td>
<td>163,400</td>
</tr>
<tr>
<td>Hit animal on road</td>
<td></td>
<td>102,300</td>
<td>79,500</td>
</tr>
<tr>
<td>Off road, on straight</td>
<td></td>
<td>119,900</td>
<td>146,100</td>
</tr>
<tr>
<td>Off road, on straight, hit object</td>
<td></td>
<td>177,500</td>
<td>206,600</td>
</tr>
<tr>
<td>Out of control, on road, on straight</td>
<td></td>
<td>98,100</td>
<td>115,700</td>
</tr>
<tr>
<td>Off road, on curve</td>
<td></td>
<td>146,900</td>
<td>175,900</td>
</tr>
<tr>
<td>Off road, on curve, hit object</td>
<td></td>
<td>191,700</td>
<td>219,700</td>
</tr>
<tr>
<td>Out of control, on road, on curve</td>
<td></td>
<td>120,100</td>
<td>112,110</td>
</tr>
<tr>
<td>Two-vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intersection (adjacent approaches)</td>
<td></td>
<td>124,000</td>
<td>173,200</td>
</tr>
<tr>
<td>Head-on</td>
<td></td>
<td>240,300</td>
<td>341,600</td>
</tr>
<tr>
<td>Opposing turns</td>
<td></td>
<td>132,700</td>
<td>168,600</td>
</tr>
<tr>
<td>Rear-end</td>
<td></td>
<td>64,200</td>
<td>109,700</td>
</tr>
<tr>
<td>Lane change</td>
<td></td>
<td>88,500</td>
<td>132,800</td>
</tr>
<tr>
<td>Parallel lanes, turning</td>
<td></td>
<td>79,900</td>
<td>104,600</td>
</tr>
<tr>
<td>U-turn/through</td>
<td></td>
<td>124,600</td>
<td>135,600</td>
</tr>
<tr>
<td>Vehicles leaving driveway</td>
<td></td>
<td>93,200</td>
<td>129,100</td>
</tr>
<tr>
<td>Overtaking same direction</td>
<td></td>
<td>97,000</td>
<td>138,000</td>
</tr>
</tbody>
</table>
Crash costs for Victoria (AU$)

<table>
<thead>
<tr>
<th>Description</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hit parked vehicle</td>
<td>112,500</td>
<td>202,700</td>
</tr>
<tr>
<td>Hit railway train</td>
<td>384,400</td>
<td>559,100</td>
</tr>
</tbody>
</table>

Source: Adapted from Andreassen (2001).

These costs are calculated based on an analysis of the average crash severity of each crash type. It is important to note, however, that crash types and crash costs will differ between jurisdictions and countries. This method takes into account crash severity but places less emphasis on locations where a single fatal crash may skew outcomes because of its very high cost. Such an outcome might be the result of a ‘random’ event, never to be repeated. This is more likely on lower volume roads or road networks where fatal crashes are very infrequent. Of higher interest are locations, routes or areas where high severity events are likely to happen again in the future. Using average crash costs by crash type, crashes at each location can be assigned a crash cost, and then locations ranked by total crash costs.

In some cases, multiple identification methods are used. These use two or more of the methods identified above. Other selection criteria are also available. Some of these are quite complex, utilising crash prediction models and Empirical Bayesian (EB) methods (e.g. AASHTO, 2010). The EB method is currently considered one of the most robust approaches for selecting crash locations. However, other approaches identified above can produce satisfactory outcomes, particularly when adequate weighting is applied to fatal and serious injury crash outcomes.

Crash sites can be assessed using statistical analysis to identify sites that are experiencing a statistically significant number of crashes in a set time period. This can be useful to distinguish between sites that are experiencing abnormally high crash rates and those that are merely experiencing variation due to chance.

The crash identification process allows for sites to be selected for further investigation. Using any of the abovementioned methods, a shortlist can be developed containing sites that will be considered for treatment. Available funding will limit the number of sites that can be treated, and so the shortlisted sites should be assessed through site inspections and an initial crash diagnosis to identify where cost-effective treatments can be implemented.
DIAGNOSING THE PROBLEM

Diagnosing the problem is the foundation for selecting an effective solution to a safety problem. To properly understand the problem, one must consider that:

- A crash is the result of a sequence of events and circumstances (rather than a single cause).
- Each event or circumstance is linked to a component of the Safe System - the persons involved, the vehicle, or the road environment.
- Each event is strongly influenced by the preceding event or circumstance.

Diagnosis of the safety problems at a crash location is a four-step process:

- Gather the relevant information about the site, such as crash data, traffic volumes, and the history of the network or location in terms of land use or physical layout changes.
- Analyse the crash data for the location (e.g. the whole area if looking to perform mass action plans, or a single site for treatment implementation) by looking for common crash types or factors, particularly those that are happening in groups.
- Inspect the site from the perspective of the road user, and closely examine the site’s physical features and layout.
- Based on the notes and findings from the above steps, draw conclusions about the likely causes of crash groupings (of similar type and/or location).

These stages are discussed in further detail in the sections below.

GATHER RELEVANT INFORMATION

Crash data is the most important information, and should be available from either the Police or road
authority. The road agency may also have information on traffic volumes and any historical information about the site such as a layout plan, any changes in traffic patterns or land use, and any previous or current concerns raised by the community or stakeholders.

**ANALYSE DATA**

An effective way to identify groupings of certain crash types or other common factors at a location is to present the data as a frequency diagram, a factor matrix, or a collision diagram of the different crash types. A brief description of each of the analysis methods is provided below:

- Examine crash types;

Typically, crashes are categorised within a crash database according to a certain crash type coding system. A common breakdown using 10 crash groupings is provided by PIARC (2013):

- single vehicle crashes;
- crashes of vehicles driving in the same direction on the road section;
- crashes of oncoming vehicles on the road section;
- crashes of vehicles entering a junction from the same direction;
- crashes of vehicles entering a junction from opposite directions;
- crashes of vehicles entering a junction from neighbouring lanes;
- crashes of vehicles and pedestrians;
- crashes with standing or parked vehicles;
- crashes with animals and rail vehicles;
- other crashes.

Other countries may use more or less crash type groupings. Given the importance of motorcycle fatal and serious injury in many countries, provision should also be made to record details of such crashes. This is typically recorded as the vehicle type as an additional variable to those provided above.

Crash type variables can be used to describe the type of the crashes in terms of parties involved, collision and vehicle/pedestrian manoeuvre just before the crash. Each variable, coded as a two digit number, describes the single specific crash type. In crashes where more than one type can be applicable, the corresponding number of variables should be selected.

A simple frequency histogram or diagram can be used to show the distribution of crashes and identify if any trends in crashes are appearing. This can be good for an initial assessment, but due to its simplicity, it should not be done as an alternative to a factor matrix or collision diagram.

