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Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
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<tbody>
<tr>
<td>iRAP</td>
<td>International Road Assessment Programme</td>
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<td>TEN – T</td>
<td>Trans European Network - Transport</td>
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<td>FPZ</td>
<td>Fakultet prometnih znanosti (Faculty of Transport and Traffic sciences)</td>
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<td>EU</td>
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<td>USA</td>
<td>United states of America</td>
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<td>FSI</td>
<td>Fatal and Serious Injury</td>
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<tr>
<td>CSV</td>
<td>Comma separated value</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic information system</td>
</tr>
<tr>
<td>SRS</td>
<td>Star Rating Scores</td>
</tr>
<tr>
<td>RSI</td>
<td>Road Safety Inspection</td>
</tr>
</tbody>
</table>
# Table of Contents

1. Introduction .......................................................................................................................... 5
2. Justification for network wide road assessment ..................................................................... 6
   2.1 What is the Network-Wide Road Assessment? ................................................................. 6
   2.2 Requirements of Directive (EU) 2019/1936 on Road Infrastructure Safety Management .......... 6
3. Network wide safety assessment methods ............................................................................. 9
   3.1 Black Spot Network Screening ....................................................................................... 10
   3.2 RAP Crash Risk Mapping .............................................................................................. 12
   3.3 Poisson Analysis ............................................................................................................ 16
   3.4 Bayes Method ................................................................................................................ 17
   3.5 Quality Control .............................................................................................................. 17
   3.6 RAP Star Rating and Fatality Estimation ........................................................................ 18
   3.7 PRACT - Predicting Road Accidents - a transferable methodology across Europe .......... 21
4. Performing network wide safety assessment ....................................................................... 23
   4.1 Poisson Test .................................................................................................................... 23
   4.2 RAP Crash Risk Mapping .............................................................................................. 24
   4.3 RAP Star Rating and Fatality Estimations ....................................................................... 28
   4.4 Understanding the results of network wide safety assessment ....................................... 31
5. Conclusion ............................................................................................................................... 38
Appendix A – Road Safety Audit ............................................................................................... 39
Appendix B – Road Safety Inspection ........................................................................................ 42
Appendix C – AASHTO Highway Safety Manual Predictive Method ......................................... 45
Appendix D – About IRAP Methodology .................................................................................. 48
Appendix E – How EuroRAP addresses the RISM .................................................................. 49
List of Tables

Table 1: Poisson Test – Hazardous road sections across the Greek TEN-T Network ........................................... 23
Table 2: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Crash distribution per RAP section .................. 24
Table 3: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Crash distribution per RAP section .......... 24
Table 4: Risk Bands 2020 Thresholds (3-year standard) ................................................................................. 24
Table 5: Scaling Factor Calculation .................................................................................................................. 25
Table 6: Calculating risk band thresholds for crash density (Risk Bands 2020) ............................................ 25
Table 7: Calculating risk band thresholds for crashes per vehicle kilometre travelled (Risk Bands 2020) .... 25
Table 8: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Collective risk per RAP section .................. 26
Table 9: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Collective risk per RAP section ............... 26
Table 10: Egnatia Motorway (Sindos I/C-Kipi, 2014-2017) – Individual risk per RAP section ................. 27
Table 11: North Road Axis of Crete (Chania-Sitia, 2014-2017) – Individual risk per RAP section .......... 27
Table 12: Star Ratings distribution for vehicle occupants, motorcyclists and pedestrians for the Egnatia Motorway - before countermeasure implementation ......................................................... 31
Table 13: Star Ratings distribution for vehicle occupants, motorcyclists and pedestrians for the North Road Axis of Crete - before countermeasure implementation ......................................................... 31

