Grant Agreement Number: INEA/CEF/TRAN/M2018/179967

Project acronym: SLAIN

Project full title: Saving Lives Assessing and Improving TEN-T Road Network Safety

Due delivery date: 30 September 2020
Actual delivery date: 15 September 2020

Organisation name of lead participant for this deliverable: RSI ‘Panos Mylonas’

D3.1 Technical Justification for Network-Wide Road Assessment

Co-financed by the Connecting Europe Facility of the European Union
Document Control Sheet

<table>
<thead>
<tr>
<th>Version History</th>
<th>Input by Consortium partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1.0</td>
<td>Draft version by RSI ‘Panos Mylonas’</td>
</tr>
<tr>
<td>V1.1</td>
<td>Second draft by RSI ‘Panos Mylonas’</td>
</tr>
<tr>
<td>V1.2</td>
<td>Version shared with EuroRAP</td>
</tr>
<tr>
<td>V1.3</td>
<td>Third draft by RSI ‘Panos Mylonas’</td>
</tr>
<tr>
<td>V1.4</td>
<td>Final version for submission</td>
</tr>
</tbody>
</table>

Legal Disclaimer

The information in this document is provided “as is”, and no guarantee or warranty is given that the information is fit for any particular purpose. The above referenced consortium members shall have no liability for damages of any kind including without limitation direct, special, indirect, or consequential damages that may result from the use of these materials subject to any liability which is mandatory due to applicable law. © 2020 by SLAIN Consortium.

Acknowledgement

The SLAIN beneficiaries are grateful to EuroRAP and iRAP for the research information provided. The report was coordinated and prepared by RSI Panos Mylonas, with final editing and liaison with INEA by the project coordinator EuroRAP.

Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAIN</td>
<td>Saving Lives Assessing and Improving Network Safety</td>
</tr>
<tr>
<td>TEN-T</td>
<td>Trans-European Network - Transport</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>SRIP</td>
<td>Safer Roads Investment Plans</td>
</tr>
<tr>
<td>RSA</td>
<td>Road Safety Audit</td>
</tr>
<tr>
<td>RSI</td>
<td>Road Safety Inspection</td>
</tr>
</tbody>
</table>
# Table of Contents

1 Objectives .......................................................................................................................... 7
  1.1 SLAIN project objectives ................................................................................................. 7
1.2 SLAIN Activity 3 .................................................................................................................. 7
2 Task descriptions and methodology .................................................................................... 8
  2.1 Task 3.1: Literature review and comparison analysis using simulated and real data .......... 8
  2.2 Task 3.2: Crash data collection and synthesis ................................................................. 8
  2.3 Task 3.3: Comparative analyses ..................................................................................... 8
3 Literature review and comparison analysis .......................................................................... 9
  3.1 Black spot Analysis .......................................................................................................... 9
    3.1.1 Definitions and principles ......................................................................................... 9
    3.1.2 Identification methods ............................................................................................ 10
      3.1.2.1 Crash based methods ......................................................................................... 10
        3.1.2.1.1 Numerical techniques .................................................................................. 10
        3.1.2.1.2 Statistical techniques .................................................................................. 11
        3.1.2.1.3 Site-related crash techniques ...................................................................... 12
        3.1.2.1.4 GIS techniques .......................................................................................... 12
      3.1.2.2 Non-crash based methods ................................................................................... 13
        3.1.2.2.1 Observational techniques .......................................................................... 13
    3.1.3 Treatment Oriented Policies ...................................................................................... 14
    3.1.4 Black spot Analysis Features ................................................................................... 14
3.2 Route Safety Assessment .................................................................................................. 15
  3.2.1 Definitions and Principles ........................................................................................... 15
  3.2.2 Division of the Road System ....................................................................................... 16
  3.2.3 Assessment Methods ................................................................................................... 18
    3.2.3.1 Crash based methods .......................................................................................... 18
      3.2.3.1.1 Numerical techniques .................................................................................. 19
      3.2.3.1.2 Statistical techniques .................................................................................. 19
      3.2.3.1.3 Site-related crash techniques ...................................................................... 21
      3.2.3.1.4 GIS techniques .......................................................................................... 21
    3.2.3.2 Non-crash based methods ..................................................................................... 21
      3.2.3.2.1 Quantitative techniques .............................................................................. 21
      3.2.3.2.2 Empirical techniques .................................................................................. 26
  3.2.4 Treatment Oriented Policies ....................................................................................... 27
    3.2.4.1 Route Action Plan ............................................................................................... 28
    3.2.4.2 Mass Action Plan ................................................................................................ 28
    3.2.4.3 Area Wide Scheme ............................................................................................. 29
3.2.5 Route Safety Assessment Features ......................................................... 29
3.3 Network-Wide Road Assessment ................................................................. 30
  3.3.1 Definitions and Principles .................................................................. 30
  3.3.2 Assessment Methods .......................................................................... 31
    3.3.2.1 RAP Crash Risk Mapping .......................................................... 31
      3.3.2.1.1 Subdivision of the network into RAP sections ..................... 33
      3.3.2.1.2 Crash Data Handling ......................................................... 34
      3.3.2.1.3 Traffic Flow Data ............................................................. 34
      3.3.2.1.4 Assessment Period ............................................................ 35
      3.3.2.1.5 Estimating rates for each road section ............................... 36
      3.3.2.1.6 Risk Mapping Specifications ............................................ 36
  3.3.3 Treatment Oriented Policies ................................................................. 37
  3.3.4 Network-Wide Road Assessment Features ........................................... 38
4 Road crash data collection and analysis for Case Study ................................ 39
  4.1 Crash data information ........................................................................... 39
  4.2 Crash data synthesis ................................................................................ 39
    4.1.1 Crash severity .................................................................................. 39
    4.1.2 Crash type ....................................................................................... 40
5 Comparative analyses .................................................................................. 44
  5.1 Black spot Analysis .................................................................................. 44
    5.1.1 Application at the Greek Core TEN-T Network ............................... 44
    5.1.2 Application in the Greek Comprehensive TEN-T Network .......... 46
  5.2 Route Safety Assessment ......................................................................... 48
    5.2.1 Application in the Greek Core TEN-T Axis .................................... 48
    5.2.2 Application in the Greek Comprehensive TEN-T Axis ................. 50
5.3 Network-Wide Road Assessment ............................................................... 52
  5.3.1 Poisson Test ......................................................................................... 52
  5.3.2 RAP Crash Risk Mapping ................................................................. 53
    5.3.2.1 Subdivision of the TEN-T Network into RAP sections .............. 53
    5.3.2.2 Calculation of Risk Band Thresholds ......................................... 54
    5.3.2.3 Collective risk ............................................................................. 56
    5.3.2.4 Individual risk ............................................................................ 57
  5.3.3 RAP Star Ratings .................................................................................. 58
6 Conclusions .................................................................................................. 62
List of Figures

Figure 1: The overall black spot identification methods ................................................................. 10
Figure 2: The overall route safety assessment methods .............................................................. 18
Figure 3: The iRAP Star Rating and Safer Roads Investment Plan process .................................... 24
Figure 4: The relationship between Star Ratings and the cost of fatalities and serious injuries .......... 25
Figure 5: The overall network-wide road assessment methods .................................................. 31
Figure 6: EuroRAP Risk Mapping Colour Palette ........................................................................ 36
Figure 7: Standard procedure for producing RAP Crash Risk Mapping ......................................... 37
Figure 8: Crash severity distribution in Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) ................. 40
Figure 9: Crash severity distribution in North Road Axis of Crete (Chania-Sitia, 2014-2017) .......... 40
Figure 10: Crash type distribution in Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) ................... 41
Figure 11: Crash type distribution in North Road Axis of Crete (Chania-Sitia, 2014-2017) ............... 41
Figure 12: Egnatia Motorway (Sindos I/C-Kipi) – Crash location type .......................................... 43
Figure 13: North Road Axis of Crete (Chania-Sitia) – Crash location type ....................................... 43
Figure 14: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Black spot Crash Severity ................. 45
Figure 15: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Black spot crash type ..................... 45
Figure 16: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Black spot Crash Severity ............ 47
Figure 17: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Black spot Crash Type ............... 47
Figure 18: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Crash distribution per section ............ 49
Figure 19: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Crash distribution per section ...... 51
Figure 20: Star Ratings-Level of risk for vehicle occupants across the Case Study ......................... 58
Figure 21: Star Ratings-Level of risk for motorcyclists across the Case Study ................................. 59
Figure 22: FSI estimation across the Case Study ............................................................................ 60

List of Tables

Table 1: Regression-to-mean change in crash rates over time ......................................................... 35
Table 2: The Greek TEN-T network under consideration ............................................................ 39
Table 3: Black spots on Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) ...................................... 44
Table 4: Black spots in North Road Axis of Crete (Chania-Sitia, 2014-2017) ................................. 46
Table 5: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Crash distribution per section .......... 48
Table 6: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Hazardous Road Sections .................. 50
Table 7: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Crash distribution per section ...... 50
Table 8: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Hazardous Road Sections .......... 52
Table 9: Poisson Test – Hazardous road sections across the examined Greek TEN-T Network ...... 53
Table 10: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Crash distribution per RAP section .... 54
Table 11: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Crash distribution per RAP section .. 54
Table 12: Risk Bands 2020 Thresholds (3-year standard) .............................................................. 54
Table 13: Scaling Factor Calculation ............................................................................................. 55
Table 14: Calculating risk band thresholds for crash density (Risk Bands 2020) .......................... 55
Table 15: Calculating risk band thresholds for crashes per vehicle kilometre travelled (Risk Bands 2020) 56
Table 16: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Collective risk per RAP section ........ 56
Table 17: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Collective risk per RAP section .... 56
Table 18: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Individual risk per RAP section ......... 57
Table 19 North Road Axis of Crete (Chania-Sitia, 2014-2017) – Individual risk per RAP section .......... 57
Table 20: Star Ratings distribution for vehicle occupants and motorcyclists across the Case Study .......... 61
Table 21: Implementation of road risk assessment approaches – Results ...................................... 62
Executive Summary

Within the framework of SLAIN Activity 3, there is an overall review of the different road risk assessment approaches, focusing specifically on “black spot”, route safety and network-wide road assessment, the techniques by which these approaches are implemented, as well as the primary principles and features of each approach.

The literature review is followed by a Case Study for demonstration purposes of the methodologies for crash analyses and risk assessments. The Case Study comprises approximately 624 km of the Greek TEN-T road network, including part of the Core and the Comprehensive network. More specifically, Egnatia Motorway (section from I/C Sindos to Kipi) and North Road Axis of Crete (NRAC - section from Chania to Sitia) were selected.

A comparison is made between the described road risk assessment approaches from the literature review, through the implementation of these approaches in the demonstrated Greek TEN-T network, in order to reach safe conclusions about the best possible crash treatment approach.

Finally, through the comparison of these approaches, an estimation of the comparative assets and benefits gained from a network safety approach is provided.
1 Objectives

1.1 SLAIN project objectives

The project’s Action fits in the EC’s 2010 Communication ‘Towards a European Road Safety Area’ and aims to contribute to the long-term goal for zero road deaths in 2050. With partners in the different countries, Project SLAIN is a transnational project aiming to extend the skills and knowledge base of partners in performing network-wide road assessment.

The main areas to be covered within the SLAIN project are:

- Demonstration of a methodology of network-wide assessment
- Assessment of the Safety Performance Management of the TEN-T core road network and, if possible, beyond in four European countries: Croatia, Greece, Italy and Spain where road surveys will be performed (10,000 km of mapping)
- Proposals of section-specific, economically viable crash countermeasures designed to raise infrastructure quality to achieve significant reductions in severe injuries and deaths
- Preparation of the readiness of Europe’s physical infrastructure for automation

The SLAIN consortium consists of eight core partners, coming from six EU member states, namely Greece, Italy, Spain, Croatia, UK and Belgium. The list of partners includes EuroRAP - Project Coordinator, Anas, FPZ, RSI Panos Mylonas, RACC-ACASA, DGT Spain, SCT Spain, TES Spain (Catalonia), and iRAP.

1.2 SLAIN Activity 3

The objective of Activity 3 is to compare network-wide road assessment alongside other methods – providing information and know-how to countries who are yet to carry out network assessment.

Initially, an overall review of different forms of network-wide road assessment and a comparison of these strategies with traditional “crash cluster” and “hot spot” approaches is conducted. Subject to suitable data availability, this task used crash data available from the Greek TEN-T network, to explain and provide a rationale for potential users of a network assessment approach. Sites and road lengths are presented with details of the crashes that have happened on those roads and a rationale is constructed of the most efficient way to treat those crashes. This is demonstrated in a way that is accessible to practising engineers who are the potential users.

This Deliverable is written both from the perspective of analysis of the currently used methods in road safety assessment and from the perspective of estimating how useful network-wide road evaluation is as a tool in approaching safe system in road safety engineering.
2 Task descriptions and methodology

2.1 Task 3.1: Literature review and comparison analysis using simulated and real data

This task engages the identification and review of the latest currently available methodologies used for road safety assessment. The review tracks the evolution of the safe system approach in the field of road safety engineering, through “hot spot”/crash cluster technique, route safety approach, route action and mass action plans to explain the rationale for network-wide safety assessment and the types of benefits that emerge from such an approach.

2.2 Task 3.2: Crash data collection and synthesis

Within the context of this task, real world crash data are gathered for over 500km of TEN-T network, while crash patterns are assessed. The whole data set is extracted from the Greek network and selected by trial and error in order to support examples of the approaches described in Task 3.1.

2.3 Task 3.3: Comparative analyses

This task examines which crashes are amenable to “hot spot”, “route action” or network-wide road assessment. An estimation of the comparative effectiveness of different approaches based on real-world crash data gained from the Greek TEN-T network is provided.
3 Literature review and comparison analysis

An overall review of different methodologies used in road safety assessment, focusing on the rationale of traditional approaches, such as black spot analysis and route safety assessment and comparing these approaches to network-wide road assessment is contained at the following.

3.1 Black spot Analysis

3.1.1 Definitions and principles

There is no standard or official definition assigned to the term of a black spot. Nevertheless, from a theoretical point of view, a black spot is considered to be any location on the road network that has a higher expected number of crashes than other similar locations, as a result of local risk factors\(^1\). Typically, black spots refer to specific roadway elements, such as intersections and curves, covering a road component no longer than 500 metres.