- Construct a factor matrix;

A factor matrix takes the frequency table approach one step further and considers additional factors such as the crash severity, year of the crash, direction of travel, type of road users, collision type, surface and lighting conditions, time of day, and day of week.
Draw a collision diagram;

A collision diagram is an illustrative presentation of the crashes that have occurred at a location. Crashes are pinpointed on a diagram of the intersection or road section, showing the crash type (through standard symbols), the direction of travel, and other relevant information (e.g. the date, time of day, weather and lighting conditions). A number of software packages allow the automatic creation of these diagrams.
Figure 10.5 An example of a collision diagram from Germany - Source: PIARC (2013).

The main purpose of these data presentation types is to identify common contributing factors of crashes at a location. Note that there are normally several factors that lead to a crash. If there is no apparent dominant crash type that appears from the data, it can be very difficult to treat the site as it will be difficult for any one treatment to solve all the different problems at the site (speed management can be the exception to this, particularly in the elimination of high severity crash outcomes). Sometimes it can be helpful to look at the individual police crash reports for greater detail on the crash circumstances, as this might shed light on a common causal factor.

SITE/ROUTE/AREA INSPECTION

The main purpose of an inspection is to identify any environmental or traffic issues that may be contributing to crashes at the location. A site inspection can allow the crash investigation team to see the location through the eyes of the road user and observe the traffic behaviours. Additional data can also be collected, such as vehicle speeds, road features, parking restrictions and speed limits, as well as enable the team to assess any other characteristics of the surrounding road environment.

Where possible it is recommended that a team conduct the assessment, rather than an individual. A team approach will generally provide a more diverse range of opinions and ideas, as it is easier to generate these through group discussion. Team members might include an expert who is trained in road safety engineering and investigation of crash locations; and police and/or road agency staff, particularly those who are familiar with the location. The group may also include someone new to the crash investigation, but who has ideally undergone some form of training. This approach is essential to ensure development of skills for future crash investigators. Guidelines on Human Factors should be considered by those investigating sites (see Design for Road User Characteristics and Compliance).

It is recommended that the data analysis described above (e.g. production of a factor matrix and collision diagram) is circulated amongst the crash investigation team in the form of a preliminary report, prior to any site inspections.

A drive-through of the location should be undertaken to fully understand the road user experience. It is often useful to select someone unfamiliar with the area to do the driving so that they can experience the location as others would for the first time. Often there will be a need to drive through the site several times. An inspection on foot will also be required to more closely observe road user behaviour and site conditions. This will also allow for the collection of photos and notes, and to document any findings from the inspection. Sometimes it is also useful to inspect the site at different times of the day or days of the week to check for any variability in traffic flows or lighting/visibility conditions. For example, if a high number of night crashes have occurred, night inspections are essential.
Table 10.2 provides a list of possible contributing factors for different crash types (including those that contribute the most to fatal and serious injury outcomes) that should be considered by investigators during a site inspection. Although not listed, speed is linked to the frequency and severity of all crashes.

<table>
<thead>
<tr>
<th>TABLE 10.2: SOME POSSIBLE CONTRIBUTING FACTORS FOR DIFFERENT CRASH TYPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right angle crashes (intersection)</td>
</tr>
<tr>
<td>• Restricted sight distance</td>
</tr>
<tr>
<td>• High approach speeds</td>
</tr>
<tr>
<td>• ‘See through’ effect on a minor approach</td>
</tr>
<tr>
<td>• Obscured control sign, control lines or signal lanterns</td>
</tr>
<tr>
<td>• Presence of intersection is not obvious (at time of day)</td>
</tr>
<tr>
<td>• Traffic volumes too high for Give Way or Stop controls (insufficient gaps)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Run-off-road crashes</th>
<th>Head-on crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Narrow lanes or narrow seal</td>
<td>• Lanes too narrow (for traffic mix, speed, curvature of road, angle of lanes)</td>
</tr>
<tr>
<td>• Severity of curve cannot be judged</td>
<td>• Centreline not visible</td>
</tr>
<tr>
<td>• Edge of the road is not evident</td>
<td>• Poor delineation</td>
</tr>
<tr>
<td>• Shoulders/roadside do not allow recovery of control</td>
<td>• Severity of curve cannot be judged</td>
</tr>
<tr>
<td>• Alignment of road is deceptive</td>
<td>• A hidden dip or crest</td>
</tr>
<tr>
<td>• Poor road surface condition</td>
<td>• Insufficient overtaking opportunities</td>
</tr>
<tr>
<td>• Poor road surface condition</td>
<td>• Inadequate skid resistance or pavement drainage</td>
</tr>
<tr>
<td>• Expected parked vehicle in traffic lane</td>
<td>• ‘Edge drop’ between road and shoulder/roadside leading to driver overcorrection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Motorcyclist crashes</th>
<th>Cyclist crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Poor delineation, especially at curves</td>
<td>• Speed environment too high</td>
</tr>
<tr>
<td>• Poor road surface (roughness, potholes, debris)</td>
<td>• Inadequate separation of traffic</td>
</tr>
<tr>
<td>• Obstacles at the roadside</td>
<td>• Interaction with vehicles</td>
</tr>
<tr>
<td>• Insufficient number of gaps in oncoming traffic</td>
<td>• Poor road surface (roughness, potholes, debris)</td>
</tr>
<tr>
<td>• Restricted sight distance</td>
<td>• Unexpected parked vehicle in traffic lane</td>
</tr>
<tr>
<td>• Unexpected lane drop or merge area</td>
<td>• Unexpected lane drop or merge area</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pedestrian crashes</th>
<th>Straight ahead rear-end crashes</th>
</tr>
</thead>
</table>

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### Right angle crashes (intersection)

- Inadequate crossing facilities
- Too much traffic for adequate crossing gaps
- Too many lanes of traffic to cross
- High-speed, multi-lane and two-way traffic
- Complex or unexpected traffic movements
- Traffic hidden by parked cars, other objects or excessive landscaping
- A marked crossing which is not evident to drivers
- Long signal cycles which encourage pedestrians to disobey signals
- Inappropriate device or lack of devices for mix of pedestrians (e.g. for disabled users)
- Inadequate lighting

### Turning crashes with oncoming crashes

- Queued turning vehicles ahead
- Traffic signals around curve or over crest
- Other unexpected cause of delay ahead
- Inadequate skid resistance or pavement drainage
- Wrong offset timing of linked signals
- ‘See through’ effect of consecutive traffic signals
- Inadequate inter-green phase on signals
- Presence of parked cars
- Unstable flow on high-speed road
- Traffic ‘friction’ due to frequent pedestrian or parking movements
- Turning vehicles where they are not expected (e.g. just before or just after signals)

### Hit-fixed-object crashes

- Islands not visible
- Complex layout
- Reasons as for run-off-road crashes

### Railway level crossing crashes

- Location of crossing is not evident
- Impending presence of train is not evident
- Form of control is not accurately identified (or is not consistent)
- Driver’s attention distracted by intersection or other feature
- Obscured control devices

### Crashes involving a parked vehicle

- Unexpected parked vehicle in traffic lane
- Edgeline not visible
- Lanes too narrow

### Crashes involving U-turning vehicles

- Inadequate turning facilities
- Insufficient number of gaps in oncoming traffic
- Poor sight distance

### Lane changing and manoeuvring

- Lanes too narrow (for traffic mix, speed, curvature of road, angle of lanes)
- Lane lines or edgelines not visible
- ‘Edge drop’ between road and shoulder/roadside
- Presence of parked cars or other obstruction
- Unexpected lane drop or merge area
- Inadequate direction information
- Roadside activity

**DRAW CONCLUSIONS**

Before summarising the analysis in a report, consideration should be given to whether any additional information is required. For instance, if the crash analysis and/or site inspections suggest that there may be issues with skidding, then skid resistance testing could be undertaken.