List of Figures

Figure 1: An overview of network-wide road assessment methods .......................................................... 9
Figure 2: Standard procedure for producing RAP Crash Risk Mapping .................................................. 13
Figure 3: Screenshot of standard RAP Crash Risk Mapping data template (Source: RAP Crash Risk Mapping: Technical Specification) ............................................................................. 15
Figure 4: Standard RAP Crash Risk Mapping colour palette .................................................................... 16
Figure 5: Star Ratings-Level of risk before countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, Egnatia Motorway .................................................................. 29
Figure 6: Star Ratings-Level of risk before countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, North Road Axis of Crete ........................................... 30
Figure 7: SRIP countermeasures for Egnatia Motorway ............................................................................. 32
Figure 8: SRIP countermeasures for North Road Axis of Crete .............................................................. 33
Figure 9: Star Rating after implementing the SRIP, Egnatia Motorway .................................................... 33
Figure 10: Star Rating after implementing the SRIP, North Road Axis of Crete ........................................ 34
Figure 11: Star Ratings-Level of risk after countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, Egnatia Motorway .......................................................... 35
Figure 12: Star Ratings-Level of risk after countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, North Road Axis of Crete ............................................ 36
Figure 13: FSI estimation map (All users) for Egnatia Motorway ............................................................... 37
Figure 14: FSI estimation map (All users) for North Road Axis of Crete .................................................. 37
1. Introduction

Optimising road safety and reducing the number of road casualties requires continuous action based on established and proven risk assessment methods. Approaches to assessing risk can be reactive, based on historical crash data, or proactive where risk is anticipated based on either expert judgement or empirical relationships between road design layouts/elements and crash likelihood or severity.

Most jurisdictions are now adopting the Safe System philosophy in their attempts to tackle road safety. Safe systems are built on two main principles.

1. Humans will always make errors when driving, so crashes are inevitable.
2. Humans are vulnerable to crash forces.

As such, Safe System requires elements of system design to work together to protect the road user in the event of a crash. Furthermore, Safe System requires a proactive approach to crash risk management to be taken. The adoption of Safe System requires a step change in approach from reacting only to crash hotspots, to also anticipating crash risk and proactively reducing risk for road users.

This manual provides an overview of the RISM directive and the processes that must be undertaken by Member States in order to fulfil their obligations. It then provides the reader, in an easy-to-understand way, with all the key information on relevant network-wide road assessment procedures, their description, main steps and implementation guidelines, coupled with an assessment case study on Greek Ten-T roads which provides an “in usage” insight of network wide road assessment procedures.
2. Justification for network wide road assessment

2.1 What is the Network-Wide Road Assessment?

To improve road safety and reduce the number of road casualties it is necessary to implement measures which are evidence-based and are supported by relevant data (e.g., road crash and road infrastructure data).

In many countries the most severe crash hotspots have already been tackled or hotspots are no longer simple to identify as crashes become increasingly sparsely distributed across networks. Therefore in order to further reduce the number of road fatalities and serious injuries, it is necessary to:

- perform more detailed investigations of the relevant road traffic accident characteristics, including the circumstances of road crashes, the mechanisms and causes leading to crashes, the severity of road crashes, the involved road users, etc.,
- periodically undertake proactive risk assessment of the road network in order be able to select and prioritise the optimal countermeasures that can be implemented.

Risk assessment methods assist in understanding the consequences of road crashes and provide information on:

- How often crashes occur
- When and where they happen
- What are the typical hazards which are present on the observed road network sections
- Which vehicle, driver and infrastructure characteristics contribute to road traffic crash occurrence

The main objective of network-wide road assessment is to support national road safety strategies and to provide an additional layer of relevant information alongside already existing approaches. Network assessment typically covers roads outside towns and cities, where fatal and serious injuries are concentrated for vehicle occupants. Not all roads carry the same risk; and examining the statistics from a wide range of countries show that around 50% of total fatalities occur on as little as 10% of total roads. Therefore, network-wide road assessment enables the identification of the safest and most hazardous road sections within observed region or country.

Network safety management follows the network safety assessment analysis and incorporates proper treatment-oriented policies to minimise risk across a road network. Network safety management uses acknowledged safety improvement programmes alongside other approaches, such as analysis at high-risk single sites.