In general, a black spot is considered to be a site that has a high number of recorded crashes during a specific period. This definition implies that black spots cannot be profoundly identified without any reference to the normal level of safety. Some of the currently engaged definitions of black spots in European countries make an explicit reference to the normal level of safety, but this is not the norm. References to the normal level of safety are generally made by comparing the number of crashes at sites documented as black spots with the number of crashes expected for similar sites, typically estimated by means of crash prediction models.

In addition, some definitions of black spots take crash severity into account, while others do not. If crash severity is considered, there is no standard way of doing so. Thus, two alternative approaches could be identified. The first approach is to set a more rigid critical value for the number of fatal or serious injury crashes than for slight injury or damage only crashes, when identifying high risk sites. The second approach is to apply weights to crashes at different levels of severity and predefine the value of a critical indicator which should be exceeded in order to define a specific site as black. According to the above described approach, a single road location is named as a black spot and is regarded as a hazardous site, when there is an increased probability of crashes happening, particularly severe or fatal crashes.

The length of the period used to identify black spots varies from one year to five years. A period of three years is frequently used. Research\(^2\) shows that the gain in the accuracy of identification obtained by using a longer period of three years is marginal and declines rapidly as the length of the period is increased. There is little point in using a period of more than five years.

Black spots are also referred to as ‘hazardous road locations’, ‘crash prone locations’, ‘dangerous crash sites’, ‘hot spots’ or ‘high risk sites’.

Finally, black spot analysis encompasses the definition and identification of black spots, analysis of crashes and local risk factors at the black spots, planning and implementation of treatments, as well as appraisal of the treatments.
3.1.2 Identification methods

Black spot analysis has a long tradition in traffic engineering and still finds application in the road safety assessment process, in several countries of the European Union. The main argument behind this fact is that it is still regarded as a vital part of the site traffic safety work done by the road administration authorities.

Since the 1950s and through the years, there is a set of methods and techniques that have been developed in order to detect hazardous sites. In general, identification methods may be disaggregated into crash based and non-crash-based methods. Furthermore, the crash-based methods can be divided into numerical and statistical techniques. In contrast, the non-crash-based methods are analysed into observational techniques. In addition, site-related crash and GIS techniques are situated among numerical and statistical techniques. Finally, the diverse methods may be combined in several ways. This is demonstrated in Figure 1.

![Figure 1: The overall black spot identification methods](image)

3.1.2.1 Crash based methods

The crash-based methods rely on data from the official crash statistics. For each country, crash statistics may be acquired either from traffic police records or from the pertinent statistical authority. Relevant traffic crash data may also be retrieved from hospital or insurance companies’ records.

3.1.2.1.1 Numerical techniques

Concerning the numerical or non-model-based techniques, these techniques constitute elementary methods of determining hazardous locations and rely on plain comparison of selected constant values. The numerical methods define the period and specific locations, on which there is a high frequency of
crashes. Apparently, these techniques do not take random fluctuation in crash counts generation into consideration. The random fluctuation in crash counts is explicated as the variation in the recorded number of crashes around a given expected number of crashes. On the opposite, non-model based methods are quite simple in use and do not require advanced scientific expertise.

Numerical techniques are further disaggregated into the crash count and crash rate calculation techniques, as in the following.

**Crash Count**

The ‘Crash Count’ technique suggests the simplest and fastest method for the determination and selection of high-risk sites. The process behind this technique is the following. Initially, the total of traffic crashes regarding a specific time period is recorded and then all crash sites are sorted in a descending order, according to the number crashes that have taken place. Subsequently, the locations with a number of crashes higher than a specified threshold-value are selected. The threshold-value is defined in a manner that it is potential to examine all of the emerging high-risk sites. In theory, every crash site should be closely studied in order to determine the local risk factors, but in practice this is not a feasible procedure.

**Crash Rate**

The ‘Crash Rate’ numerical technique focuses on the calculation of the crash rate on a particular site. For the purposes of black spot analysis, crash rate is defined as the number of (injury or not) crashes per million vehicles approaching a site (e.g. intersection). The crash rate expresses the level of risk in a single location, due to the level of use of the road element, during a specific period. The reasoning behind this method is that considering only the absolute number of crashes that have occurred at a single location could lead to deceptive conclusions, when traffic volumes alter substantially from one site to another. It is quite evident that two different road spots containing the same amount of crashes cannot be equally hazardous, when the traffic volumes assigned to each spot vary at a noticeable level. This rational gap is filled by the crash rate calculation. The identification stage follows the same process as the one of the crash count method. The crash sites are sorted in a descending order, according to the related crash rate and finally the sites with a crash rate higher than a defined critical value are selected. Likewise, the critical value is defined in a manner that has potential to examine all of the emerging high-risk sites.

Finally, a combination of the two methods described above is likely to be made. In this perspective, sites that recorded a number of crashes greater than a defined value (e.g. the average crash count among the population of sites), and had a higher crash rate than a critical value (e.g. the average crash rate) are classified as black spots.

### 3.1.2.1.2 Statistical techniques

As an alternative, model based, or statistical techniques are used in order to locate black spots. The rationale behind these techniques is that they take random variations in crash counts into consideration due to the stochastic nature of crashes. Thus, these methods use – in general – crash models or functions to estimate the local expected number of crashes at a specific location. The most significant statistical methods used are the Poisson analysis and Bayes Method, as detailed below.

*Poisson Analysis*
The Poisson analysis considers that traffic crashes follow the discrete distribution of Poisson. Thus, the probability of a certain number of crashes occurring in a particular location can be estimated. Basically, it describes the probability that any given number of crashes will occur in terms of this number and a quantity which is called the expected number of crashes.

The first crucial step towards the application of this method is to define a certain level of statistical confidence. Subsequently, it is recommended to estimate the expected number of crashes regarding the examined location. In this approach, the expected number of crashes (or Poisson distribution average) is equal to the average number of crashes of all locations under study, for the perceived period. After the above tasks have been accomplished, it is possible to calculate the critical number of crashes referring to the site under investigation. Finally, a single location is considered to be a black spot, if the recorded number of crashes exceeds the critical number of crashes (as calculated for a defined level of significance).

**Bayes Method**

In the Bayes method, the local expected number of crashes on a specific site is estimated as a weighted mean of the registered number of crashes at the location and the general expected number of crashes for similar sites estimated by crash models. In fact, the Bayes analysis relies on the traffic crashes record of a particular location in combination with the risk profile of other similar locations in order to define black spots. Therefore, locations with an extraordinary expected number of crashes are regarded as high-risk sites and investigated further.

### Site-related crash techniques

Site-related or site-specific crash techniques are located among both the numerical and statistical analysis techniques. The black spot determination process relies exclusively on site-related crashes through specific crash themes or types of crashes associated with road related risk factors whereby all interference from non-site-specific crashes is removed already in the identification stage. In this manner, the hot spot analysis is, to some degree, already on track in the identification procedure. The main argument supporting this technique is that there will be a more effective traffic safety work as an outcome, compared with the traditional crash-based techniques.

However, site-related crash techniques incorporate some negative features. First of all, an essentially high number of crashes at a location compared with similar locations must indicate that there are local risk factors and it is thus redundant to tie the identification to road related crashes to detect sites with road related traffic safety problems. Furthermore, it can turn out to be a problem to limit the crash data, which already is limited in many countries due to crash under-reporting. In addition, site-related crash recognition requires a relatively comprehensive identification process, which may demand quite a high amount of resources. Moreover, concentrating on particular themes and crash profiles could result in the failure to identify other traffic safety problems on the sites.

### GIS techniques

GIS (Geographic Information System) based techniques are frequently used alongside other crash based techniques. In general, the principle is that the area under study is separated into squares, and the number of crashes in every square is counted. Black spots are then defined as the squares containing most crashes.
3.1.2.2 Non-crash based methods

As mentioned above, the crash-based methods depend on the official traffic crash statistics. However, due to severe under-reporting of crashes in many countries, a question emerges about the validity of the recorded data. Thus, there is an increased possibility that the registered statistics have a low and unbalanced coverage in comparison with the actual situation. This implies that there is a risk of focusing on some wrong locations and causing problems during the analysis. To avoid this problem, many efforts of developing and implementing non-crash based methods have been made in the past years. In the subsequent section the most significant non-crash based technique is presented.

3.1.2.2.1 Observational techniques

Public authorities in many countries have made serious efforts to develop and publish specific non-crash based methods in the field of road safety assessment and, consequently, attempt to recognize hazardous sites. A significant non-crash based, observational technique that is used across the globe is the traffic conflicts technique.

Traffic Conflicts technique

Traditionally road crash statistics are used to assess the level of road safety and evaluate road safety programs. In some cases, though, the lack of valid and reliable crash records has hampered proper analyses. Moreover, traffic crash data are often not suitable for diagnosing safety problems at points of interest (e.g. intersections) or for evaluating the effectiveness of improvements. A considerable approach that overcomes these problems is the traffic conflicts technique which relies on observations of critical traffic situations for safety analysis. A traffic conflict is considered to be a traffic event involving two or more road users, in which one user performs some atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive manoeuvre is undertaken. A traffic conflict is possible to be the outcome either from an evasive action (e.g. aggressive lane change) or traffic violation (e.g. crossing a signalized intersection with a red light).

In general, there is an increased possibility that traffic crashes occur at sites where a considerable number of evasive manoeuvres and traffic violations are observed and recorded. Therefore, traffic conflict techniques enable transportation engineers to locate and investigate hazardous road sites without the need to obtain crash data. These techniques are the most developed indirect measure of traffic safety. The concept of these techniques is based upon the ability to identify the occurrence of near-crashes and therefore, offer a faster and, in many respects, a more representative way of estimating potential crash frequency and crash outcomes.

Although the above traffic conflict definitions and techniques have high face validity as indicators of safety hazards, it is still difficult to tie such events in a statistical fashion to traffic crashes. The main reason behind this statement is that traffic conflicts, as stochastic traffic events, vary quite markedly in number and rate from day to day even under nominally identical conditions, just as other traffic events such as crashes and turning volumes do. Furthermore, the assessment of conflicts engages an element of subjective judgement and therefore it is important to ensure that suitably skilled and experienced personnel undertake the analysis. Even though an individual could become extremely proficient and produce very repeatable results from day to day, it is operationally significant to recognize that the events themselves are not totally repeatable. As a consequence, traffic conflict techniques are mostly regarded as supplements, rather than replacements for crash data based methods. Finally, from the
traffic conflict definition itself, it is concluded that traffic conflict techniques refer mostly to high risk spots rather than hazardous road sections.

3.1.3 Treatment Oriented Policies

Black spot analysis and single site investigations are the foundation of Road Safety Engineering. The identification of single high-risk sites and the investigation of crashes occurring at a single location lead to an understanding of the cause of the crashes. Thus, it is feasible for road authorities to develop proper treatment policies and countermeasures that help eliminate local risk factors and help future road users to cope.

The suggested countermeasures, following the black spot analysis, usually concern simple remedial measures that significantly reduce the problem on a local-basis level. By identifying and eliminating the features that make a site hazardous, road safety level can be considerably upgraded. This typically means reducing the complexity of an intersection by decreasing the number of possible manoeuvres or enabling manoeuvres to be made in stages, through the establishment of a traffic signalization system. The reduction of the number of decisions drivers must take, simplifies the driving task and helps drivers to progress in safety and comfort with a minimum level of interaction with motorised traffic, cyclists and pedestrians.

The potential treatments can be disaggregated into three classifications, according to which element of the road safety system is benefited the most:

a) Road Treatments
b) Vehicle Treatments
c) Pedestrian Treatments

3.1.4 Black spot Analysis Features

The main features underlying the rationale of black spot analysis is summarized in the following:

- Black spot analysis is associated with the definition and identification of hazardous road locations, typically referring to a single road element (e.g. intersection, curve, etc.).
- Black spot analysis constitutes a quite simplified approach of the road safety assessment process.
- The proposed countermeasures, following the completion of black spot analysis, are related to the upgrade of road safety on a low-scale (microscopic) level.
- Black spot analysis may resolve traffic safety issues concerning a single hazardous site, but other underestimated high risk locations may arise in the future.
- Countermeasures proposed to solve a local level safety issue mostly concern low-cost solutions on a short-term basis, but they may turn out to be cost-ineffective solutions on a long-term basis, as it is possible that financial resources might be inadequate to confront new hazardous sites that may emerge in the future.
3.2 Route Safety Assessment

3.2.1 Definitions and Principles

Encouraged by the results of single site techniques, Engineers began to look for wider applications for these techniques. One practice to emerge from this search was the crash analysis along sections of a specific route, which is part of the route safety assessment process. The analysis is used to identify the route’s crash problems so that crash countermeasures may be designed and implemented. Therefore, more and more countries have supplemented black spot analysis with route safety assessment.

Route safety assessment comprises the definition and identification of hazardous road sections along a route, analysis of crashes and section based risk factors at the hazardous road sections, proposing and implementing treatments, as well as undertaking evaluation of the treatments.

Similar to black spots, no international standard definition of hazardous road sections exists. Moreover, no definitions have been explicitly formulated with the exception of a few references. It is also very difficult or maybe impossible to make a simple and short definition of hazardous road sections because it is necessary to consider many parameters in the formulation. However, definitions can indirectly be interpreted from the identification method.

Based on the explicitly formulated definitions, interpretation of current method and common understanding about route safety assessment, it is concluded that hazardous road sections most often are defined in the same way as black spots. This means that hazardous road sections can be defined as any section at which the site-specific expected number of crashes is higher than for similar sections, due to local and section based risk factors present at the site.

Nonetheless, this particular definition on hazardous road sections has been exposed to criticism. The main argument is that the definition and, subsequently, the identification method should not be based solely on site-specific crashes through specific crash themes or types of crashes associated with road related risk factors because this will remove all interference from non-site specific crashes already at the identification stage. In addition, this definition should not only include the number of crashes but also severity.

Another criticism of the typical definition of hazardous road sections is that cost effectiveness is not directly included in the definition. However, this is more or less indirectly included in the typical definition, because the primary focus is on local detailed road layout and traffic behaviour, which can be treated relatively inexpensively because it is only the detailed road layout and traffic behaviour that have to be changed and not the general road layout. To include cost effectiveness directly in the definition and identification would also result in a very comprehensive identification stage because a crash analysis and suggestion for treatment in principle have to be made as part of the identification.