A summary report should be prepared to clearly inform readers of the conclusions that were drawn from the analysis. This provides the basis from which treatment options are considered and selected. The report should include a description of the area or site, results from the data analysis (e.g. crash diagrams),
observations from the site inspections, including possible contributing factors to crashes, comments on any identified common factors leading to crashes and possible remedial measures (see Intervention Options and Selection).
10.4 PROACTIVE IDENTIFICATION

As mentioned in the previous section, there are established methods that help detect, prioritise and treat high crash-risk sites based solely on prior crash history. Although these locations should be a target for funding and attention, they only comprise a small proportion of the network that is responsible for casualty crashes, especially in higher income countries. For example, SWOV (2007) reports that in the Netherlands during 1987–89, only 10.5% of all fatal and hospital in patient crashes occurred at blackspot locations. In the 1997–99 period, this had declined to 6%. For the period between 2004 and 2006, the figure was only 1.8%. This study concludes that an increasing number of serious crashes occur at locations that are not blackspots.

In LMICs, accurate crash data may not be available, and so the crash-based approach to risk assessment might not be possible. In the USA, it is noted that some states have had difficulties in meeting safety targets by only investing in high crash locations (Preston et al., 2013). In these instances, additional proactive responses are required to help assess and treat risk. Proactive approaches are newer than crash-based assessment approaches. They are evolving and improving over time and cover a range of techniques for assessing and treating risk.

Proactive safety actions can be employed to avoid future crashes by:

- ensuring the safest road design scheme is selected for construction;
- checking that the proposed road infrastructure or feature is designed and built to minimise the occurrence of road safety problems;
- treating safety issues on existing road networks before crashes occur at these locations.

It should be noted that proactive actions, whilst being a preventative measure, should not be a simple check of compliance with design standards. Often the design can meet standards, but due to the configuration, or due to adoption of minimum standards on a number of road elements, the design may be unsafe.

This section will discuss several types of road safety checks that are generally performed at different stages of implementation of a road scheme. These checks may occur for a new road or road feature, modification to an existing road or feature, and even during the usual operation of a road.

Although the focus of this chapter is on identifying risks, and the tools used in this process, some of the approaches described also help in the identification of solutions or even in the prioritisation of interventions (both discussed in Intervention Selection And Prioritisation). The content beyond the risk identification stage is also included in this chapter where relevant for completeness. Therefore, this material should be read alongside the following chapter on treatment selection and prioritisation.

The road safety check types are:

- road safety impact assessments – used to ensure the scheme is selected (out of a number of different schemes) that has the best outcome for road safety
- road safety audits – performed to check that the selected scheme is designed and constructed in such a way as to yield the greatest road safety benefits, and to detect any potential hazards throughout the design and construction
- road safety inspections – undertaken as part of an inspection of an existing road, or through maintenance procedures to enable the detection of potential crash risks
- road assessment programmes – typically undertaken on existing roads, these quantify the expected safety outcomes for a network, route or location.
It should be noted that safety inspection of existing roads is sometimes referred to as an audit of existing roads in some countries, but the terms refer to a similar process.

The aim of each of these road safety checks are similar, however, the main distinction is in the timing and scope of the procedures, as shown in Figure 10.6. Road assessment programmes are typically used to assess roads that are already in use, but recent developments have extended this to include assessment of road design.

Given the different timing and scope of each procedure, all can be undertaken in parallel. It is up to individual countries as to which procedures are adopted. Each has different advantages and weaknesses, and these are documented in the following sections.

Some of the main objectives and benefits of undertaking any of these road safety checks include (PIARC 2012a):

- the future minimisation of crash risk, severity and occurrence at the site and on adjacent roads;
- recognising the importance of considering safety in road design;
- reducing long-term operating/maintenance costs and the need for remedial work (through efficient and safe design selection);
- bringing an increased awareness to road safety issues and solutions amongst policy-makers and scheme designers.

The different road safety check types are thoroughly outlined in a number of national guidelines, some of which are available internationally. Example guidelines are provided throughout the remainder of this chapter.

Other tools to assess safety at the planning and development stage are included in Management Tools. Some of these tools are designed for use by practitioners with little or no road safety experience, and are intended to identify and address risk at the earliest stages of project and programme development.

Road safety checks generally follows a similar managerial procedure. This is outlined in Figure 10.7, which
also indicates who has responsibility for each stage of the process.

<table>
<thead>
<tr>
<th>Safety check steps</th>
<th>Responsibility of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select the safety check team</td>
<td>Client/designer</td>
</tr>
<tr>
<td>Provide background information</td>
<td>Designer</td>
</tr>
<tr>
<td>Hold commencement meeting</td>
<td>Client/designer</td>
</tr>
<tr>
<td>Assess documents ↔ Inspect site</td>
<td>Safety check team</td>
</tr>
<tr>
<td>Write report</td>
<td>Safety check team</td>
</tr>
<tr>
<td>Hold completion meeting</td>
<td>Safety check team</td>
</tr>
<tr>
<td>Write responses</td>
<td>Client/designer</td>
</tr>
<tr>
<td>Implement changes</td>
<td>Designer</td>
</tr>
</tbody>
</table>

Figure 10.7 Steps involved in a safety check and allocation of responsibility

ROAD SAFETY IMPACT ASSESSMENT

Road safety impact assessment is conducted for infrastructure projects at the initial planning stage before the infrastructure project is approved. It indicates the road safety considerations which contribute to the selection of the proposed solution and provides all relevant information necessary for a cost-benefit analysis of the different options assessed. This allows a comparison of the impact of different road or traffic schemes on safety performance. These could be for a new road or for modification to an existing road. This is a procedure that should first be performed in the initial planning stage of a project to assist in the selection process for major infrastructure projects, and should then be continually reviewed during the draft design phase. Safety impact assessment often precedes road safety audit (Road Safety Audit in Proactive Identification), but is done as a complementary process. As identified in Examples of Infrastructure Policies, Standards and Guidelines in Policies, Standards and Guidelines, impact assessment is required for all infrastructure projects on the trans European network as part of an EU Directive.