2.2 Requirements of Directive (EU) 2019/1936 on Road Infrastructure Safety Management

In the Directive (EU) 2019/1936, it is stated that the road infrastructure safety management (‘RISM’*) procedures implemented on the TEN-T network have helped reduce fatalities and serious injuries in the Union. It is clear from the evaluation of the effects of Directive
2008/96/EC that Member States which have been applying RISM principles on a voluntary basis to their national roads beyond the TEN-T network have achieved much better road safety performance than Member States which did not do so. It is therefore also desirable for those RISM principles to be applied to other parts of the European road network.

A large proportion of road crashes occur on a small proportion of roads where traffic volumes and speeds are high and where there is a wide range of traffic travelling at different speeds. Therefore, the limited extension of the scope of Directive 2008/96/EC to motorways and other primary roads beyond the TEN-T network should contribute significantly to the improvement of road infrastructure safety across the Union. In order to ensure that such extension of scope has the intended effect, it is logical that primary roads other than motorways include all roads belonging to the highest category of road below the category ‘motorway’ in the national roads classification. For the same reason, Member States should be encouraged to ensure that at least all roads to which Directive 2008/96/EC applied before the entry into force of Directive (EU) 2019/1936, including on a voluntary basis, remain covered by this Directive.

Following the directive 2008/96/EC specifications, Network-Wide Road Assessment, should be carried out by experts. The amended directive has an extended scope. It applies to:

- Roads which are part of the trans-European road network, to motorways and to other primary roads, whether they are at the design stage, under construction or in operation;
- Other roads situated outside urban areas, which do not serve properties bordering on them, and which are completed using EU funding, except for roads not open to, or not designed for, general traffic.

The Network-Wide Road Assessment consists of measuring the safety performance of existing roads, then by targeting investments to the road sections with the highest level of risk (collective) and/or the greatest FSI reduction potential. According to the Directive 2008/96/EC:

- EU countries must carry out a network-wide road safety assessment, by 2024 at the latest and every 5 years subsequently, on the entire road network in operation covered by the directive. These assessments must assess accident and impact severity risk, based on:
  - a visual examination, either on site or by electronic means, of relevant road design characteristics; and
  - an analysis of sections of the road network which have been in operation for more than 3 years and where there have been a large number of serious accidents in proportion to the traffic flow.
- Assessment findings must be followed up by targeted road safety inspections or, if necessary, remedial action.
- Periodic road safety inspections must also be made, frequently enough to maintain adequate safety levels for the road infrastructure in question.
- The specific needs of vulnerable road users such as cyclists and pedestrians must be considered systematically in all road safety management procedures.
➢ Safety assessments must be published to highlight the safety level of road infrastructures across the EU.

➢ Existing and future procedures for road markings and road signs must focus on readability and detectability for human drivers and automated driver assistance systems.

➢ An assessment by a group of experts established by the Commission must, by June 2021, assess the opportunity to set common rules considering:
  ▪ The interaction between various driver assistance technologies and infrastructure.
  ▪ The effect of the weather and atmospheric phenomena as well as traffic on road markings and road signs present on EU territory.
  ▪ The type and frequency of maintenance efforts necessary for various technologies, including an estimate of costs.

➢ EU countries must notify the Commission of all the motorways and primary roads on their networks, as well as those roads exempt because they have a proven low safety risk, by 17 December 2021.

➢ The Commission must publish a map of the European road network within the scope of the directive, accessible online, highlighting different categories according to their level of safety.

Within the chapter 3, various network wide road assessment methodologies which have the potential to assist road authorities on implementing the requirements of RSIM (either fully or partially) are described, and a step-by-step overview of each methodology is provided.
3. Network wide safety assessment methods

Mobility Package 3, which is the last part of the European Commission’s Mobility Package proposals covering legislative initiatives in the areas of safe, clean and connected mobility, incorporates adjustments on the Road Infrastructure Safety Management (RISM) directive including the network-wide road assessment. There are several proposed methods for rating the safety of infrastructure which consider various parameters about operational conditions and infrastructure characteristics.