Based on the above analysis, the following definition of hazardous road sections is mostly used. Thus, a hazardous road section is any section that has a higher expected number and severity of crashes than other similar road sections as a result of local and section based crash and injury factors.

Hazardous road sections are also referred to as ‘dangerous segments’, ‘problem roads’, ‘grey’ or ‘red’ road sections, ‘crash prone locations’, ‘one-star roads’ or ‘roads for safety investigation’. The most common and frequently used term is hazardous road sections.
The time period used to identify hazardous road segments varies from one year to five years. Typically, a period of three years is used. Nevertheless, the period used in route safety assessment could be shorter than the period used in black spot analysis, because normally more crashes are concentrated on the long hazardous road sections, than on the short black spots\textsuperscript{11}. On the contrary, if route safety assessment is implemented in the safest countries, a longer time period has to be used.

The main difference between black spot analysis and route safety assessment with regard to basic philosophy for the work is that black spot analysis has a remedial and retrospective nature, while route safety assessment typically has both a remedial and retrospective nature as black spot analysis and a preventive and prospective nature. Route safety assessment has a remedial and retrospective nature because the identification stage relies on crash history. The more preventive and prospective nature is located in the subsequent analysis and improvement stages because they typically are based on both crashes and general traffic safety issues and standard improvements. In this approach, the rationale is that remedial improvements on crash locations are spread out on the whole road section and thereby also gain a preventive and prospective nature. For instance, the application of median barriers along a route helps prevent head-on crashes across the entire road segment, not merely at single sites with relevant crash history.

Finally, a major difference between black spot analysis and route safety assessment is, by definition, the length of the road elements considered. Black spots typically have a length of up to 0.5 kilometres, whereas hazardous road sections have a length of between 2 and 10 kilometres.

3.2.2 Division of the Road System

The first crucial step towards the application of route safety assessment and the identification of hazardous road sections is the division of the road system into discrete road segments. Thus, a basic question in relation to application of route safety assessment is how the road system should be separated into smaller road sections and how long these sections should be.

The division of the road system regularly depends on the method used to identify hazardous road sections. However, there are some common principles applied during the division process.

First of all, the road sections should have variable and not constant length. Variable length means that the road sections have different lengths, e.g., between two and ten kilometres. This is recommended because it offers the opportunity to ensure road sections that are more or less homogeneous with regard to parameters that have substantial influence on the number of crashes. Moreover, the road sections have to be homogeneous in order to have comparison able results between the different segments. Therefore, division can be done by complying with the following four principles:

1. Section based principle
2. Point based principle
3. Crash based principle
4. Combination of the above

The first two principles can be characterized as road and traffic-based division principles. In the first principle, the road system is divided into sections that are homogeneous with regard to selected traffic and road design parameters that have essential influence on the number of crashes.
The second principle is a point-based principle, where intersections, towns or other “points” are utilised as division points.

The third principle is based on registered crashes in the study period. Either there has to be a certain number of crashes on each road section or there has to be a uniform crash concentration or pattern on each road section.

Finally, the last principle is the combination of the above described principles. An obvious opportunity is to combine the first two principles. The two principles differ a lot from each other, but in practice, they will result in some more or less similar division and can therefore advantageously be combined. The reason that the two principles approximately give the same result is that significant changes in road design and traffic apparently coincide with larger intersections and towns.

To ensure trustworthy identifications and a potential for efficiently reducing the number of crashes, the first two principles could be combined with the 3rd principle that each road segment is necessary to have a particular number of crashes. Note that the principles about homogeneous road sections and a certain number of registered crashes often will be conflicting.

It is also recommended that the road and traffic-based division principles are used. The argument is that these principles more or less will lead to similar division of the road system for different time periods, which makes it possible to compare the crash level for different time periods for each road section.

The recommendation about how to divide the road system into road sections has relatively general character. Furthermore, road systems vary much from country to country, i.e., the use of the identical principle could result in road sections with varied length in different countries. Therefore, it is recommended that the road section length should be between 2 and 10 kilometres.

The reasoning for the minimum length is that the sections should not be too short, because route safety assessment would resemble black spot analysis. In addition, the road sections should have a specific length in order to make it possible to identify some general problems, and in order for general measures to have an effect. Finally, the sections should have a certain length to avoid great sensitivity to each crash.

On the other hand, the argument for the maximum length is that the sections should not be too long, as the consequence may be that shorter sub-sections incorporating specific problems would not be identified, as the many crashes on these sections “drown” in the overall average for the road section as a whole. Likewise, it may be difficult – during the analysis stage – to get an overview of very long sections and long sections may also be very expensive to improve if the given measures are to be carried out on the total length of the road section.

The interval from 2 to 10 kilometres may be considered as a large interval, but even so, it is recommended to make sure that it is possible to get homogenous sections. The large interval is also recommended, so that the method can be adapted to different national conditions with regard to, for example, geographical conditions, infrastructure and density of intersections and towns. It can, for example, be assumed that the average section length is shorter in smaller countries than in larger countries. Finally, the large interval offers the opportunity to choose section length depending on measures. If expensive measures are applied short sections could be used, while long sections may be considered when more inexpensive measures are implemented.
Note that it is impossible to get all road sections to be 100% homogeneous, because it would result in too many very short road sections. Moreover, it might be impossible for the road to be divided into sections that all have a length between 2 and 10 kilometres. Some would be a bit shorter than 2 kilometres and some could be a bit longer than 10 kilometres.

Of course, the above-mentioned section length intervals do not completely apply to motorway segments, which in general tend to be consistent in much longer sections (e.g. between intersections).

### 3.2.3 Assessment Methods

The methods used to assess the road safety level along a route and identify hazardous road sections follow the same rationale as the pertinent methods used in black spot analysis. Hence, identification methods for hazardous road segments are separated into crash based and non-crash-based methods. The major difference between black spot identification methods and hazardous road section identification methods is located on the unit used to express risk, in each technique. Moreover, there are some supplementary identification techniques implemented in route safety assessment, while others used in black spot identification do not find application in the detection of hazardous road segments. The various methods used to assess route safety level and identify hazardous road sections are demonstrated in Figure 2.

![Figure 2: The overall route safety assessment methods](image)

#### 3.2.3.1 Crash based methods

The crash-based methods implemented to locate hazardous road sections may also be separated into numerical, statistical, site-related and GIS techniques.

Regarding the numerical or non-model based techniques, these techniques are still considered to be the simplest methods of determining hazardous segments and rely on plain comparison of selected constant values.
Numerical techniques are further disaggregated into the crash density and crash rate calculation techniques.

**Crash Density**

The first technique suggests the simplest and fastest method for the detection of dangerous road segments. The process behind this technique is the following. Initially, the total of traffic crashes regarding a specific road section during a period is recorded and then all crash sites are sorted in a descending order, according to the crash density. Crash density is defined as the number of crashes per kilometre and is used as a risk measurement tool in order to make the comparison of road segments with different lengths possible. Subsequently, the segments with crash density higher than a specified threshold-value are selected and considered to be crash prone sections. The threshold-value is defined in a manner that allows examination of all the emerging high-risk sections. In theory, every crash prone section should be closely studied in order to determine the local and section risk factors. Nevertheless, in practice, this is not a financially sustainable procedure.

**Crash Rate**

The crash rate numerical technique focuses on the calculation of the crash rate on a specific road section. For the purposes of route safety assessment, crash rate is defined as the number of (injury or not) crashes per million vehicles using a specific section of the examined route. The crash rate expresses the level of risk across a segment, due to the level of use of the segment, during a specific period. The reasoning behind this method is that considering solely the crash density associated with a road section could lead to deceptive conclusions when traffic volumes alter significantly from one section to another. It is quite apparent that two different road segments containing the same amount of crashes or the same crash density cannot be equally hazardous, when the traffic volumes assigned to each segment vary at a noticeable level. This rationale gap is filled by the crash rate calculation. The identification stage follows the same process as the one of the crash density method. The examined road sections are sorted in a descending order, according to the assigned crash rate and finally sections with a crash rate higher than a defined critical value are selected and regarded as hazardous road sections. Likewise, the critical value is defined in a manner that it is potential to examine all of the emerging high-risk sections.

Finally, a combination of the two above described methods is likely to be made. In this perspective, sections that recorded a crash density greater than a defined value (e.g. the average crash density among the population of sections), and had a crash rate higher than a critical value (e.g. the average crash rate) are classified as hazardous road sections.

**Statistical techniques**

In general, the statistical methods used to identify hazardous sections follow the same classification and rationale as the pertinent methods used in black spot analysis. However, there is one supplementary statistical method, which is applicable in the hazardous sections identification stage, i.e., the Quality Control method.

**Poisson Analysis**

The Poisson analysis considers that traffic crashes follow the discrete distribution of Poisson. Thus, the probability of a certain number of crashes occurring in a particular section can be estimated. Basically, it describes the probability that any given number of crashes will occur in terms of this number and a
quantity which is called the expected number of crashes, also known as the Poisson distribution average.

The first key step towards the application of this method is to define a certain level of statistical confidence. Subsequently, it is recommended to estimate the expected number of crashes regarding the segment under examination. In this manner, the expected number of crashes (or Poisson distribution average) is equal to the average number of crashes of all segments under study, for the perceived period. After the above tasks have been accomplished, it is possible to calculate the critical number of crashes related to the section under investigation. Finally, a road section is considered to be a hazardous section, if the recorded number of crashes exceeds the critical number of crashes (as calculated for a defined level of significance).

**Quality Control**

Statistical quality control, equivalent to the pertinent techniques employed in industrial quality control, can be applied to the study and management of traffic crashes\(^\text{14}\).

Statistical quality control was initially developed as a method of dynamically controlling the quality of industrial production. As a result, most of its growth focused on the development of methods and concepts for finding out what was happening in an industrial process. The methods developed were quite successful in indicating when something went wrong and helped in locating what was wrong. Obviously, traffic crashes are not the result of a manufacturing process, and it is almost meaningless to refer to the “quality” of crashes or their “control”. Therefore, it was found that, starting with the techniques used in statistical quality control, a considerable method, from both a theoretical and practical aspect, could be developed for the study of traffic crashes.

This statistical technique is based upon the division of the road facility into a number of road intervals. These road sections must be homogenous, in terms of traffic volume referring to a particular period, as it is considered that the proper unit of risk is the crash rate, i.e. the number of crashes occurred at a certain section per million vehicle-kilometres travelled during a specific period (e.g. a year). In addition, the road should be divided in a manner that each road interval contains approximately 14 to 25 crashes. The main argument behind this rationale is to eliminate the random variation in crash counts generation and, thus, reduce the interference of the stochastic nature of crashes.

With regard to the underlying statistical theory, it is assumed that each vehicle-kilometre is a sort of discrete entity and that the probability of a crash is the same for each vehicle-kilometre. It is also assumed that the vehicle-kilometres are statistically independent and that the number of traffic crashes follow the discrete distribution of Poisson. Thus, the probability of a certain number of crashes occurring in a specific number of vehicle-kilometres can be estimated. Basically, it describes the probability that any given number of crashes will occur in terms of this number and a quantity, which is called the expected number of crashes. The expected number of crashes may differ from segment to segment.

The fundamental idea underlying the method is the computation of upper and lower control limits, after the expected number of crashes has been estimated. The computation of upper and lower control limits relies on the use of a table of the Poisson distribution. From this table, upper and lower limits on number of crashes may be obtained. Dividing these by the number of vehicle-kilometres, the upper and lower limits for the observed crash rate may be calculated.
Finally, the comparison of the observed crash rate to the upper control limit is crucial. Thus, if the observed crash rate is higher than the upper control limit, it is concluded that the examined segment is “out of control”, which means that the actual number of crashes is not related to randomness (at a certain level of confidence). Furthermore, the observed number of crashes is associated with site-related factors which may lead to the generation of traffic crashes. Therefore, the segment under study should be further investigated.

**Bayes Method**

In the Bayes method, the local expected number of crashes on a particular section is estimated as a weighted mean of the registered number of crashes at the section and the general expected number of crashes for similar sections estimated by crash models. In fact, the Bayes analysis relies on the traffic crashes record of a particular segment in combination with the risk profile of other similar segments in order to define hazardous road sections. Therefore, sections with an extraordinary expected number of crashes are regarded as hazardous sections and further investigated.

### 3.2.3.1.3 Site-related crash techniques

Site-related or site-specific crash techniques implemented during route safety assessment are similar to the ones applied during the black spot identification stage. The detection of hazardous sections relies solely on site-related crashes through specific crash themes or types of crashes associated with local and section related risk factors whereby all interference from non-site-specific crashes is removed already in the identification stage. In this manner, the route safety assessment is, to some degree, already on track in the identification procedure.

### 3.2.3.1.4 GIS techniques

GIS based techniques are frequently used alongside other crash based techniques. In general, the principle is that the area under investigation is separated into squares, and the number of crashes in every square is counted. Hazardous road sections are then defined as the squares containing most crashes. Yet, the use of these methods is questionable from a practical point of view. The key problem is that crashes are associated with areas, not road sections, thus it might be impossible to determine traffic and road design during the identification of hazardous road sections.

### 3.2.3.2 Non-crash based methods

As already described above, the main benefit gained from the implementation of non-crash based methods in the route safety approach is that the level of risk on a particular road section or network can be defined without the need for detailed crash data, which is often the case in low-and middle-income countries where data quality is poor. The non-crash based methods implemented in route safety approach are further separated into quantitative and empirical techniques.

#### 3.2.3.2.1 Quantitative techniques

Researchers and public authorities in many countries have made serious efforts to develop and publish specific non-crash based, quantitative methods in the field of road safety assessment and, consequently, attempt to recognize hazardous segments.

The RAP protocols governed by iRAP and managed within Europe by EuroRAP include “EuroRAP Star Rating”. A remarkable non-crash based, quantitative technique used to assess route safety is the ‘Star Ratings’ technique developed by the iRAP.