There are five main steps to a road safety impact assessment, as outlined by Eenink et al. (2008):

1. Establish the baseline situation (year zero). This should be a measurement in terms of traffic volumes, crashes per road type, and therefore risk factors per road type. A site inspection is required to collect this data (see Diagnosing the Problem in Crash-based Identification (‘Reactive’ Approaches) for further detail regarding site inspections). The site inspection should consider all road users, the surrounding road network, topography, local amenities and activity centres, local weather conditions, previous road safety reviews, and any complaints received from the community regarding the site.

2. Determine the future situation without any implemented measures (known as the ‘Do Nothing’ or ‘Do Minimum’ scenario). This should consider current circumstances and conditions, and should account for traffic growth.

3. Determine the future situation under each of the applied road safety schemes. This should include a wide variety of alternatives and an estimate of the effects per road type. It should consider each road user group for each of the schemes. Each scheme should be measured in terms of its impact on the number of crashes and crash severity through a crash prediction model (see AASHTO, 2010).
4. Perform cost-benefit analysis for each possible road safety scheme. This is done by assigning a monetary value to the safety impacts of each scheme, and allows for the schemes to be ranked in order of effectiveness.

5. Optimize the plans of each scheme. This is done to achieve the optimal safety effect and best cost-benefit rating.

A detailed final report should be completed at the end of the road safety impact assessment. This should include such details as:

- the definition of the problem and project objectives (both in terms of infrastructure changes and road safety);
- how the road network will be affected by the proposed scheme;
- analysis of the existing road safety problems on the current network;
- analysis of crash history in the area;
- consideration of the consequences of the ‘Do Minimum’ approach;
- a detailed description of each alternative road scheme;
- comparison of each scheme, including cost-benefit analysis from a safety perspective compared to the ‘Do Minimum’ approach. This is the main element of the report and an assessment of the effectiveness of each scheme must be made in terms of predicted crashes;
- ranking of the scheme options, ordered in terms of the road safety savings.

During a road safety impact assessment it is important to ask certain questions. Are the road safety policy targets realistic or ambitious? Are there other cost-effective schemes that have not been considered yet? Are the selected schemes suitable, not just in terms of safety, but in terms of other issues such as impacts on the environment, or accessibility and connectivity for all road users? Are there any associated social issues, such as a lack of support from the community?

It is important to note that a road safety impact assessment does not replace a road safety audit; it is merely a preliminary step towards selecting the most beneficial design for a project. Road safety audits are essential for ensuring all hazards are identified throughout the detailed design and construction processes, which will be discussed in detail in Road Safety Audit in Proactive Identification.

Part C of the Highway Safety Manual (AASHTO, 2010) provides information on crash prediction models for different road types, including rural two-lane, two-way roads, rural multi-lane highways, and urban and suburban arterials. It covers both undivided and divided roadway segments, and intersections with various control devices and numbers of legs. This can be used to predict the expected average crash frequency, which is determined based on traffic volumes and roadway characteristics. More on the Highway Safety Manual can be found in Box 10.3.

**BOX 10.3: THE HIGHWAY SAFETY MANUAL AND ASSOCIATED TOOLS**

The Highway Safety Manual (AASHTO, 2010; also see [http://highwaysafetymanual.org](http://highwaysafetymanual.org)) was developed to help embed safety considerations in decision-making relating to roadway planning, design, operations, and maintenance. A number of tools have been developed to support these objectives, including Safety Analyst (discussed in Section 9.4), the CMF Clearinghouse (see Intervention Option and Selection), and the Interactive Highway Safety Design Model (IHSDM; also see Box 9. In Assessing Potential Risks And Identifying Issues).

The IHSDM is a suite of software for evaluating the safety and operational effects of geometric design decisions (from design plans). They are advanced safety analysis and prediction tools, and considered ‘best practice’ by many safety professionals (see e.g. Schermers et al., 2011).
The development of these tools is based on a wide and robust range of research including on crash prediction models and crash modification factors (CMFs) undertaken mainly in North America over the last 15 to 20 years. IHSDM is particularly useful for selecting the safest option from a list of possible options and for understanding the safety trade-off that might result from a lower standard design that may be required due to site constraints or construction cost savings. This tool uses crash prediction models and CMFs to predict crash occurrence. The models and CMFs are continually being refined as new research becomes available. IHSDM has calibration procedures that allow it to be customised for each US state or for other jurisdictions. Testing of these procedures has occurred in some European countries as well as Australasia.

The international Road Assessment Programme (iRAP) has developed a technique to star rate design plans. Although not strictly an impact assessment, the process fulfils a similar purpose. Details on this approach can be found in the case study in Management Tools.

**ROAD SAFETY AUDIT**

A road safety audit is defined as a formal and independent technical check of a road scheme design and construction, to identify any unsafe features or potential hazards and to provide recommendations for rectifying them during all stages, from planning to early operation (PIARC, 2011; ETSC, 1997; NRA, 2012).

The main aim of a road safety audit is to identify and address any road safety issues. A road safety audit is not a check against design standards, but a hazard detection tool. A road scheme, when audited, should be analysed under all operating conditions and consider all road users.
Road safety audit is thought to be a cost-effective measure for identifying and addressing likely safety issues. The earlier the audit is undertaken, the greater the benefit, as adjusting design plans can be a cheaper option than retrofitting safety features once a scheme has been built. Several studies have documented the benefits of conducting road safety audits. As an example, Macaulay and McInerney (2002) estimated that a sample of design stage audits had a benefit cost ratio (BCR) of between 3:1 and 242:1 by implementing all the recommendations from individual audits. In addition, 75% of recommendations had a BCR greater than 10, and 90% of recommendations had a BCR greater than 1.

Road safety audits (as well as other proactive methods) are very important for LMICs, as they provide an opportunity to develop a culture of road safety amongst those responsible for the planning and delivery of road infrastructure. On this basis alone there is a very strong case for the development of a formalised process for road safety audits for all major infrastructure projects. Box 10.4 provides an example of some of the added benefits that can be gained from large road safety audit projects in LMICs.

**BOX 10.4: CASE STUDY – ROAD SAFETY AUDIT OF 1062 KM OF ROAD (KAZAKHSTAN)**

The problem: There was a need to establish safe and efficient transport corridors along the Western Europe to Western China International Transit Corridor.

The solution: Relevant standards including road design safety standards and available data about road accidents were reviewed. The designs of sections not yet under construction or finalized were audited and other sections in the stages of pre- and post-traffic opening inspected. This process involved training of 16 participants from different institutions related to the Ministries of Transport and of Internal Affairs. PIARC guidance on road safety audit and safety inspection was used as the basis for this work, but was tailored for local use. The main deficiencies found included the straight monotonous alignment causing tiredness and speeding, unstable shoulders and passive safety installations, dangerous U-Turns, lack of pedestrian safety at bus stops at many unsafe intersections with small roads along the road. To reconstruct them as roundabouts with the bus stops and pedestrian crossings has been recommended as a safe and cheap solution.