The classification and identity of methods used to perform Road Safety Assessments are shown in the Figure 1.

Reactive methods can be applied only on existing roads since data requirements (Crash rates, Annual Average Daily Traffic (AADT), etc.) for performing such methodologies usually require the road to already be in use. Proactive methods however can be applied to either Existing roads or New Roads since they examine the “in-built” safety of the roads. Road Safety Audits and Road Safety Inspections are listed in Figure 1, but doing a network wide surveys with either can be an impractical and costly in terms of personnel resource, thus they will not be included within the chapter, but rather an Appendix to the document for the purpose of comprehensiveness. Similarly, RAP Star Rating of new roads and designs is shown in the
diagram for completeness but is not a network level approach, rather it is applied to new schemes as they are planned and implemented.

Methods described within Chapter 3 have the potential to carry out the ranking of high accident concentration sections and network safety ranking, in accordance with an Annex III of Directive 2008/96/E.

Some network assessment methods (such as RAP protocols) also support performance tracking, which demonstrates how risk on the network has changed over a given period. Knowing where risk has been reduced and which of the countermeasures have proven most cost-effective is essential in building best practice and knowledge transfer.

3.1 Black Spot Network Screening

Network screening is defined as a process for reviewing a transportation network with the goal of detecting black spots and ranking sites from most critical to least critical with the aim of achieving a reduction in crash rates by implementing effective countermeasures. Sites which are recognized as most likely to realize a reduction in crash frequency are examined in more detail with the aim of identifying crash patterns and finding critical factors influencing a crash, as well as identifying appropriate countermeasures. Network screening can also be used to prepare and carry out policies, for instance prioritizing the replacement of all non-standard guardrail at sites with a high number of run-off-the-road crashes within a network. By using network screening techniques (simple ranking, sliding window, peak searching), it is possible to detect a crash black spot according to 13 different performance measures and datasets. Screening road sections requires identifying the location that is most likely to gain from a countermeasure, primarily by a reduction in crash frequency and/or severity. Having an insight of what portion of the roadway section controls the segment’s critical crash frequency will enable easier and more effective identification of effective countermeasures.

When performing network screening process, five major steps should be undertaken:

1. Establishing Focus

Very first step within network screening process is establishing the focus of the analysis. Network screening can be performed while concentrating on one or both of the following:

- Identification of sites with capability of the average crash frequency or crash severity reductions.
- Evaluation of the road network in order to detect sites with specific crash type or severity, with the goal of preparing and carrying out a policy (e.g., identification of sites with a high number of run-off-the-road crashes to prioritize the replacement of nonstandard guardrail, within a state network).

If network screening is being applied in order to detect spots where adjustments could reduce the number of crashes, same performance measures should be applied to all sites. Based on the results, those spots that show potential for improvement are identified and flagged for additional examination. This type of analysis is similar to a typical “black spot” analysis conducted in order to identify the “high crash locations.”
2. Identifying the Network and Establishing Reference Populations

Step one should form the foundation for the second step in the network screening process, which includes identifying the network elements that should be screened and grouping these elements into reference populations (a reference population is a grouping of sites with similar characteristics). Aspects to be considered for reference grouping can be related to control type, functional classification, area type, traffic volume ranges, etc.

3. Selecting Performance Measures

The third step in the network screening process is to select a performance measure to be used in evaluating the potential to reduce the number of crashes or crash severity at a site. Multiple performance measures can be selected as well. Performance measures are defined as measures which can enable quantitative performance measurements (for example average crash frequency, expected average crash frequency, critical crash rate, etc.). In network screening, using more than one performance measure to assess each spot may improve the level of confidence of the results. Several key factors should be kept in mind when selecting performance measures: data availability, regression-to-the-mean bias, and how the performance threshold is established.