**Star Ratings**
The Road Assessment Programmes (RAP) method

The protocols described here were developed by iRAP which is a registered charity dedicated to saving lives by eliminating high risk roads throughout the world. Like many life-saving charities working in the public health sector, iRAP uses a robust, evidence-based approach to prevent unnecessary deaths and suffering.

iRAP works in partnership with governments, road authorities, mobility clubs, development banks, NGOs and research organisations to:

- assess high-risk roads and develop Star Ratings, Risk Maps and Safer Roads Investment Plans
- provide training, technology and support that will build and sustain national, regional and local capability
- track road safety performance so that funding agencies can assess the benefits of their investments.

The programme is the umbrella organisation for EuroRAP, AusRAP, usRAP, ChinaRAP, et.al. Road Assessment Programmes (RAP) are now active in more than 100 countries across the globe.

iRAP is financially supported by the FIA Foundation for the Automobile and Society and the Road Safety Fund. Projects receive support from the Global Road Safety Facility, automobile associations, regional development banks and donors.

National governments, automobile clubs and associations, charities, the motor industry and institutions such as the European Commission also support RAPs around the world and encourage the transfer of research and technology. In addition, many individuals donate their time and expertise to support iRAP. iRAP is a member of the United Nations Road Safety Collaboration.

In general, RAP Star Ratings, FSI Estimation (fatal and serious injury) and Safer Roads Investment Plans (commonly referred to as a “SRIP”) are the outputs of assessments using the RAP methodologies. Star Ratings show the inherent risk to the individual road user built into the assessed road network (per road user), while an Investment Plan guides future safety upgrades on the road network.

The main objective of the RAP Star Rating and Investment Plan method is the improvement of road users’ safety by proposing cost-effective investment plans. The most crucial point in the RAP is that engineers and planners in developed countries have, for over twenty years, adopted an underlying philosophy of designing a forgiving road system to minimize the chances of crash occurrence and the severity of injuries when road users make mistakes that result in crashes. The method indicates that the likelihood of road crash and the severity of a road crash can be reduced through the intervention at the sequence of events happening during this crash. As is known, an injury crash results from a chain of events, starting with an initial event, probably resulting from several factors, which leads to a dangerous situation. The basic idea is to intervene at any point of this chain, in order to reduce the kinetic energy of all road users who are involved in the crash to a tolerable level. Such an intervention may not only reduce the number of crashes but also the severity of injuries.

The initial step for the implementation of the RAP method is the inspection and subsequent recording of the infrastructure elements of a road network (or the conversion of existing asset data), which relate to road safety. The data recorded leads to the quantification of the safety that a road section provides to its users by calculating relative risk scores (Star Rating Scores) for four road user groups. The Star
Rating Scores are then classified into a Star Rating scale that expresses the safety capacity of a road section for each road user in a 5-Star scale that can be used as an international benchmark. This quantification aims to identify how the level of risk varies across a road network. The FSI estimation extends the Star Rating to reflect the collective risk to the road users and in calibrated to the specific road network assessed. The Safer Roads Investment Plan (SRIP) includes more than 90 proven countermeasures to generate affordable and economically sound investment plans that will save lives. Thus, the SRIPs are considered as a valuable tool for the authorities, stakeholders and investors in order to decide the most cost-effective and efficient road infrastructure investments.

Measuring the road infrastructure safety

The assessment of road safety requires Road Safety Inspections (RSI) of the road network sections and the assignment of a safety score to them. The inspection is conducted by visual observation and recording of the road infrastructure elements which are related directly, or not, to road safety and have a proven influence on the likelihood of a crash or its severity. The RAP assessments utilise inspection systems (varying from simple camera based solutions up to the inspection systems used for asset management inspections) to collect recorded georeferenced image/video data. The georeferenced image/video data can then be used to manually record the required road features at 100m intervals. It should be noted that as part of i.e. iRAP initiative, iRAP is working with a number of global and regional partners harness existing data sources and AI technologies to reduce the reliance on manual collection of the road features.

Following the RSI, the Star Rating Score (SRS) is calculated for 100m road segments. The SRS is a measure of relative individual risk, which describes the level of safety built into the roads infrastructure for each road user type. The road user types currently included are vehicle occupants, motorcyclists, bicyclists and pedestrians. For each 100m road segmentation the SRS is calculated for each road user type as follows:

\[
SRS^u_n = \sum_c L^u_n \cdot S^u_n \cdot OS^u_n \cdot EFI^u_n \cdot MT^u_n
\]

where

“n” is the number of 100m road segments,
“u” the type of road user and
“c” the crash type that the road user type “u” may be involved in.

The following variables are taken into consideration:

L: the Likelihood that the “i” crash may be initiated,
S: the Severity of the “i” crash, OS: the degree to which risk changes with the Operating Speed for the specific “i” crash type,
EFI: the degree to which a person’s risk of being involved in the “i” type of crash is a function of another person’s use of the road (External Flow Influence),
MT: the potential that an errant vehicle will cross a median (Median Traversability). This is only considered in the vehicle occupant and motorcyclist driver side LOC types.

The Star Rating process
The figure below illustrates the process used to undertake Star Rating and SRIPs, which can be used as part of a systemic, proactive approach to road infrastructure risk assessment and renewal based on research about where severe crashes are likely to occur and how they can be prevented.

![Diagram of iRAP Star Rating and Safer Roads Investment Plan process]

**Figure 3: The iRAP Star Rating and Safer Roads Investment Plan process**

With regard to the Star Rating methodology, iRAP Star Rating is an objective measure of the likelihood of a road crash occurring and the severity of the outcome. The focus is on identifying and recording the road attributes which influence the most common and severe types of crash, based on scientific evidence-based research.

Star Ratings are based on road inspection data and provide a simple and objective measure of the level of safety which is “built in” to the road for vehicle occupants, motorcyclists, bicyclists and pedestrians. In this way, the level of risk to a road user on a particular road section or network can be defined without the need for detailed crash data, (which is often the case for low and middle-income countries where data quality is poor) or where crash data has been reduced to the level that it has low statistical reliability. 5-star roads are the safest while 1-star roads are the least safe. Research shows that a person’s risk of death or serious injury is highest on a 1-star road and lowest on a 5-star road.

Therefore, Star Ratings represent the risk of a fatal or serious injury to an individual road user. For instance, for vehicle occupants, Star Ratings associate to the number of deaths and serious injuries per vehicle kilometer travelled on a road. Collective risk, that is the number of fatalities and serious injuries of a road, is a function of individual risk (Star Ratings) and traffic volume as represented by the RAP FSI estimations.

A direct relationship between Star Ratings and the cost of fatalities and serious injuries per driven km has been demonstrated in a number of studies. For every incremental increase in Star Ratings, the cost of fatalities and serious injuries per km are typically halved.
A Star Rating Score (SRS) is calculated for each 100m segment of road for vehicle occupants, motorcyclists, pedestrians, and bicyclists. Subsequently, Star Rating Scores are apportioned to Star Rating Bands to determine the Star Rating for each 100 metres of road. For the purposes of producing a route or network level map showing Star Ratings, 100 metres is too much detail and makes it difficult to map and analyse. To address this, the 100m segments are combined into longer sections (3km for rural roads, and 1km for urban) for the calculation of Star Ratings across a route or network.

In the Star Ratings approach, the level of risk to a road user on a particular road section or network can be defined without the need for detailed crash data, which is often the case in low-and middle-income countries where crash data quality is poor.

Star Ratings can also be used to objectively quantify the level of risk associated with new road designs (where crash data is not available) to assist in evidence-based decisions on safety improvements. They are also useful where low crash frequency limits the ability of crash analysis to influence performance monitoring and investment prioritization.

Star Ratings are underpinned by four guiding principles central to the Safe System approach. These are:

1. People make mistakes that can lead to road crashes.
2. The human body has a known, limited physical ability to tolerate crash forces before harm occurs.
3. While individuals have a responsibility to act with care and within traffic laws, a shared responsibility exists with those who design, build, manage and use roads and vehicles to prevent crashes resulting in serious injury or death and to provide post-crash care.
4. All parts of the system must be strengthened in combination to multiply their effects, and road users are still protected if one part fails.

While it may not possible to eliminate road crashes, safe roads—those with a high Star Rating—can reduce the likelihood and change the outcome (severity) of the crashes that do occur.

Furthermore, iRAP is committed to helping road agencies to lift the safety performance of road networks and set Star Rating targets.

For road upgrade projects, it suggested that a target is framed in the following way:
The road shall achieve a smoothed 3-Star Rating for vehicle occupants, motorcyclists, pedestrians and bicyclists, subject to the availability of economically viable infrastructure countermeasures. At locations where it is not economically viable to lift the Star Ratings to at least 3-Stars using infrastructure countermeasures, lowering operating speeds should be considered. Star Ratings should not decrease because of the project.


SRIPs follow the Star Rating process. An Investment Plan is a prioritised list of countermeasures (safety treatments) that can cost-effectively improve Star Ratings and reduce infrastructure-related risk. More than 90 road improvement options can be analysed by the iRAP model to generate affordable and economically sound investment that improve a road’s Star Ratings and, when implemented, can save lives.

Investment Plans are based on an economic analysis of a range of countermeasures, which is undertaken by comparing the cost of implementing the countermeasure with the reduction in crash costs that would result from its implementation. They contain extensive planning and engineering information such as road attribute records, countermeasure proposals and economic assessments for 100 metre segments of a road network.

In interpreting the results of an iRAP assessment, it is important to recognise that an Investment Plan is designed to provide a network-level assessment of economically justified countermeasures. For this reason, implementation of countermeasures identified in an Investment Plan will ideally include:

1. Local examination of proposed countermeasures (including a “value engineering” type workshop including all relevant stakeholders)
2. Preliminary scheme investigation studies, and
3. Detailed design and costing, final evaluation and construction.

Research has demonstrated that it is crucial to ensure that local communities have an opportunity to both contribute to road designs but also understand the intended use of various road design features.

3.2.3.2 Empirical techniques

In general, a road infrastructure project consists of several formal stages, as indicated below.

- Stage 1 – completion of preliminary design.
- Stage 2 – completion of detailed design.
- Stage 3 – completion of construction (preferably before road is opened to the public).
- Stage 4 – initial operation phase (3 to 12 months post construction).

Empirical techniques have been developed and are implemented in order to evaluate the road safety level during the above stages. Road Safety Audit and Road Safety Inspection are considered to be the most effective non-crash based, empirical techniques to assess the level of safety along a route and identify hazardous routes or road sections, based on local and section related risk factors.

The two terms are often combined and merge into one, simply known as Road Safety Audit. However, in this report, the two terms are separated and considered to be completely discrete entities.
Road Safety Audit

Road Safety Audit (RSA) is defined as a formal, independent assessment of the safety performance of a new road or proposed road design\(^\text{18}\). The objective of road safety audit is to identify aspects of engineering interventions that could give rise to road safety problems and to suggest modifications that could improve road safety. It is important to note that road safety audit is not intended to be a technical check of compliance with design requirements.

Highly trained auditors identify potential hazards and suggest recommended remedial treatments based on experience gained from crash investigation studies, road safety engineering schemes and associated research.

A RSA undertaken by competent, qualified auditors can provide a preventive approach regarding road safety issues already in the planning or design phases. Designs of current or planned roads or intersections are evaluated in terms of road safety, according to each auditor’s level of experience and perception. In this manner, a number of risk factors can be detected at a primary level of design and proper countermeasures (e.g. alterations to the road geometry) can be made before any actual problem emerges.

An Audit team works together on the audit to identify potential road safety problems and suggest suitable measures. In addition, the audit team is independent of the design team and often comprises members with different skills and abilities, a team leader and several team members (may include law enforcement officer and/or client representative).

Road Safety Inspection

Road Safety Inspection is a formal, independent assessment of the safety performance of an existing road that takes place in the field. Road Safety Inspection (RSI) constitutes one of the most recognizable and valuable road safety evaluation techniques for roads already constructed and operated for years (perhaps with outdated standards). This is also a major difference between Road Safety Inspection and Road Safety Audit.

The main benefit gained from Road Safety Inspection is that it is a process not affected by the crash record of a specific location and, thus, additional site-related risk factors may be identified during the inspection. Lack of crashes or a certain profile of crashes on a particular site does not mean that this specific site should not be further investigated. It might be only the outcome of mere randomness due to the stochastic nature of traffic crashes generation. Thus, the objective of Road Safety Inspection is also to locate potential risk factors that may expose road users to an unpredictable risk level and where possible to propose suitable treatments to eliminate or reduce risk.

3.2.4 Treatment Oriented Policies

There is a wide number of treatment-oriented policies implemented in road safety engineering in order to improve safety on a large-scale level, i.e., along a route or network. The most significant policies are the ones described below. Note that the design and implementation of these policies require that route or network crash problems have already been identified in the assessment process.
3.2.4.1 Route Action Plan

A standard route action plan, or route treatment includes all viable safety measures along a route (or network) optimised to reduce the highest number of fatalities and serious injuries. Plainly, a route action plan may be defined as the application of known remedies along a hazardous route or segment.

A route action plan may be customised to meet other requirements of the client or the context of the road assessment. There are many ways to customise route action plans. The most common approaches to customising route action plans include:

- To meet a defined budget or threshold for economic return. For example, where there is either a specified budget with which to undertake road safety upgrades, a minimum return or investment (in terms of benefit cost ratio or internal rate of return), or both.

- Ease of implementation. This is to assist road authorities to stage road upgrades in a way that accounts for construction lead times or budget appropriation. This way, upgrades that can be done immediately (such as delineation) are prioritised and more significant upgrades could be introduced to the planning pipeline for capital works.

- To support a maintenance program. This limits an Investment Plan to those things that generally be undertaken as part of road maintenance and do not require capital works approval, planning or budget.

- To meet a Star Rating Target. A standard Star Rating target is 3-Star or better. A Star Rating target may be an official policy target or may be specified by the client for the specific road project.

3.2.4.2 Mass Action Plan

A mass action plan is defined as the application of a specific remedy to locations with a common crash problem.

A mass action begins by having a measure that is known to reduce certain types of traffic crashes (e.g. the establishment of a central barrier prevents head-on crashes). Subsequently, the database is used to search for locations with a history of those crashes. Obviously, this procedure implies that the identification of risk factors along a crash prone route (or network) has been completed.

The practice works towards implementing the measure at the most suitable sites or locations. The remedy is known and is applied at locations with specific problems.