A review of several relevant laws and bylaws was also undertaken as part of this work, with recommendations made regarding improvements in regulation of road safety audits and safety inspections. A review was also undertaken of traffic management at road works.
The outcome: Outcomes from this work included the recommendations for safety improvements along this route; development of guidance suitable for local conditions; recommendations regarding amendments to relevant laws; and training of key staff. Another key outcome is that the client learned during the training and discussions that road safety is not only a road user problem. It was important to include the Traffic Police and the Road Maintenance managers into the discussion about safe roads. They understood that without the proactive identification of road safety deficiencies they would have to make improvements through their small maintenance budgets.

Source: Hans Vollpracht, World Road Association (PIARC)

Many international guides exist on how to conduct road safety audits. PIARC developed a Road Safety Audit Guide (2011; [www.piarc.org/ressources/publications/7/6852_WEB-2011R01-TM.pdf](http://www.piarc.org/ressources/publications/7/6852_WEB-2011R01-TM.pdf)) that provides a comprehensive step-by-step procedure on how to conduct a road safety audit, as well as providing detailed individual checklists for motorways, inter-urban and urban main roads at each of the design stages (feasibility study, preliminary design, detailed design, and pre- and post traffic opening). The guide also provides checklists for road safety audit, which are discussed in more detail below. Other useful guides include the FHWA Road Safety Audit Guidelines (2006; also see [http://safety.fhwa.dot.gov/rsa/](http://safety.fhwa.dot.gov/rsa/)) and the Austroads Guide on Road Safety Audit (2009b). The African Development Bank (2014b) has recently released guidance that is specifically intended for use in LMICs.

Road safety audit can be undertaken at each, or all, of the following stages:

- feasibility;
- preliminary design;
- detailed design;
- pre-opening;
- post-opening (either as part of monitoring performance, or audit of existing roads).

A road safety audit may also be undertaken in other circumstances; for example, to assess the safety of proposed traffic management at roadworks, particularly in busy and complex situations.

As identified in Section Examples of Infrastructure Policies, Standards and Guidelines in Policies, Standards and Guidelines, the EU Directive on road infrastructure safety management states that road safety audit be conducted on all infrastructure projects on the trans-national highway in Europe, and suggests that these should also occur for all national roads. The Directive also states that such audits should be conducted at the draft design, detailed design, pre-opening and early operation stages.

The PIARC (2011) guide identifies three parts in the auditing process – commissioning, undertaking and completion. Details on each of these stages are provided in that document.

The selection of an appropriately skilled audit team is an important part of the commissioning phase of the audit process. It is essential that the team is independent of the design team. The size and make-up of the team will vary depending on the size and complexity of the project and the stage of audit being undertaken. It is important that the team members, and particularly the team leader, have the necessary training to undertake a road safety audit. Many countries have developed formal training requirements (sometimes referred to within national guidance on road safety audit) and registers of appropriately qualified auditors. For smaller projects, it may be possible for a single auditor to complete a ‘road safety check’, and although this is not ideal, it is certainly preferable to no audit at all.
The availability and development of suitably skilled road safety auditors is an important challenge for those in LMICs. Capacity can be increased in the short term by training of key staff (either within their own country, or through established courses in HICs). In the medium term it is desirable to establish capacity within a country to train auditors. This will typically require some form of longer term ‘train the trainer’ approach, whereby a small number of experts are provided with advanced training and on-going support. These experts then develop skills through experience to a point where they are in a position to train others.

Many countries have developed checklists for conducting road safety audits. These checklists provide examples and reminders of issues that should be assessed by audit teams during their assessment. They are useful to ensure that key issues are considered, but it also needs to be recognised that every situation differs, and therefore checklists should typically be used as guides only. This is because there may be other issues identified during an audit that were not anticipated by the existing checklist. Different checklists have been developed for different stages of the road safety audit process, or for specialist types of audit (for example, pedestrian and bicycle audits).

One criticism of road safety audits in the past is that the recommendations from the audit are not implemented. It is therefore critical that there be a process to complete the audit, including a formal response to the report. This should document a response to each of the actions recommended; and in cases where recommendations have not been accepted, the reasons for this and any other mitigating strategy that will be undertaken to help minimise risk should be stated. This written response to the audit report should become part of the project documentation.

Harwood et al. (2014) suggested that audit was a costly method for identifying interventions, and that there is potential to miss interventions that could be added that are cost-effective ways to improve safety. Also, economic assessment of interventions is typically not included unless conducted as an addition to the normal audit process. On the positive side, they suggest that audit is a useful way to identify safety features that are missing or in poor condition, and that they are a good way to bring together expert staff to review safety. They also identified advantages in conducting field reviews (i.e. site inspections), a process not always undertaken in other methods of risk assessment.

It is important to note that the road safety audit process has been around for many years. It was first established in the late 1980s, with documentation developed in many countries from the 1990s. However, there has been little recent adjustment of the road safety audit process to include Safe System concepts. In some countries, the focus is shifting to better capture issues related to eliminating death and serious injury, although this has always been an integral part of the audit process. The focus remains primarily on road-based deficiencies and the solutions are generally aimed at improving the road environment. In many situations, this approach may be adequate; however, in an attempt to take a Safe System-based approach, some jurisdictions have developed assessment frameworks that could be considered Safe System audits. These differ to traditional audits because they focus attention on the reduction of fatal and serious casualties and/or take a more holistic view of problems (and solutions) involving each of the Safe System pillars (e.g. safe user issues such as fatigue, potential for speed related crashes). The case study in Box 10.5 provides one such example.

BOX 10.5: CASE STUDY – APPLICATION OF THE SAFE SYSTEM APPROACH THROUGH SAFE SYSTEM AUDIT/REVIEW

The problem: In 2007, the Commissioner of Main Roads Western Australia directed that the road safety aspiration for a major road project would be zero deaths within the first five years of operation and the minimum condition of satisfaction would be a 10% reduction compared with best practice for the context of the road (i.e. a 10% improvement over existing best practice design). As the best design standards of the day were to be complied with and thorough road safety audit/review processes were to
be applied (as per normal practice) it was unclear how road safety could be further improved.

The solution: A new approach that focused attention on the fatal and serious injury crash risks was developed and applied. This provided a structured approach to the assessment of the project against Safe System objectives. A key feature of this framework is that it seeks to limit forces in the event of a crash to those that can be withstood by the human body. Another key feature is the recognition that road authorities need to use their limited resources in the most cost-effective manner. To address this issue, the framework provides a ‘hierarchy of control’ for treatments. This structured approach meant that there was greater use of ‘sustainable’ solutions (such as wire rope safety barrier) that would ensure high rates of protection for road users in the event of a crash.