4. Selecting Screening Method

The fourth step in the network screening process involves deciding on a particular network screening method. When screening the network for critical sites, there are three main methods which can be chosen, which are:

a) Sliding window method

In the sliding window method, a window of a specific length is conceptually moved on the road section from beginning to an end in increments of specific size. The performance measure which is chosen to screen the segment is applied to each position of the window, and the results of the analysis are recorded for each of the windows. A window relates to an examined section if at least some portion of the window is within the boundaries of the segment. From all the windows that pertain to a given section, the window that shows the most potential for reduction in crash frequency out of the whole section is identified and is used to represent the potential for reduction in crash frequency of the whole section. After all sections are rated according to the respective highest value, those sections with the greatest potential for reduction in crash frequency or severity are further studied with the aim of identifying potential countermeasures. Each window is moved forward until it reaches the end of connecting set of sections. Once the window nears the end of connecting set of sections, the window length remains the same, while the increment length is adjusted so that the last window is positioned at the end of the section.

b) Peak searching method

In the peak searching method, each individual roadway section is partitioned into windows of comparable length, potentially growing incrementally in length until the length of the window equals the length of the entire section. The
windows cannot span across multiple sections. Chosen performance measure is calculated per each window and based upon the statistical precision of the performance measure, the window with the maximum value of the performance measure within a section will be used to rank the probability for reduction in crashes in relation to the other screened sites.

**c) Simple ranking method**

A simple ranking method can also be utilized on sites and sections. In this method, the performance measures are calculated for all of the investigated sites, and the results are then arranged from high to low. The simplicity of this method is the greatest strength. However, it should be mentioned that for sections, the results are not as reliable as the other section screening methods.

The selected performance measure (Step 3) should be used on all sites and sections under consideration using a chosen screening method. The usage of particular screening methods for following instances is advised:

- Sections (e.g., roadway sections or ramps) should be screened using either sliding window or peak searching methods.
- Nodes (e.g., intersections or ramp terminal intersections) should be screened using simple ranking method.
- Facilities (combination of nodes and sections) should be screened using a combination of section and node screening methods.

**5. Screening and Results evaluation**

The performance measure and the screening method are applied to one or more of the sections, nodes, or facilities according to the methods outlined in Steps 3 and 4. Selected performance measure should be calculated and recorded for each section or node under consideration. Results can either be recorded in a table format or on maps as deemed appropriate. The output of the screening process will be a list of sites ordered according to the selected performance measure. Those sites higher on the list are considered most likely to benefit from countermeasures intended to reduce crash frequency. In general, it can be useful to apply multiple performance measures to the same data set. In doing so, some sites will repeatedly be at the high or low end of the resulting list. Sites that repeatedly appear at the higher end of the list could become the focus of more detailed site investigations.

**3.2 RAP Crash Risk Mapping**

Crash Risk Mapping (CRM) is an economical and easy to present methodology for network-wide road assessment. Risk Mapping provides a colour-coded representation of the crash occurrence on roads of the assessed network.

Risk Maps are designed in a way which supports national road safety strategies and can add an additional layer of information alongside established approaches. RAP CRM usually covers roads outside of towns and cities, where deaths and serious injuries are most concentrated for vehicle occupants. CRM identifies the safest and most dangerous road sections within a
region or country by utilising an international and common basis of measurement that can be used to assess priorities. The outputs obtained based on the CRM procedure offer an insight on the vehicle crash occurrence rate on a network, easily understandable by policy makers and the broader public.

Risk maps can show different data that has relevance to different audiences, the main two maps show:

- Crashes per kilometre – shows collective or community risk and can help road authorities understand where crashes are concentrated across the network
- Crashes per kilometre travelled – shows the crash risk to an individual as they move around the network which is useful to the media and to the public

The data underpinning CRM provide a good opportunity to track overall performance over time, by jurisdiction and by road type or road user. This can offer valuable insights into road safety performance across a network. The performance of individual sections over time can also be tracked and followed up through consultation with authorities. Knowing where risk has been reduced and the measures that have worked is essential in building best practice and knowledge transfer.