As the experience of a public authority or road manager develops and grows, monitoring exercises will identify several low cost but effective measures and practices. Road safety engineers may take advantage of this by using mass action plan techniques. The effective measures are then applied to a large number of problematic locations quickly and efficiently.

A mass action plan might include work along hazardous road sections of a highway or at individual locations. Most highway agencies use a variety of mass action plans to improve the road network.

Finally, a mass action plan could be used to improve:

- The road safety level across a route or network, through an upgrade or maintenance works – by the implementation of road surface programs.
Traffic capacity – by implementing traffic engineering measures at junctions along a route.

The general roadside environment – by carrying out a landscaping program of planting trees and shrubs along a route or in areas.

3.2.4.3 Area Wide Scheme

An area wide scheme is the most common concept of investigating crashes across a wider area, particularly urban residential areas. Area wide road safety engineering turns attention to residential areas where both the problem of crashes and the approach to crash reduction is quite different. In an urban area it would not be uncommon to find over 80 reported personal injury crashes per square kilometre per year. If treatment is carried out over say 3 sq. km., the potential for crash reduction may be high. Crashes in residential areas are more likely to be scattered throughout the area. They often involve different crash types and consequently routine blackspot and route-wide practices are less likely to be effective.

This treatment-oriented policy is beyond the scope of route safety assessment as the route safety approach is only related to the road network rather than a residential area. However, authorities responsible for urban areas may need to involve route safety-oriented principles when devising strategies for reducing crashes in residential areas as many residential areas may contain hazardous routes.

3.2.5 Route Safety Assessment Features

The main features of Route Safety Assessment are summarized in the following:

➢ Route Safety Assessment is associated with the definition and identification of hazardous road sections along a route, based or not on the crash statistics.

➢ Route Safety Assessment is based on the division of the road system into smaller consistent segments.

➢ The proposed treatment oriented policies (e.g. route action plans), subsequent to the completion of route safety assessment, concentrate on the improvement of road safety along hazardous road sections.

➢ In the route safety approach, a hazardous road section may consist of several black spots, but also any other location belonging to the hazardous road section is regarded as a potential crash prone location and is further investigated in order to eliminate possible local or sectional risk factors.

➢ The proposed remedies (e.g. route action plans) comprise both responsive and anticipatory viable safety measures along a route optimised for the highest number of fatalities and serious injuries prevented.

➢ Countermeasures proposed to resolve sectional traffic safety issues may initially seem like high cost solutions, but they may prove to be cost-effective resolutions on a long-term interval, as a considerable number of crashes may be prevented from occurring in locations without crash history, thus, minimizing the socio-economic impact.
3.3 Network-Wide Road Assessment

3.3.1 Definitions and Principles

Network-wide road assessment is defined as a systematic and proactive risk mapping procedure to assess the “in-built”, or inherent, safety of roads across the EU\textsuperscript{20}. Thus, network assessment is built on the philosophy of route safety assessment, where the risk of death and serious injury is estimated on individual road sections across a road network. Network assessment is based on the principle that different routes of a specific type (e.g. highway routes) are combined and shape a network.

The main objective of network assessment is to support national road safety strategies and add an extra layer of information alongside existing approaches. As such, network assessment typically covers roads outside towns and cities, where deaths and serious injuries are mostly concentrated. Not all roads carry the same risk; examining the statistics from a wide range of countries show that 50% of fatalities occur on just 10% of roads\textsuperscript{21}. Therefore, network assessment enables the identification of the safest and most hazardous road sections within a region or country.

In addition, network assessment supports performance tracking. Performance tracking demonstrates how risk on the network as a whole, and on individual road sections, has changed over time. Knowing where risk has been reduced and the measures that have worked are essential in building best practice and knowledge transfer. Thereby, performance tracking is a way of measuring success and the effectiveness of investment in safer roads.
3.3.2 Assessment Methods

Network assessment methods follow the same classification, as the methods applied to assess the road safety level along a route and identify hazardous road sections. The classification and identity of methods used to implement network assessment are illustrated in Figure 5.

However, there is one supplementary method to the ones already illustrated, which assesses the crash risk level along a road network. This method is known as RAP Crash Risk Mapping and is described in the subsequent section.

3.3.2.1 RAP Crash Risk Mapping

iRAP provides the RAP protocol associated with network safety management, i.e. Crash Risk Mapping. The European Road Assessment Programme (EuroRAP) is an international not-for-profit organisation dedicated to saving lives through safer roads overseeing the application of the RAP protocols (including Crash Risk Mapping) within Europe.

It aims to:

- Reduce deaths and serious injuries on Europe’s roads through a systematic programme of risk assessment, identifying major safety shortcomings that may be addressed by practical road improvement measures;

- Ensure risk assessment lies at the heart of strategic decisions on route improvements, crash protection and standards of route management;

- Forge partnerships between those responsible for a safe road system – motoring organisations, vehicle manufacturers and road authorities; and lastly
• Provides a consistent basis to measure risk between jurisdictions and across boundaries.

The Crash Risk Mapping protocol follows a route safety approach rather than focusing on high-risk single sites. In order to assess the level of risk across a road network and produce the data required for RAP Crash Risk Mapping analyses, crash and traffic flow data need to be assigned to individual road sections.

Crash Risk Mapping, by its very nature, relies on the use of existing crash and traffic flow data. As such, when published, some routes may already have had road safety improvements. Others may be more difficult to change, and, on these roads, it is particularly important for road users to be aware that they face higher risks than they might expect. Crash Risk Mapping should therefore be updated at regular intervals to ensure that it represents the most up-to-date picture.

Crash Risk Maps based on crash rates show the combined influence of behaviour, road infrastructure, vehicle and post-crash care. Various types of mapping are available:

- Crash risk per vehicle km travelled - Risk rate expressed as fatal and serious injury crashes per billion vehicle km
- Crash density - Risk rate expressed as the number of fatal and serious injury crashes per km per year
- Crash risk by road type - Risk rate expressed as fatal and serious injury crashes per billion vehicle km, relative to the average rate of roads with a similar traffic flow

Each of the above may be extended further to show risk ratings by crash types and road users where the availability and robustness of the data warrants doing so

They show the relative risk to an individual road-user (generally a vehicle occupant), or to the community as a whole, of being involved in a road crash involving fatal or serious injury.

In contrast, they do not disaggregate the extent to which the behaviour of a specific road-user might result in higher or lower than the average risk or the extent to which a road-user might make a mistake, and recover from it, without serious injury.

The public is often most interested in their personal risk on the road as individual users. The risk to any particular road-user will be lower if they are behaving within acceptable boundaries of road use (wearing a seatbelt, not intoxicated, not using a mobile phone, and obeying speed limits). The simplest way to represent this is in terms of crash risk in relation to exposure. Crash rates per vehicle kilometre travelled can show the likelihood of a particular type of road-user (e.g. car driver, motorcyclist, lorry driver, pedestrian or cyclist), on average, being involved in a fatal or serious road crash.

Crash Risk Maps can improve the recognition among road-users that risk can significantly vary across road networks. In producing maps aimed at individual risk, it is therefore important to counter the common assumption that their purpose is to inform the road-user of how best to modify the route taken to minimise their likelihood of being involved in a crash. This is especially true where mapping covers only higher-tier road networks, since it is known that roads off the main road network typically have higher crash rates.
The main purpose of mapping individual risk is to:

- Inform road-users of how and where their behaviour needs to be modified to minimise risk and, in doing so, to help them to understand the role of road infrastructure in determining the risks they face. It is hoped that, over time, this will aid clearer recognition of the influence of road design on risk and how it can vary on different types of road; and

- Illustrate more generally how high-level infrastructure variables, such as carriageway type and road standard, influence risk.

On the contrary, collective (or ‘community’) risk is used by road providers to reflect more broadly how the total risk to all road-users is distributed across a network. This information is crucial in determining how to spend available budgets effectively.

At the simplest level collective crash risk maps show the density, or total number, of crashes on a road over a given length. However, rates expressed in this way are largely influenced by the number of vehicles using a particular road section or link, given the positive correlation between fatal and serious crashes with traffic flow.

The RAP route structure is based on simple rules aimed at keeping as coherent a design as possible within any road section, while at the same time extending the section length far enough to give sufficient crash numbers to minimise year-on-year variation. Crash and traffic flow data are assigned to each section, typically compiled into three-year periods to give a statistically reliable estimate of risk. The assessment period can be extended where crash numbers are low.

Finally, the Crash Risk Mapping protocol converts both individual and collective risk into five coloured categories to visualise the level of risk across a network. These well-known colour coded maps show the risk to a road user of being killed or seriously injured. They highlight the significantly changing risk, for example, as the same drivers in the same vehicles turn from one road section into another. These Crash Risk Maps have become a key national road safety measurement of risk on roads in some countries (e.g. for the Strategic Route Network and Major Route Network in the UK).

As far as the methodology of EuroRAP Crash Risk Mapping is concerned, the basic building blocks of Crash Risk Mapping and the rationale of the criteria adopted for road network and length, crash severity, type and numbers, traffic volume, and assessment period are detailed below.

### 3.3.2.1.1 Subdivision of the network into RAP sections

First of all, to identify road sections which demonstrate differences in general road standard performance, it is essential to assess lengths that minimise the impact of year-on-year variability in crash numbers and present a stable longer-term estimate of crash risk.

While it is typical for fatal and serious crash rates to differ from road type group averages, variability is considerably greater for short sections. Where a section comprises a short length between junctions, crash rates may be unrepresentative of average rates, since crashes at junctions will form a disproportionately large contribution to the total in that length. This may be due to a proportionately higher influence from junction crashes at the ends of the short sections.

Research conducted by the Transport Research Laboratory (TRL) during the development of EuroRAP showed that the number of fatal and serious crashes on busy networks over a three-year data period for sections of at least 5kms provided a reasonably robust estimate of risk. Sections less than 5kms
tended to show greater year-on-year variability in crash numbers in addition to being more likely to change risk rating from one period to another and were therefore less reliable when compared over time. For motorways and dual and single carriageways these differences were significant up to section lengths of 10kms.

When assessing whether individual sections have fatal and serious crash rates that are above or below average, minimum thresholds of 10kms for motorways and dual carriageways and 5kms for single carriageways should be used as a starting point in assessing crash numbers. Where it is not possible to aggregate short sections, care must be taken when interpreting risk ratings.

The network being investigated is divided into road sections, such that as far as possible the design of the road within each is uniform, and the traffic flow consistent. This is implemented in a number of ways:

- Census points: Where traffic census data is available, collection points are associated with a short length of road, typically 5km for a national strategic road network. Census point lengths can be combined to create individual routes.
- Major junctions: Sections between major junctions are defined: typically using an algorithm to divide the road network into sections which start and end at consecutive major junctions.
- Adjacent short lengths: The road network is divided into adjacent 1km lengths in order to match the way in which crash and traffic data are collated.

### 3.3.2.1.2 Crash Data Handling

After defining individual road sections across a network, crash and traffic data are assigned to each section.

EuroRAP protocols focus on fatal and serious crashes. In addition to reflecting the key policy targets across Europe, such crashes reflect the ability of the road design to ‘contain’ the event and are likely to be reported more consistently than those falling in the ‘slight injuries’ and ‘damage only’ categories. They also represent the severity levels generally used in national targets and those that can have life-changing consequences.

Analysis has shown that when crash numbers are compared over time, the general relationship is strong, but the variation in frequency can become large when the numbers fall below 20 crashes per road section over three years. As such, when constructing the EuroRAP network, the target is for each road section to have a minimum of 20 fatal and serious collisions within the assessment period, although it is recognised that this will not always be achieved.

Where crash numbers are low, three options are available:

1. increasing route length,
2. increasing the time period over which risk rates are calculated.
3. using all-injury crash data in addition to fatal and serious crashes,

### 3.3.2.1.3 Traffic Flow Data

Traffic flow data is used as an exposure measure in expressions of fatal and serious crash risk in EuroRAP Crash Risk Mapping.
For each road section, the average of all the traffic flows along the section is calculated (using all vehicles on the carriageways in both directions).

Where a section has been aggregated from various shorter sections, traffic flow is weighted by the length of the road section to which it belongs. This is typically achieved with a computerized system, where each link is considered as a series of straight sections and a box created around each straight section. As with crash data, a tolerance of 1km or 10% of section length was used in the matching procedure.

In general, data is obtained from road authorities for the same assessment period used for crashes. It represents Annual Average Daily Traffic (AADT) for all motorised vehicles, representing the bi-directional traffic count for an average 24-hour day in a year. Where data are not available from relevant sources, it is necessary to collect data from short-period counts.

Traffic counts are generally taken as a “spot count” even when they are intended to represent a flow over a road section or similar length. Efforts are therefore made to avoid any locations at which there will not be a substantial loss or gain of flow over the section the count represents because of junctions on the section.

3.3.2.1.4 Assessment Period

A widely misunderstood aspect of road safety relates to the way in which crash numbers vary from year to year and can appear to show a trend that requires urgent attention, only for the trend to reverse a year later. Regression-to-mean, also sometimes called ‘bias by selection’, can complicate evaluations at sites with high crash numbers. Often chosen for treatment following a year with particularly high numbers, in practice these will tend to reduce in the next year even if no treatment is applied. It is believed that the regression-to-mean effect can over-state the effect of a treatment by 5-30%, dependent on the assessment period.

A simple way of assessing regression-to-mean and changes in the environment uses control sites chosen in exactly the same way as the treated sites, identified as having similar problems, but left untreated. In practice, it is difficult to find matched control sites and, if investigated, to justify not treating them.