The outcome: Despite the process commencing during the project’s construction (limiting opportunities to improve the project) a 28.6% lower fatal and serious injury rate compared to previous WA best practice was reported.

In addition to improving road safety, the approach can improve other project outcomes. For example, the second project reported a cost saving amounting to nearly 10% of the project budget and a significantly reduced environmental footprint.


A further example was developed by the Department of Planning, Transport, and Infrastructure (DPTI) in South Australia. This involved a full Safe System assessment for a major project, and was used as part of a successful business case to government to secure funding. The approach differed from a typical audit because it assessed vehicle and behavioural issues as well as the typical infrastructure issues. Interestingly, some of the vehicle and behavioural issues identified were able to be addressed through infrastructure changes (also see the discussion in Designing Infrastructure to Encourage Behavior).

In a recent development, quantified audits have been undertaken to determine the impact of new design. Changes can be made to this design and likely safety improvements determined. An example of this approach is provided in Management Tools.
The PIARC Road Safety Inspection Guideline for Safety Checks of Existing Roads (2012a) defines a road safety inspection (RSI) as a systematic, on-site review of an existing road with the aim of identifying hazardous conditions, faults and deficiencies that may lead to serious crash outcomes. An RSI must be carried out by an independent, qualified individual or team with the relevant experience, and is specific to existing roads, not those under construction. It is also a proactive method in that the prevention of crashes is achieved through identification of potential safety issues, rather than responding to recorded crashes in a crash location investigation.

Road safety inspections are useful as they can:

- complement blackspot treatments;
- identify issues with current maintenance procedures;
- identify locations for mass action treatments (i.e. hazardous features across a whole road network);
- allow for proactive treatment of potential crash locations (before crashes occur);
- check for consistency of road features;
- check for adequacy of traffic management features.

The PIARC (2012a) guide identifies the following topics as necessary to be covered during an RSI, as well as some of the questions a safety check team should be considering during an investigation:

- road function – is the road/speed limit appropriate for the role it plays in the network?
- cross-section – is the road wide enough; are the line markings sufficient; are the road surface conditions adequate?
- alignment – how do the horizontal and vertical alignments interact; are sight distances adequate?
- intersections – is the intersection layout and design appropriate for the volume of traffic passing through and the turning movements?
• public and private services – are there sufficient deceleration/acceleration lengths leading up to and away from service and rest areas; are the parking and loading facilities for public transport sufficient?
• vulnerable road user needs – have pedestrian, cyclist, scooter/moped and motorbike rider needs been accounted for?
• traffic signing, line marking and lighting – are traffic signs and line markings appropriate and clear; is the site well lit?
• roadside features and passive safety installations – are there roadside obstacles present that may pose safety issues?

There are four main steps to a road safety inspection on an existing road.

• desk study;
• on-site field study;
• road safety report;
• implementation of remedial measures.

An on-site field study component of RSI has evolved in recent years. Survey vehicles can be equipped with automated devices to measure and record design and road management elements (e.g. horizontal and vertical alignment, super-elevation, pavement surface condition, presence of roadside hazards, road inventory etc.). This information can be assessed to detect issues with routes, such as anomalies in curvature (e.g. unexpected severe curves); slippery road surface or presence of roadside hazards. Further details on this data collection can be found in Section 5.4.

A road safety inspection of an existing road aims to detect features that may lead to future crashes, and past crash information is not always a good indicator of this. Crash investigation and prevention programmes look at features that contribute to the occurrence and severity of crashes that have already happened. An RSI does not require crash data, but it can be a useful tool in terms of providing guidance towards prioritising which roads should be inspected. For instance, if the road authority only has enough funding to inspect a select number of roads, priority can be given to roads with a high number of crashes per kilometre, or crashes per traffic volume. More detail on prioritisation of policies, projects and treatments can be found in Priority Ranking Methods and Economic Assessment. Road safety inspections can be a useful complement to reactive approaches, such as high crash location investigations.

Sometimes RSI is undertaken on specific themes, for instance to identify issues relating to pedestrians or bicycles. This approach has been developed even further in France, where a method involving a specially equipped bicycle has been established to assess the bicycle network. Further information on this approach can be found at the following link: http://www.ouest.cerema.fr/IMG/pdf/120925_Securite-routiere_Vealudit_cle....

An RSI is not the same as a routine maintenance check, where issues such as vegetation, road surface inconsistencies and poor quality signage are reviewed and remedied. However, an RSI can identify safety issues that are a result of poor maintenance, such as poor signing, line marking or visibility issues.

Road safety inspections can lead to:

• the identification of inadequate road management practices;
• the initiation of new works programmes;
• changes in prioritisation of existing programmes;
• changes to maintenance procedures to meet road user needs.

Human factors are a crucial part of identifying hazards at a site. Further discussion on this issue can be found in Design for Road User Characteristics and Compliance.
Road safety inspections can be performed on the whole road network or on specific locations that are regarded as being the greatest risk. This is dependent on the road authority. It is important to note that road safety inspections of existing sites can result in a huge number of identified hazards and road safety issues. Under these circumstances, it is not economically viable to attend to all the issues listed. There is also little benefit to conducting an RSI on a site if the resources will not allow the majority of hazards to be addressed following the inspection. Sometimes it is more beneficial to invest in a maintenance programme to address a number of issues rather than conduct a formal RSI.

The PIARC Road Safety Inspection Guideline for Safety Checks of Existing Roads (2012a) provides a number of helpful checklists for different road types to ensure that each investigation of a site considers all the necessary elements. The checklists are similar in nature to those used for road safety audit. The guide also provides examples of appropriate RSI reports for both inter-urban and urban main roads. The African Development Bank (2014c) has recently released guidance on Road Safety Inspection that is specifically intended for use in LMICs.

Road Assessment for Safety Infrastructure

The proactive approach has been extended with a method that takes a quantified approach to the inspection of existing roads and road designs. Although several approaches exist, the most commonly applied is the Road Assessment Programme (RAP). Different RAP programmes exist in different regions, including EuroRAP, USRAP, AusRAP, KiwiRAP and ChinaRAP. These all fall under the global banner of iRAP (the International Road Assessment Programme). PIARC (2012b) notes that the iRAP approach is of great benefit where crash data is unavailable or coverage is limited.

RAPs take the concept of road safety audit and inspection a step further by estimating the risk (based on likelihood and severity) for different road sections based on road and roadside characteristics. A number of road elements are collected (e.g. through video and subsequent desk-based assessment; also see Non.
Crash data and Recoding Systems). Based on research conducted over many years, a lot is known about each of these variables, and the level of risk each produces. As an example, a straight section of road is safer than a road with a severe bend, and this risk level can be quantified. Each of the variables is quantified and an algorithm determines the risk of a fatal or serious injury for each segment of road (iRAP uses 100 m segments).

Such an assessment can be used to identify the highest risk and lowest risk segments of a network or road. A five-star rating system is used, with a one-star road providing the poorest road infrastructure, while on a five-star road the likelihood of a crash occurring and the severity of those that do occur is lowest. This information can also be colour-coded to provide a quick visual indication of road infrastructure safety. The process also allows separate star ratings for different types of road user (e.g. the vehicle occupant, pedestrian, bicyclist and motorcyclist).

The information can also be used to identify safety improvements that may be implemented, both at specific locations and across a whole network. Calculations can be updated to determine the likely safety benefit from such improvements. With knowledge of treatment costs and their benefit, as well as estimates of fatal and serious crash outcomes for a road network, an economic calculation can be undertaken to determine the most beneficial group of treatments to be applied to a road network or at a location. The software for this analysis is available online, and is provided free to road authorities to use. Further details on this can be found in Intervention Selection and Identification while a detailed description of the iRAP approach can be found at www.irap.org.

Reflecting the strong empirical basis behind the iRAP model, there is a strong linkage between the star rating of a road and the actual safety performance. An analysis performed by McInerney & Fletcher (2013) based on star ratings and crash cost (the average vehicle occupant fatal and serious injury crash costs per vehicle kilometre travelled) for almost 1,700 km of highway provides an example of this relationship. For each reduction in star rating (i.e. improvement in safety), the crash cost roughly halved. When moving from 1 star to 2, the crash cost reduced by 40%; from 2 star to 3 costs reduced by 61%; and from 3 star to 4 costs reduced by 44%.

Harwood et al. (2014) assessed the US RAP tools and compared this approach to other methods of assessing risk. They suggested that the approach was the most robust and quantitative in selecting interventions to improve safety, and that the recommendations were accompanied by economic assessment often missing in other methods. However, the approach was also identified as being quite labour intensive, with reliance on collecting roadway data and the coding of this data by skilled staff. However, they also suggested that this could be accomplished in a reasonably efficient manner. The consideration of risks associated with specific road user groups (motorcyclists, pedestrians, bicyclists as well as vehicle occupants) was also seen as an advantage.

A similar approach was adopted in South Africa, with the use of Netsafe (Box 10.6).

**BOX 10.6: IDENTIFICATION OF HAZARDOUS LOCATIONS USING NETSAFE – SOUTH AFRICA**

The problem: Accident statistics in South Africa are of poor quality. This makes it difficult to identify hazardous locations and the causes of accidents.

The solution: The solution involved the identification of potential hazardous locations on roads based on the existing road elements. South African National Roads Agency Ltd (SANRAL) developed a Road Safety Management System (RSMS) that outlines a holistic approach to road safety on their approximately 20 000 km of roads. An element of the RSMS was the development of the Netsafe algorithm.

SANRAL annually collects data on their roads using a survey vehicle with cameras and laser measuring
equipment. This data was previously only used for maintenance purposes, but by analysing this data and assessing the relationships between gradient, lane width, posted speed limit, available recovery area, type of median, spacing between accesses etc., a method was developed whereby potential hazardous locations can be identified along their routes.

Data was previously collected through a survey vehicle for road maintenance purposes. Analysing the data required for Netsafe, identified several issues relating to the completeness and accuracy of the data. GIS was used to filter several of these quality issues, and it took a substantial time to correct the data before it could be used reliably in Netsafe.

The roads were divided into sections of 10 metres and the geometric features of each section were then assessed, and based on a combination of these geometric features, a risk index was calculated. Taking into account the traffic volumes on the road, a priority index was calculated.

The outcome: The methodology was tested on some of the major routes in the country, namely the R61 between Mthata and Port St Johns, the N4 from Pretoria to Nelspruit and the N3 from Heidelberg to Durban.

These routes had reasonably accurate accident statistics available and a relatively good correlation was found between the Netsafe calculated high risk areas and the actual location of accidents.

As part of the RSMS, road safety audits became compulsory on all new SANRAL road upgrade projects.

Netsafe emphasized the need for rigorous quality control when doing data collection and capturing. Also, from this exercise, it was evident that accidents on mostly rural roads are quite rare, and also random. It is seldom that a potential hazardous location is clearly identified by real accident statistics – with a tool like Netsafe, the potential hazardous locations can be identified and prioritized. This is important when limited funds for additional more detailed road safety investigations are required.

**Source: Randall Cable, SANRAL**
10.5 COMBINING CRASH DATA AND ROAD DATA

Both the historical crash-based approach (reactive) and the assessment of risk through proactive means provide information on likely future crash locations. Combining these two approaches can provide a fuller picture of current risk locations, and where fatal and serious injury (FSI) casualties are most likely to occur in the future. Several approaches are emerging around the world that attempt to combine these methods to provide a fuller understanding of crash risk.

A ‘systemic’ safety project approach has recently been developed in the USA (Preston et al., 2013). The systemic approach focuses on network-wide solutions, and has been trialled by different states in the USA over the past decade. The tool is still being developed on a national level. This approach involves several steps, drawing on both crash data as well as other sources of information to identify and treat risk. The steps are as follows:

- analyse road crash data – by system (state and local level), road type, location, and location type (urban/rural, divided/undivided, intersection/segment), with a focus on severe crashes;
- identify crash locations;
  - by selecting crash types and facilities with the greatest number of severe crashes across the system;
  - by identifying and evaluating crash risk factors through examining the traffic volume, roadway/intersection features, posted speed limit, etc.
  - by prioritising locations through conducting a risk assessment and prioritising roadway facilities.
- select countermeasures – for each targeted crash type and establish their effectiveness, implementation and maintenance cost information;
- prioritise programmes – through a countermeasure selection decision process, developing safety projects and prioritising their implementation;
- rank projects – by determining the distribution of safety funds among the projects identified through site analysis and systemic risk assessment;
- evaluation – of consistency (whether the programme met the spending goals), changes in severe target crash types, and countermeasure performance.

The systemic approach identifies treatment sites that are not typically identified through traditional reactive analytical techniques (see Crash-based Identification (‘Reactive’ Approaches)). Central to this approach is the risk assessment approach, which involves the collection of roadway and traffic characteristics that relate to the selected risk factors and crash types. This is used to help identify the potential for locations or road segments to have severe crash outcomes. It is suggested that such information be collected either from existing road and traffic databases, or collected as part of a field review. In an example provided by Preston et al. (2013), an assessment of curves on a rural network identified a number of sites that had common risk characteristics as locations with severe crash outcomes, but that did not have a documented severe crash. It should be noted that the approach can be used with or without crash data.