The effect does, however, tend to be diminished if longer periods of time are selected. In a study of yearly crash rates in two British counties, Abbess et al., calculated that regression-to-mean had the following effects at sites with high crash rates (i.e. more than eight injury crashes per year):

<table>
<thead>
<tr>
<th>Regression-to-mean change in annual crash rate</th>
<th>Period of crash data considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-26%</td>
<td>1 year</td>
</tr>
<tr>
<td>7-15%</td>
<td>2 years</td>
</tr>
<tr>
<td>5-11%</td>
<td>3 years</td>
</tr>
</tbody>
</table>

Where crash numbers are insufficient to meet the criteria suggested of 20 per road section over three years, the data period could be extended. However, it should be noted that extending the period beyond three years will increase the likelihood of significant network changes over the period of investigation and therefore a thorough review of planned or potential large scale changes should be assessed at an early stage.
3.3.2.1.5  **Estimating rates for each road section**

Finally, collective risk and individual risk are estimated for each road section. Collective (or ‘community’) risk demonstrates the crash density along a road section and is expressed as the number of fatal and serious crashes per kilometre per year:

\[
\text{Collective Risk} = \frac{\text{Fatal and serious crashes over assessment period}}{\text{Length} \times \text{Years in assessment period}}
\]

On the contrary, individual risk or crash risk per kilometre travelled is expressed as the number of fatal and serious crashes per billion kilometres travelled:

\[
\text{Individual Risk} = \frac{\text{Fatal and serious crashes}}{\text{Length} \times \text{AADT} \times 365 \times \text{Years in assessment period}}
\]

3.3.2.1.6  **Risk Mapping Specifications**

In order to show the varying levels of risk across a road network, individual sections are allocated into one of five colour coded risk bandings.

![EuroRAP Risk Mapping Colour Palette](image)

**Figure 6: EuroRAP Risk Mapping Colour Palette**

The standard EuroRAP Road Risk Mapping colour palette is based on five colour bands signifying low to high risk.

The standardisation of colours provides an internationally recognised system allowing comparisons across borders, i.e. a high-risk road section in one country is the same as a high risk road section in another.

The colour palette has been designed to meet the following criteria:

- Achieves international consensus;
- Is based on the significance of particular colours (such as black and red to signify danger) in different countries and is therefore meaningful to a wide audience;
• Adjoining colours are easily distinguishable from one another; and
• Ensures that the information is clear and distinguishable when presented in a variety of media (online, print, high resolution, low resolution).

RAP Crash Risk Mapping is based on the distribution of risk across a road network. In developing different forms of Crash Risk Mapping, standard thresholds for expected distributions were adopted. These base numbers are used to set the upper and lower boundaries for the rating colour bandings.

The methodology used is formed in a way that any authority can apply and is further described in the RAP-RM-2-1 Risk Mapping Technical Specification in the methodology section of the iRAP website: [http://resources.irap.org/Specifications/RAP-RM-2-1_Risk_Mapping_technical_specification.pdf](http://resources.irap.org/Specifications/RAP-RM-2-1_Risk_Mapping_technical_specification.pdf).

RAP-RM-2-1 sets out the technical specification for the production of RAP Crash Risk Mapping to a standardised format. It details how networks are constructed and the rationale for the selection of road sections and their related parameters in building a data set.

RAP-RM-3-1 sets out the design and cartographic specification for the production of RAP Crash Risk Mapping to a standardised format and will be considered for use in future productions of these maps. It too is stored on the iRAP website: [http://resources.irap.org/Specifications/RAP-RM-3-1_Risk_Mapping_design_specification.pdf](http://resources.irap.org/Specifications/RAP-RM-3-1_Risk_Mapping_design_specification.pdf).

In summary, the standard procedure for producing RAP Crash Risk Mapping is illustrated in next Figure.

![Figure 7: Standard procedure for producing RAP Crash Risk Mapping](image)

### 3.3.3 Treatment Oriented Policies

Network safety management follows the network safety assessment procedure and incorporates proper treatment oriented policies in order to minimise risk across a road network. Furthermore, network safety management uses acknowledged safety improvement programmes alongside other approaches, such as analysis at high-risk single sites. In general, network safety management advocates the use of economically viable mass action programmes (e.g. mass action plans) focusing on route safety as opposed to often lower cost improvements at spot locations.

Although network assessment may show that some sections carry higher risk than others, it does not necessarily mean that road authorities will and should regard these as the highest priority for improvement. Authorities rank roads for safety improvement, taking account of both the number of crashes likely to be saved through improvements and the cost of implementation. While not all roads can be managed to the same risk level, emphasis should be on keeping risk within acceptable
boundaries. Discussion with authorities and police has shown that these bodies review high risk roads, comparing the output with road sections flagged by their own internal processes and in seeking to develop practical measures to reduce the risk to road users.

To assess how to best reduce risk across a network, it is important to understand not just the present level of risk, but also the extent to which a lower level can be achieved on a particular road at reasonable cost. Information provided by network assessment can also be used as the basis for considering investment decisions, providing authorities and policymakers with a valuable tool for estimating the total number of crashes that could potentially be avoided if safety on a road were improved. Used with cost information, this can indicate locations where the largest return on investment can be expected.

An alternative insight into network safety management is provided by the evaluation of crash rates related to road type averages. These demonstrate road sections with higher or lower risk after the expected variability between different road groups (i.e. motorways, dual carriageways, single carriageways, mixed carriageways) is taken into account. Benchmarking in this way involves highlighting roads that should be targeted, exploring why they fall short of the average safety standards for their road type, and assessing whether it is appropriate to apply countermeasures known to be effective on roads with similar design and usage characteristics.

3.3.4 Network-Wide Road Assessment Features

The primary features of Network-Wide Road Assessment are summarized as follows:

➢ Network-wide road assessment is a systematic and proactive procedure aiming to assess the “in-built”, or inherent, safety of roads.

➢ Network assessment follows the philosophy of route safety assessment, where the risk of death and serious injury is estimated on individual road sections across a road network.

➢ Network assessment is a provides a supplementary layer of information alongside existing approaches (route safety assessment).
4 Road crash data collection and analysis for Case Study

Crash data collection and synthesis for approximately 624 km of the Greek TEN-T road network were collected. This information is required for a demonstration of all previously described methodologies, through a Case Study in the following Chapter.

4.1 Crash data information

The network, from which crash data were extracted, incorporates approx. 348 km of the Egnatia motorway and approx. 276 km of the North Road Axis of Crete (NRAC). Note that the Egnatia motorway belongs to the Core TEN-T network, whereas it is part of the European E90 corridor. Likewise, the North Road Axis of Crete is part to the Comprehensive TEN-T network, being also part of the European E75 corridor. Furthermore, the majority of the NRAC is consisted from a single carriageway, while Egnatia is a motorway with dual carriageway. Details about the examined network are shown in Table 2.

Table 2: The Greek TEN-T network under consideration

<table>
<thead>
<tr>
<th>Road Axis</th>
<th>Road No.</th>
<th>Road Description</th>
<th>Length (km)</th>
<th>Carriageway Type</th>
<th>TEN-T Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egnatia Motorway</td>
<td>A2-E90</td>
<td>Sindos I/C-Kipi</td>
<td>348</td>
<td>Motorway</td>
<td>Core</td>
</tr>
<tr>
<td>North Road Axis of Crete</td>
<td>90-E75</td>
<td>Chania-Sitia</td>
<td>276</td>
<td>Single</td>
<td>Comprehensive</td>
</tr>
</tbody>
</table>

All relevant data on road crashes within the considered TEN-T network were extracted from Road Safety Institute ‘Panos Mylonas’ database which has been acquired from the Hellenic Statistical Authority. The data are the latest available (for the most recent time period, i.e. years 2014-2017). The traffic crash data are comprised of all severity type crashes, thus containing fatal, serious and slight crashes.

4.2 Crash data synthesis

The crash data collection is followed by the synthesis and analysis of the pertinent data for each of the two considered TEN-T axes, including disaggregation of the data by crash severity and assessment of crash patterns.

4.1.1 Crash severity

The following two Figures (8 and 9) illustrate the distribution of the crashes for each road axis, according to the crash severity.
The above two Figures indicate that approximately 20% of the recorded crashes are fatal on Egnatia Motorway, while the majority (55%) of the road crashes on NRAC lead to fatalities. This difference is mostly explained by the carriageway type of the two axes, i.e. by design, motorways are the safest road type and provide – in general – higher safety standards than single carriageways.

4.1.2 Crash type

The disaggregation of traffic crashes by crash type is displayed in Figures 10 and 11 below.
Figure 10: Crash type distribution in Egnatia Motorway (Sindos I/C-Kipi, 2014-2017)

Figure 11: Crash type distribution in North Road Axis of Crete (Chania-Sitia, 2014-2017)

From the Figures above, a number of remarkable facts are indicated.

First of all, there are no recorded head-on crashes on Egnatia motorway, in contrast with North Road Axis of Crete, where about 11% of traffic crashes is associated with head-on crashes. This crash type is closely related to the road infrastructure type. Therefore, divided roads and specifically dual
carriageways and motorways prevent – to an effective degree – head-on crashes from occurring. This is the primary reason why Egnatia motorway has no head-on crashes.

Head-on crashes are generally the most severe of all vehicle crash types. The combined mass and speed of vehicles often result in serious or fatal consequences for vehicle occupants. Even in the most modern cars, the chances of surviving a head-on crash at speeds above 70 km/h are greatly reduced. For older vehicles, or in collisions involving vehicles of different size, surviving such a crash is less likely at far lower speeds. This crash type occurs when one vehicle leaves its path and comes into the path of the oncoming vehicle. This also explains – to some extent – why about 3 out of 4 crashes occurring in NRAC, which is mostly an undivided road (single carriageway), are serious or fatal crashes.

In addition, due to the carriageway type, there is a significant difference between the angle collisions for each road axis, respectively. The portion of angle collisions recorded on NRAC (33%) is around 3 times higher than the pertinent one referring to Egnatia motorway (11%).

Furthermore, it is observed that the percentage of rear-end crashes on Egnatia motorway (24%) is almost 5 times higher, in comparison with the corresponding percentage on NRAC (5%). A rear-end crash involves one vehicle or road user running in to the back of another vehicle or road user. This can occur when the front vehicle slows down or stops, or because the following vehicle is travelling faster than the front vehicle. This is a common crash type met on divided roads, such as motorways, although the severity is often less than for other crash types because the relative speeds of vehicles involved in a rear-end collision are generally lower, as they are travelling in the same direction. Also, they frequently occur after both vehicles have undertaken braking action, and thus any secondary impact with the surrounding road environment is less severe. They can be more serious in nature when vehicles of different mass come into contact (e.g. car and vulnerable road users, or a truck and car).

Moreover, the proportion of run-off crashes recorded is pretty high, both on Egnatia motorway (48%) and NRAC (33%). In general, run-off road crashes are common, especially in high speed areas. They occur at bends and on straight sections of the road. In high speed environments they can have severe outcomes, particularly if a rigid object (e.g. a tree) is hit or there is a steep embankment or cliff. Of course, speed is the leading cause of this crash type, whereas in terms of road infrastructure, the presence of road curves, the severity of which is underestimated, can contribute further to a higher incidence of run-off road crashes.

The high proportion of run-off crashes can be explained, if the location type of traffic crashes is considered. The following two figures show that approximately 1 out of 3 traffic crashes occur at a road bend.
Finally, from Figures 10 and 11, it is noted that the share of crashes, involving vulnerable road users and specifically pedestrians, on NRAC (11%) is about 3 times higher than the corresponding proportion on Egnatia motorway. This is merely explained by the fact that there are many informal or unprotected pedestrian crossings across the NRAC, in addition to the already existing uncontrolled access points. In contrast, Egnatia motorway comprises a closed road system with controlled access points (graded entrance and exit points) where pedestrians are prohibited.
5 Comparative analyses

This chapter utilizes the crash data extracted from the Greek TEN-T network and examines which crashes are appropriate for to black spot analysis, route safety assessment or network-wide road assessment. Subsequently, an estimation of the comparative effectiveness of the approaches described within Chapter 3 is provided.

5.1 Black spot Analysis

This section uses black spot analysis as a tool to identify hazardous road sites across the examined Greek TEN-T Network.

The following criteria were adopted in order to characterise a road site as a black spot, with a maximum range of 500 metres:

- At least 3 recorded traffic crashes in a consecutive 3-year period (i.e. 2014-2016 or 2015-2017) or
- At least 4 recorded crashes in the entire 4-year assessment period (i.e. 2014-2017).

It is noted that all injury crashes were taken into consideration for the detection of black spots.

5.1.1 Application at the Greek Core TEN-T Network

There are six sites which meet the defined black spot identification criteria, and thus were recognized as hazardous sites along the specific part of the Greek Core TEN-T network (i.e. Egnatia Motorway, Sindos I/C-Kipi). The detected black spots along with further location and crash details are summarized in the following Table.

<table>
<thead>
<tr>
<th>Black spot No.</th>
<th>Chainage</th>
<th>Location Type</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>320+000</td>
<td>Straight Segment</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>326+500</td>
<td>Left Turn Curve</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>327+500</td>
<td>Straight Segment</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>328+500</td>
<td>Straight Segment</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>330+000</td>
<td>Straight Segment</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>331+500</td>
<td>Straight Segment</td>
<td>4</td>
</tr>
</tbody>
</table>

From the Table above, it can be seen that 5 out of 6 (83%) black spots occurred on straight segments. In compliance with this, 24 out of 27 (88%) recorded traffic crashes in the apparent black spots occurred at straight segments, compared with the corresponding percentage (68%) for the total of crashes.

Figure 14 presents the crash severity distribution among the black spot crashes.
From the above Figure, it is apparent that approximately 19% (5 out of 27) of the recorded crashes in the examined black spots lead to fatalities, which is close to the relevant percentage (20%) when analysing the total amount of crashes in Egnatia motorway. The majority of the crashes (74%) located at black spots still involve slight crashes, indicating the high level of road safety provided by a motorway.

Additionally, black spot fatal crashes constitute about 1 out of 5 (19%) of the overall fatal crashes, whereas the corresponding percentage for serious crashes is estimated at 11% (2 out of 18). Finally, slight traffic crashes recorded at black spots are almost 1 out of 4 (23%) of the total slight crashes. Note that the ratio of the overall crashes concentrated at black spots to the overall crashes placed in the examined axis is estimated at approx. 20% (27 out of 131).

Furthermore, the disaggregation of traffic crashes by crash type is demonstrated in the following Figure.

Through further analysis, it is estimated that 37% of crashes that occurred at the examined black spots are related to rear-end crashes. This percentage is about 50% higher than the corresponding one (24%) when considering the total of crashes placed in the inspected road axis. In addition, 31% of rear-end crashes belong to black spots.
Likewise, the share of black spot angle collisions is about 22% of the total of black spot crashes, double than the relevant share when analysing the total of crashes for the entire road axis. Additionally, note that 40% of the overall angle collisions is placed at black spots.