Harwood et al. (2014) reviewed the systemic approach, identifying several strengths as well as areas for potential improvement. They suggested that this approach required less roadway data than other tools, did not require crash data to identify specific crash locations, and provided greater flexibility for target crash types and risk factors. However, this flexibility was also seen as a possible weakness, as there is a
reliance on users to identify potential risk factors, weight these risk factors, include issues such as traffic volume, and to conduct a cost-benefit analysis (an optional task) as part of intervention selection.

An approach has been developed in Australia that combines crash data with a more proactive approach. The Australian National Risk Assessment Model (ANRAM) provides road agencies in Australia with a nationally-consistent system for identification, measurement and reporting of severe crash risk. ANRAM was developed in close consultation with road agencies and the Australian Automobile Association (AAA) to ensure that the system’s outputs could drive preparation of future road safety engineering programmes. This was especially important for rural and local roads where severe crashes are generally too scattered to attract traditional blackspot funding. However, it was also recognised that these scattered crashes form a large proportion of all fatal and serious injury crash outcomes.

ANRAM draws together a number of approaches, from traditional crash-based assessment, Road Assessment Programmes and the US Highway Safety Manual (HSM; AASHTO, 2010). The HSM proposes a method that identifies a level of safety performance for different types of roads. There will be individual variation from this mean crash frequency, which may be due to each location’s variation in road features and operational factors that differ from the mean represented by the model, and due to statistical error. This variation in road features can be measured and the effect of this variation calculated; and in the case of ANRAM, the iRAP model (AusRAP in Australia) is used to do this. The process leads to a predicted number of crashes based on road design elements and features. This ‘proactive’ assessment of risk forms one of the key inputs to the identification of fatal and serious injury crash locations.

Australia also has a useful source of information on historic crash locations, although as with most crash data systems, this does not provide perfect knowledge of prior crash locations. However, this observed crash performance can be used to augment the predicted value identified in the model. This ‘reactive’ information supplements the proactive assessment of risk. An Empirical Bayesian approach is used, where the statistical robustness of the predicted crash value and the observed crash data are taken into consideration when assigning a weight to each. In situations where volumes are low and crashes are more scattered, a greater weighting is generally assigned to the predicted crash outcome. In situations with higher traffic volumes and consistent crash patterns, the observed crash outcomes have a higher weighting.

The basic structure of ANRAM is provided in Figure 10.9. Further details on this approach can be found in Steinmetz et al. (2014).

![Figure 10.9 Structure of the Australian National Risk Assessment Model (ANRAM)](image-url)

In New Zealand, the High Risk Rural Roads Guide (NZ Transport Agency, 2011) provides guidance on the use of crash data and predictive risk approaches (such as KiwiRAP) to determine high risk locations.
The New Zealand approach involves calculation and assessment of collective and personal (or individual) risk. Collective risk indicates crash frequency as experienced by the community, i.e. annual average crashes per kilometre of road being assessed. Personal (or individual) risk indicates risk to an individual road user expressed per kilometre of travel by a vehicle, i.e. annual average crashes per vehicle-kilometres travelled (VKT). Historical crash data (reactive) and/or predictive risk assessment (proactive) is used. Both approaches use a scale to categorise the level of risk: high (black), medium-high (red), medium (orange), low-medium (yellow) and low (green).

Using historical crash data (reactive approach) to identify the highest risk sections along the road, the collective and personal risk is categorised into different risk levels. Using this information, the highest risk sections of the road can be identified.

Alternatively, or in addition, a predictive risk assessment approach can be used. KiwiRAP star rating and road protection scores assess road crash risk based on road infrastructure (engineering) features. Star ratings (which typically apply to five kilometre road sections) are derived from the road protection scores (which are calculated for each 100 m segment). Figure 10.10 provides an example of risk categorisations that may be applied.

<table>
<thead>
<tr>
<th>Risk descriptions</th>
<th>Star rating (5km)</th>
<th>Road protection score (100m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>5</td>
<td>&lt;1.05</td>
</tr>
<tr>
<td>Low-medium</td>
<td>4</td>
<td>1.05-4.5</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
<td>4.5-10</td>
</tr>
<tr>
<td>Medium-high</td>
<td>2</td>
<td>10-25</td>
</tr>
<tr>
<td>High</td>
<td>1</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

Figure 10.10 Example of predictive assessment ('proactive') - Source: NZTA (2011).

The New Zealand Guide (NZ Transport Agency, 2011) recommends crash data analysis and review of key risk factors to inform development of an appropriate treatment programme to address the identified risk. Consideration of a road’s collective and personal risk helps guide the approach to road safety investment (refer to Project-Level and Network-level Approaches).
PATHWAY TO EFFECTIVE ASSESSMENT OF RISKS AND IDENTIFICATION OF ISSUES

GETTING STARTED

- Guidance documents on the assessment of risk should be adopted by road agencies, and training provided for key staff and external stakeholders on treatment of high crash locations, impact assessments, road safety audits, safety inspections, and road assessment programmes.
- Policies and processes should be put in place by road agencies to embed these approaches as part of core business.
- Investigation of high risk routes and areas should be undertaken to identify locations with a high incidence of fatal and serious crash outcomes. Demonstration projects should be instigated at these locations as a way of improving safety, but also to assist in building capacity and engaging with key stakeholders.
- Where available, crash data should be used to help assess high risk locations. Where crash data is not available, collection should commence, at least on high volume, high risk routes.
- Presentation of crashes on maps is an easy way to identify high crash locations, and can be a useful starting point to address crash risk.
- Data on safety-related road elements (e.g. through safety audit and road assessment programmes) should be collected to identify high risk locations. Other survey data (such as speed surveys) can also help identify high risk locations. This is particularly useful in the absence of accurate crash data.

MAKING PROGRESS

- Review and internationally benchmark existing guidance documents and approaches on risk assessment and update to ensure these are in accordance with international good practice.
- Refine adopted road safety tools to ensure that they meet local needs, and reflect good practice. Ensure core road agency staff and stakeholders (internal and external) are adequately trained in these tools and approaches and applying these in their role. This includes staff responsible for national, regional and local roads.
- Ensure that risk on all roads is investigated to determine locations with a high incidence of fatal and serious casualties. This should include through the analysis of crash data and safety-related road elements. This data should be integrated with other safety-related information (including behavioural survey results) to help identify risk locations, as well as effectively manage road safety outcomes through a performance management framework.

CONSOLIDATING ACTIVITY

- Continue to review and internationally benchmark existing guidance documents and approaches on risk assessment and update to ensure these are in accordance with international good practice.
- Continue to refine tools and adapt them to meet local needs. Ensure that these tools are used by all relevant stakeholders.
- Ensure all relevant staff and stakeholders (internal and external) are adequately trained in these approaches and applying these in their role. Develop systems to ensure staff and stakeholders maintain high levels of skill.
- Continue to investigate risk on all roads to determine locations with a high incidence of fatal and serious casualties. This assessment should utilise all relevant sources of information, including a combination of crash data, safety-related road elements and other safety-related information.
10.6 REFERENCES


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