Respectively, nearly 1 out of 4 (26%) crashes recorded at black spots is associated with run-off crashes. This percentage is almost half of the relevant one when considering the total of crashes placed in the examined axis (Egnatia Motorway). Beyond this, only 1 out of 9 of the total run-off crashes occur at black spots.

Once more, there are no recorded head-on crashes and the relevant number for overturning crashes and other type of crashes is also zero. What is more, the ratio of collisions with stopped vehicle(s) recorded at black spots to the overall respective collisions is calculated at 1:5, whereas the corresponding percentage for pedestrian collisions is 2:5.

5.1.2 Application in the Greek Comprehensive TEN-T Network

Concerning the considered part of the Greek Comprehensive TEN-T network (i.e. NRAC, Chania-Sitia), 3 road sites among the potential locations met the defined black spot identification criteria, and thus were regarded as hazardous sites. The identified black spots along with further site and crash details are displayed in Table 4.

<table>
<thead>
<tr>
<th>black spot No.</th>
<th>Chainage</th>
<th>Location Type</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>30+000</td>
<td>Right Turn Curve</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>118+000</td>
<td>Left Turn Curve</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>157+000</td>
<td>Straight Segment</td>
<td>3</td>
</tr>
</tbody>
</table>

The above Table shows that 2 out of 3 black spots identified across NRAC are road bends. In line with this, 6 out of 9 recorded crashes in the considered black spots took place in a road bend, which is opposite to the corresponding ratio (nearly 1 out of 3) for the total of crashes.

Figure 16 illustrates the crash severity distribution among the black spot crashes.
From Figure 16, it is concluded that approximately 8% of the total fatal crashes occur at the examined black spots. The corresponding percentage for serious and slight crashes is estimated at 36% and 12%, respectively. Note that the proportion of the overall crashes concentrated at black spots to the overall crashes placed in the examined axis is estimated at nearly 15%.

The disaggregation of traffic crashes by crash type is displayed in the following Figure.

The above Figure shows that the majority of black spot crashes are either head-on crashes or angle collisions. This explains why 7 out of 9 black spot crashes are also fatal or serious crashes, considering that these two crash types are closely associated with serious injury or fatal crashes.
5.2 Route Safety Assessment

This section utilizes route safety assessment as a tool to identify hazardous road sections across the examined Greek TEN-T Network.

Initially, each of the two considered TEN-T road axes was divided into 10-km long sections, in order to have homogeneous segments, in terms of road design characteristics and traffic volumes. It is considered that consistency is totally accomplished along each road segment for length intervals of this range. In addition, the registered traffic crashes were assigned to the corresponding road section.

Subsequently, the Poisson test was regarded as the best applicable statistical technique for the identification of hazardous road segments, as it provides objective criteria for the route safety assessment process, considering simultaneously the stochastic nature of traffic crashes.

In order to implement the method, the Poisson distribution average (or expected number of crashes) was calculated, i.e. the average number of crashes for each road section and the level of confidence was defined at 95%. Successively, the critical number of crashes was estimated, through the Poisson random events distribution chart. Finally, every road section, where the recorded number of crashes surpassed the critical number of crashes, was characterised as a crash-prone location.

Note that all injury crashes in a 4-year assessment period (i.e. 2014-2017), were taken into account in order to have the most representative sample.

The application of the Poisson method is presented for each of the two considered axes of the Greek TEN-T network, in the following two subsections.

5.2.1 Application in the Greek Core TEN-T Axis

The following Table presents the considered road sections for Egnatia motorway, along with the relevant allocated traffic crashes.

<table>
<thead>
<tr>
<th>Road Section ID</th>
<th>Section’s Start Point (Chainage)</th>
<th>Length (km)</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>310+000</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>320+000</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>330+000</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>340+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>350+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>360+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>370+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>380+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>390+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>400+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>410+000</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>420+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>430+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>440+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>450+000</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>
From Table 5, the following Figure is formed, where the crash distribution within the considered sections is depicted.

![Crash distribution per section](image)

Figure 18: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Crash distribution per section

The following parameters are estimated:

- Poisson distribution average: 3.74 crashes per road section.
- Statistical confidence: 95%.
- Critical number of crashes: 5.

Consequently, road sections which have more than 5 crashes are considered to be hazardous segments.

The identity of the hazardous road sections is demonstrated in following Table.

**Table 6: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Hazardous Road Sections**

<table>
<thead>
<tr>
<th>Road Section ID</th>
<th>Section’s Start Point (Chainage)</th>
<th>Length (km)</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>310+000</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>320+000</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>330+000</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>20</td>
<td>500+000</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

Apparently, in this approach, 4 road segments (or 40 km equivalently) of the considered Core TEN-T network are regarded as crash-prone sections and, therefore, need further investigation with proper treatment measures.

**5.2.2 Application in the Greek Comprehensive TEN-T Axis**

The examined road sections for North Road Axis of Crete, along with the associated crashes, are displayed in Table 7.

**Table 7: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Crash distribution per section**

<table>
<thead>
<tr>
<th>Road Section ID</th>
<th>Section’s Start Point (Chainage)</th>
<th>Length (km)</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>0+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>10+000</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>20+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>30+000</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>40+000</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>50+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>60+000</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>70+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>80+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>90+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>100+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>110+000</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>120+000</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>130+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>140+000</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>150+000</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>17</td>
<td>160+000</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>18</td>
<td>170+000</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>180+000</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>
### Table 8: Traffic Crashes

<table>
<thead>
<tr>
<th>Road Section ID</th>
<th>Section’s Start Point (Chainage)</th>
<th>Length (km)</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>20</td>
<td>190+000</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>200+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>22</td>
<td>210+000</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>23</td>
<td>220+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>230+000</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>240+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
<td>250+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>27</td>
<td>260+000</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>28</td>
<td>270+000</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

From the above Table, the following Figure is formed, where the crash distribution within the considered 10-km sections is illustrated.

**Figure 19: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Crash distribution per section**

Successively, the subsequent parameters are evaluated:

- Poisson distribution average: 2.18 crashes per road section.
- Statistical confidence: 95%.
- Critical number of crashes: 4.

As a result, road segments, where more than 4 crashes have occurred, are regarded as hazardous sections.

The identity of road sections that meet the above condition is demonstrated in Table 8.
Table 8: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Hazardous Road Sections

<table>
<thead>
<tr>
<th>Road Section ID</th>
<th>Section’s Start Point (Chainage)</th>
<th>Length (km)</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>8</td>
<td>70+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>90+000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>16</td>
<td>150+000</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

From the above Table, it is evident that 3 road sections (or approximately 30 km) of the examined Comprehensive TEN-T network are considered to be high-risk sections and, thus, require further attention in order to be treated properly.

5.3 Network-Wide Road Assessment

In this section, network-wide road assessment is conducted in order to examine the road safety level across the entire considered TEN-T network. Network assessment is performed through the following methods:

- Poisson Test
- RAP Crash Risk Mapping
- RAP Star Ratings & Investment Plans

Note that all injury crashes, in a 4-year assessment period (i.e. 2014-2017), were considered in order to implement the Poisson test, as well as the Risk Mapping (EuroRAP). On the contrary, Star Ratings (iRAP) is a non-crash-based method, based on road inspection, as already described.

The application of the above methods is further described below.

5.3.1 Poisson Test

In order to apply the Poisson test across the examined TEN-T network, the already considered 10-km long road sections for each axis are integrated into one sample.

Consecutively, the following parameters are estimated:

- Poisson distribution average: 3.05 crashes per road section
- Statistical confidence: 95%
- Critical number of crashes: 5

Accordingly, road sections, where the recorded number of crashes is higher than 5, are considered to be crash-prone sections.

The identified hazardous road sections across the examined TEN-T network are presented in Table 9.
Table 9: Poisson Test – Hazardous road sections across the examined Greek TEN-T Network

<table>
<thead>
<tr>
<th>Road Axis</th>
<th>Section ID</th>
<th>Section’s Start Point (Kilometric Position)</th>
<th>Traffic Crashes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Egnatia Motorway</td>
<td>1</td>
<td>310+000</td>
<td>8 1 0 7</td>
<td></td>
</tr>
<tr>
<td>Egnatia Motorway</td>
<td>2</td>
<td>320+000</td>
<td>19 5 1 13</td>
<td></td>
</tr>
<tr>
<td>Egnatia Motorway</td>
<td>3</td>
<td>330+000</td>
<td>16 1 1 14</td>
<td></td>
</tr>
<tr>
<td>Egnatia Motorway</td>
<td>20</td>
<td>500+000</td>
<td>7 3 0 4</td>
<td></td>
</tr>
<tr>
<td>NRAC</td>
<td>16</td>
<td>150+000</td>
<td>9 2 5 2</td>
<td></td>
</tr>
</tbody>
</table>

Note that when applying the Poisson test for the entire considered TEN-T network, the total number of hazardous road sections is 5, instead of 7, when performing the Poisson test for each individual road axis. This is explained by the fact that the majority of the crashes (around 68%) are recorded in Egnatia motorway and, thus, the overall Poisson distribution average is increased (3.05 crashes/section), in comparison with the corresponding value for the NRAC (2.18 crashes/section). As a result, the critical number of crashes is also increased (5 instead of 4), respectively, and therefore 2 NRAC sections are no longer regarded as dangerous.

5.3.2 RAP Crash Risk Mapping
5.3.2.1 Subdivision of the TEN-T Network into RAP sections

According to the EuroRAP protocols, where possible each RAP road section should aim to achieve the following criteria:

- Average approximately 30km in length: to yield sufficiently robust crash numbers over time. The general rule of thumb shows that as, a minimum, single carriageway sections should be at least 5 km and motorways and dual carriageways at least 10 km.

- Contain approximately 20 fatal and serious crashes over a three-year period: to minimize the extent that risk rates are influenced by random distribution of crashes over the network and ensure that higher or lower rates truly represent the long-term rate for the section.

Nevertheless, it is recognized that these requirements cannot always be met, as well as in the current case of study.

Therefore, the investigated network was divided into road sections, in a manner that each road section has approximately 20 all injury crashes within a 4-year assessment period. In some road intervals, the route length is also increased. In addition, the subdivision of the network into RAP sections was performed, such that as far as possible the design of the road within each is uniform, and the traffic flow consistent.

The considered RAP sections for Egnatia motorway, along with the allocated crashes, are shown in Table 10.
Table 10: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Crash distribution per RAP section

<table>
<thead>
<tr>
<th>RAP Section ID</th>
<th>Section’s Description</th>
<th>Length (km)</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start Point</td>
<td>End Point</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>310+000</td>
<td>327+000</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>327+000</td>
<td>340+000</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>340+000</td>
<td>400+000</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>400+000</td>
<td>460+000</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>460+000</td>
<td>510+000</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>510+000</td>
<td>570+000</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>570+000</td>
<td>658+000</td>
<td>88</td>
</tr>
</tbody>
</table>

Likewise, Table 11 shows the perceived RAP sections for NRAC, along with the corresponding traffic crashes.

Table 11: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Crash distribution per RAP section

<table>
<thead>
<tr>
<th>RAP Section ID</th>
<th>Section’s Description</th>
<th>Length (km)</th>
<th>Traffic Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start Point</td>
<td>End Point</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>0+000</td>
<td>42+000</td>
<td>42</td>
</tr>
<tr>
<td>2</td>
<td>42+000</td>
<td>103+000</td>
<td>61</td>
</tr>
<tr>
<td>3</td>
<td>103+000</td>
<td>167+000</td>
<td>64</td>
</tr>
<tr>
<td>4</td>
<td>167+000</td>
<td>230+000</td>
<td>63</td>
</tr>
<tr>
<td>5</td>
<td>230+000</td>
<td>276+000</td>
<td>46</td>
</tr>
</tbody>
</table>

5.3.2.2 Calculation of Risk Band Thresholds

The first thresholds used for the risk bands (“Risk Bands 2010”) were established in the development of EuroRAP in 2000 and are based on consistent crash distributions and ratios across countries. New thresholds (“Risk Bands 2020”) were defined for data periods starting from 2010 which address the reductions achieved over the ten-year period which occurred. Additionally, Risk Bands 2020 is utilized when results are considered for international comparisons. Therefore, Risk Bands 2020 is the preferred approach.

Table 12 shows the “Risk Bands 2020” thresholds. These express fatal rates and are based on a standard 3-year data period.

Table 12: Risk Bands 2020 Thresholds (3-year standard)

<table>
<thead>
<tr>
<th>Risk Bands 2020</th>
<th>F rates/vehicle km</th>
<th>F rates/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0 to &lt;1.2</td>
<td>0 to &lt;0.08</td>
</tr>
<tr>
<td>Low-medium</td>
<td>1.2 to &lt;4.9</td>
<td>0.08 to &lt;0.16</td>
</tr>
<tr>
<td>Medium</td>
<td>4.9 to &lt;8.4</td>
<td>0.16 to &lt;0.24</td>
</tr>
<tr>
<td>Medium-high</td>
<td>8.4 to &lt;14.2</td>
<td>0.24 to &lt;0.32</td>
</tr>
<tr>
<td>High</td>
<td>≥14.2</td>
<td>≥0.32</td>
</tr>
</tbody>
</table>
To obtain the proper thresholds for each risk banding, the upper and lower limits for fatal (F) crashes from the Table above are multiplied by the scaling factor for the considered TEN-T network.

In the current case of study, the scaling factor is defined as the ratio of all the injury crashes to the fatal crashes. A scaling factor is generally used in order to consider the variations in the FSI definition and crash severity distribution across a network and therefore adjust the standard upper and lower Risk Bands thresholds.

The scaling factor is calculated as follows in Table 13.

<table>
<thead>
<tr>
<th>Route Description</th>
<th>Assessment Period: 2014-2017 Crash Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Injury</td>
</tr>
<tr>
<td>Sindos I/C-Kipi</td>
<td>131</td>
</tr>
<tr>
<td>Chania-Sitia</td>
<td>61</td>
</tr>
<tr>
<td>Totals</td>
<td>192</td>
</tr>
<tr>
<td>Scaling Factor = All Injury/Fatal</td>
<td>3,1475</td>
</tr>
</tbody>
</table>

To obtain the thresholds for each risk banding, the upper and lower limits for fatal (F) crashes from Table 12 are multiplied by the scaling factor regarding the examined TEN-T network.

The upper and lower boundaries for RAP Crash Risk Mapping based on crashes per kilometre (crash density) are calculated by using the following procedure. Crash density is presented as the annual average rate. The (all injury / fatal) scaling factor is used as a multiplier against the annual equivalent of F rates/km:

<table>
<thead>
<tr>
<th>Risk Band</th>
<th>F rates/km (3 year standard)</th>
<th>F rates/km (annual equivalent)</th>
<th>Scaling Factor</th>
<th>Adjusted lower-upper limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0 to &lt;0,08</td>
<td>0 to &lt;0,03</td>
<td>3,1475</td>
<td>0 - &lt;0,08</td>
</tr>
<tr>
<td>Low-medium</td>
<td>0,08 to &lt;0,16</td>
<td>0,03 to &lt;0,05</td>
<td>3,1475</td>
<td>0,08 - &lt;0,17</td>
</tr>
<tr>
<td>Medium</td>
<td>0,16 to &lt;0,24</td>
<td>0,05 to &lt;0,08</td>
<td>3,1475</td>
<td>0,17 - &lt;0,25</td>
</tr>
<tr>
<td>Medium-high</td>
<td>0,24 to &lt;0,32</td>
<td>0,08 to &lt;0,11</td>
<td>3,1475</td>
<td>0,25 - &lt;0,34</td>
</tr>
<tr>
<td>High</td>
<td>≥0,32</td>
<td>≥0,11</td>
<td>3,1475</td>
<td>≥0,34</td>
</tr>
</tbody>
</table>

Likewise, for calculating the upper and lower boundaries for RAP Crash Risk Mapping based on crashes per vehicle kilometres travelled, based on a 3-year data period, the (All injury / Fatal) scaling factor is used as multiplier against the F rates/vehicle km values:
Table 15: Calculating risk band thresholds for crashes per vehicle kilometre travelled (Risk Bands 2020)

<table>
<thead>
<tr>
<th>Risk Band</th>
<th>F rates/vehicle km</th>
<th>Scaling Factor</th>
<th>Adjusted lower-upper limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0 to &lt;1,2</td>
<td>3,1475</td>
<td>0 - 3,78</td>
</tr>
<tr>
<td>Low-medium</td>
<td>1,2 to &lt;4,9</td>
<td>3,1475</td>
<td>3,78 - &lt;15,27</td>
</tr>
<tr>
<td>Medium</td>
<td>4,9 to &lt;8,4</td>
<td>3,1475</td>
<td>15,27 - &lt;26,28</td>
</tr>
<tr>
<td>Medium-high</td>
<td>8,4 to &lt;14,2</td>
<td>3,1475</td>
<td>26,28 - &lt;44,70</td>
</tr>
<tr>
<td>High</td>
<td>≥14,2</td>
<td>3,1475</td>
<td>≥44,70</td>
</tr>
</tbody>
</table>

5.3.2.3 Collective risk

Collective risk demonstrates the crash density along a road section and is expressed as the number of all injury crashes per kilometer per year (annual average):

\[
\text{Collective Risk} = \frac{\text{All injury crashes over assessment period}}{\text{Length x Years in assessment period}}
\]

The following Tables (Table 16 and Table 17) present the collective risk for each of the Egnatia motorway and NRAC sections, respectively. Subsequently, the risk band where each section falls into is estimated, according to Table 14.

Table 16: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Collective risk per RAP section

<table>
<thead>
<tr>
<th>RAP Section ID</th>
<th>Length (km)</th>
<th>All Injury Crashes</th>
<th>Collective Risk (Crashes/km/year)</th>
<th>Risk Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>20</td>
<td>0,29</td>
<td>Medium-high</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>23</td>
<td>0,44</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>19</td>
<td>0,08</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>17</td>
<td>0,07</td>
<td>Low</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>21</td>
<td>0,11</td>
<td>Low-medium</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>16</td>
<td>0,07</td>
<td>Low</td>
</tr>
<tr>
<td>7</td>
<td>88</td>
<td>15</td>
<td>0,04</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 17: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Collective risk per RAP section

<table>
<thead>
<tr>
<th>RAP Section ID</th>
<th>Length (km)</th>
<th>All Injury Crashes</th>
<th>Collective Risk (Crashes/km/year)</th>
<th>Risk Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42</td>
<td>10</td>
<td>0,06</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>19</td>
<td>0,08</td>
<td>Low-medium</td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>20</td>
<td>0,08</td>
<td>Low-medium</td>
</tr>
<tr>
<td>4</td>
<td>63</td>
<td>12</td>
<td>0,05</td>
<td>Low</td>
</tr>
<tr>
<td>5</td>
<td>46</td>
<td>0</td>
<td>0,00</td>
<td>Low</td>
</tr>
</tbody>
</table>
According to the estimated crash density rates, two RAP sections of Egnatia motorway (equivalent to 30 km or 5% of the considered TEN-T network, approximately) are classified as medium or higher risk sections.

5.3.2.4 Individual risk

Individual risk or crash risk per kilometre travelled is defined as the number of all injury crashes per billion kilometers travelled:

\[
\text{Individual Risk} = \frac{\text{All injury crashes}}{\text{Length x AADT x 365 x Years in assessment period}} \times 1 \text{ billion (10}^9)\]

Before calculating the individual risk for each of the considered RAP sections, the Average Annual Daily Traffic, regarding the assessment period (2014-2017), is allocated to each individual section. The relevant traffic data were collected by the Hellenic Ministry of Infrastructure, Transport and Networks.

Tables 18 and 19 show the individual risk for each of the Egnatia motorway and NRAC sections, correspondingly. Successively, the risk band for each RAP section is estimated, according to Table 15.

### Table 18: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Individual risk per RAP section

<table>
<thead>
<tr>
<th>RAP Section ID</th>
<th>Length (km)</th>
<th>All Injury Crashes</th>
<th>AADT (2014-2017)</th>
<th>Individual Risk (Crashes/veh<em>km</em>10^9)</th>
<th>Risk Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>20</td>
<td>10.470</td>
<td>76.96</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>23</td>
<td>10.470</td>
<td>115.74</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>19</td>
<td>10.577</td>
<td>20.51</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>17</td>
<td>11.752</td>
<td>16.51</td>
<td>Medium</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>21</td>
<td>12.460</td>
<td>23.09</td>
<td>Medium</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>16</td>
<td>8.257</td>
<td>22.12</td>
<td>Medium</td>
</tr>
<tr>
<td>7</td>
<td>88</td>
<td>15</td>
<td>4.908</td>
<td>23.79</td>
<td>Medium</td>
</tr>
</tbody>
</table>

### Table 19 North Road Axis of Crete (Chania-Sitia, 2014-2017) – Individual risk per RAP section

<table>
<thead>
<tr>
<th>RAP Section ID</th>
<th>Length (km)</th>
<th>All Injury Crashes</th>
<th>AADT (2014-2017)</th>
<th>Individual Risk (Crashes/veh<em>km</em>10^9)</th>
<th>Risk Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42</td>
<td>10</td>
<td>13.349</td>
<td>12.22</td>
<td>Low-medium</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>19</td>
<td>8.529</td>
<td>25.01</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>20</td>
<td>12.634</td>
<td>16.94</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>63</td>
<td>12</td>
<td>8.443</td>
<td>15.45</td>
<td>Medium</td>
</tr>
<tr>
<td>5</td>
<td>46</td>
<td>0</td>
<td>8.443</td>
<td>0.00</td>
<td>Low</td>
</tr>
</tbody>
</table>
From the Tables above, it is implied that 10 out of 12 RAP sections (equivalent to 536 km or 85% of the investigated TEN-T network) have a medium or higher risk profile. This is a major difference, compared with the crash density approach, which does not take into account the level of use of the examined road infrastructure.

### 5.3.3 RAP Star Ratings

The following Figure depicts the level of risk for vehicle occupants across the examined Greek TEN-T network, based on the most recent Star Ratings conducted (SENSoR Project, 2014).

Figure 20: Star Ratings-Level of risk for vehicle occupants across the Case Study
As added value, the Star Ratings methodology can also provide the level of risk across a network for motorcyclists, pedestrians and cyclists. Figure 21 illustrates the level of risk for motorcyclists across the considered Greek TEN-T network, based on the most recent Star Ratings conducted (SENSoR Project, 2014).

Figure 21: Star Ratings-Level of risk for motorcyclists across the Case Study
The next Table shows the Star Ratings distribution across the considered network, for vehicle occupants and motorcyclists. From Figure 20 and Table 20, it is implied that the entire examined TEN-T network falls under a 4-Star rating score, when considering vehicle occupants.
Table 20: Star Ratings distribution for vehicle occupants and motorcyclists across the Case Study

<table>
<thead>
<tr>
<th>Star Ratings</th>
<th>Vehicle Occupant</th>
<th>Motorcyclist</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (km)</td>
<td>Percent</td>
</tr>
<tr>
<td>5 Stars</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>4 Stars</td>
<td>0.10</td>
<td>0.01%</td>
</tr>
<tr>
<td>3 Stars</td>
<td>610.50</td>
<td>62.35%</td>
</tr>
<tr>
<td>2 Stars</td>
<td>143.20</td>
<td>14.62%</td>
</tr>
<tr>
<td>1 Star</td>
<td>225.40</td>
<td>23.02%</td>
</tr>
<tr>
<td>Not applicable</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>Totals</td>
<td>979.20</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
6 Conclusions

This section provides a comparison between the implemented network assessment methods and the traditional methods (black spot analysis and route safety assessment), based on the real crash data provided by the demonstrated Greek TEN-T network.

Table 21 displays the number of the identified hazardous road elements, as well as the amount of the examined network (in terms of length) which is considered to be hazardous, and thus should be further investigated, according to each of the applied approaches and methods. For the purposes of black spot analysis, according to the criteria already described and adopted, a crash-prone site of 500 m (maximum) is regarded as a hazardous road element, whereas for the purposes of route safety assessment or network assessment, a hazardous road element is considered to be a high-risk road section.

Additionally, note that specifically for the Risk Mapping (EuroRAP) technique, road sections with medium or higher risk profile were classified as hazardous, either the collective or individual risk is used. Similarly, from the Star Ratings (iRAP), road segments with a rating of 3 stars or lower were regarded as high-risk sections, although it is widely recognised that a 3-Star minimum is acceptable for each road segment. The Star Ratings outcome concerns the risk rating for vehicle occupants.

Table 21: Implementation of road risk assessment approaches – Results

<table>
<thead>
<tr>
<th>Risk Assessment Approach</th>
<th>Method</th>
<th>Hazardous Road Sections (Number)</th>
<th>Length of hazardous road sections (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black spot</td>
<td>Crash Count</td>
<td>9</td>
<td>4,5</td>
</tr>
<tr>
<td>Route Safety</td>
<td>Poisson Test</td>
<td>7</td>
<td>70,0</td>
</tr>
<tr>
<td>Network Safety</td>
<td>Risk Mapping</td>
<td>Collective Risk</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Individual Risk</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Star Ratings</td>
<td>35</td>
</tr>
</tbody>
</table>

From the results presented in the above Table, it is implied that, following the black spot approach, treatment policies should be undertaken in order to improve road safety on a very small proportion (nearly 1%) of the total network, whereas adopting a route safety approach, countermeasures should focus on about 70 km out of 624 km (nearly 11%) of the examined network.

Likewise, following a network-wide road assessment approach and depending on the adopted method, it seems that a significant proportion (8%-86%) of the considered network should be re-examined or further investigated in order to identify and eliminate possible infrastructure risk factors. This advocates the use of cost-effective mass action plans, thus, leading to a large scale improvement of the road safety level. Furthermore, it is recognised that Star Ratings cannot be directly compared with the other implemented methods, as it is entirely based on road-inspection and not the traffic crash history of the road.

Considering the research from the literature review on road risk assessment approaches, as well as the outcome from the implementation of these approaches in the demonstrated Case Study (Greek TEN-T network), a technical illustration of why it is best to use network-wide road assessment rather than the other methods, as they have already been described and demonstrated, is provided below.
The rationale for selecting and implementing the network safety approach relies on the following features of network assessment, which are also the comparative assets of this approach:

- Network assessment is regarded as a substantial tool for evaluating investment plans, thus, indicating locations where the largest return of investment – in terms of risk reduction – is expected.
- Network assessment, as a systematic procedure, supports performance tracking, a way of evaluating success and the effectiveness of investment in safer roads.
- Network safety management, which follows network assessment, advocates the use of financially viable mass action plans focusing on route safety as opposed often lower cost improvements at spot location.
- Network assessment is utilized to support national road safety strategies and plans.

In addition, the proposed framework underlying the network assessment follows the Safe System approach. This approach is based on the principle that human beings can and will continue to make mistakes and that it is a shared responsibility of actors at all levels to ensure that road crashes do not lead to serious or fatal injuries. According to the Safe System approach, the safety of all parts of the system must be improved — roads and roadsides, speeds, vehicles and road use so that if one part fails, other parts will still protect those involved.

Road infrastructure will continue to be very much part of the network safety approach. Well-designed and properly maintained roads can reduce the probability of road traffic crashes, while ‘forgiving’ roads (roads laid out in an intelligent way to ensure that driving errors do not immediately have serious consequences) can reduce the severity of crashes that do happen.

In conclusion, the network safety approach is totally in compliance with international best practice. Currently, international best practice is developing long-term programmes with the goal of eliminating death on the roads. These ‘vision zero’ programmes are developing a ‘safe system’, in which the driver, vehicle, and road are seen as one combined system protecting all road users from serious harm.
References

5 Thorson 1970.
10 OECD Road Research Group, 1976.
11 Ogden, 1996.
12 Lynam et al. 2003.
13 Renshaw and Everett, 1980.
16 McInerney R. and Fletcher M., 2013 Relationship between Star Ratings and crash cost per kilometer travelled on the Bruce Highway, Australia
17 BRAC, 2009.
18 IRAP-Road Safety Toolkit.
19 Royal Society for the Prevention of Accidents, UK.
22 The variability of group estimates with different combinations of road sections is investigated in more detail in section 5 of Lynam et al. (2003). European Road Assessment Programme – Pilot Phase Technical Report.