The main benefits of the methodology are its reliability and fast implementation, as well as relatively low implementation costs. High comparability and transferability of the methodology enables a comparison of the road network safety state between countries. The CRM methodology relies on the use of recorded crash and traffic flow data. CRM allows a dialogue about investment priorities across a network, with the opportunity to identify priority sections for investment across a network.

Standard RAP Crash Risk Mapping process is divided into 8 steps, displayed in the Figure 2.

![Figure 2: Standard procedure for producing RAP Crash Risk Mapping](image)

1. Obtaining the licence

It is important to mention that RAP Crash Risk Mapping protocol should only be used if a licence to do so is acquired. The licence provides full access to the detailed technical and design specifications, and it ensures consistency of output in both form and style. The licence also gives access to the RAP name and logo for the communication of results. Licences are issued annually to all RAP Members.
2. Defining the network to be assessed.

Typically, it is recommended to map higher tier roads first (where data is typically more readily available and more detailed), developing the network to the regional levels over a period of time. The distribution of crashes on different network levels (i.e., national roads, regional roads, motorways, dual and single carriageways) should be explored as a starting point.

Typically, a RAP network includes motorways, plus at least national non-motorways and main regional roads, and should usually include a mix of dual and single carriageways. Using this information, the base network should be established accordingly, and individual road sections should be defined with the aggregated data that can fit the sections.

3. Compiling a sample network and data set.

RAP methodology supports a route safety approach rather than focusing on high-risk single spots. With the aim of generating the data required for RAP Crash Risk Mapping analyses, crash and traffic flow data need to be assigned to specific road sections. The following list sets out the minimum data requirements for each individual road section:

- Section identifiers (in the form of a unique code)
- Length (to the nearest 0.1km)
- Latitude and longitude of start and end points, bounding box, or grid coordinates (these should be unique references from which the section can be clearly identified on a map)
- Description of start and end points (e.g. village/town/city names or points of interest)
- Carriageway type (e.g. motorway, dual, single, mixed (dual and single))
- Number of fatal crashes
- Number of serious injury crashes
- Traffic flow (in both directions, separately or combined) converted to AADT

Furthermore, road type, fatal and serious crashes by crash type and by user type, traffic flows by user type, speed limits and junction type data can also be integrated when available.

4. Quality assurance review

The data sheet with the data set should then be reviewed and crash definitions, traffic flows and road characteristics should be revisited. Figure 3 provides an example of the data sheet.
Aforementioned road sections need to be divided in such a way that as far as possible the design of the road is uniform, and the traffic flow consistent. This can be 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 1,000m or kilometre lengths in order to match the way in which crash and traffic data are collated.

Wherever feasible, each RAP road section should aim to accomplish 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 5km and motorways and dual carriageways at least 10km.
- Contain approximately 20 fatal and serious crashes over a three-year period: to minimise 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.

6. Defining the target audience and deciding how the data should be processed

Safety indicators based on the road network, crash numbers and traffic flow can be used to produce different types of RAP Crash Risk Mapping, aimed at different target audiences:

- Road-users are generally more interested in the risks they face as individual users.
- Authorities and policy makers, on the other hand, are interested in how they can improve safety across the network in order to spend available budgets effectively.

7. Production of standardised maps from the calculated ratings

In order to show the varying levels of risk across a road network, individual sections are assigned one of five colour coded risk bandings, displayed in Figure 4.

![Figure 4: Standard RAP Crash Risk Mapping colour palette](image)

The standard RAP Crash 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 black road in one country is the same as a black road in another.

8. Communication of results to the target audience.

RAP Crash Risk Mapping gives various insights to risk for different audiences. For road-users it is important that the output demonstrates how risk can change across a network, leading to a better understanding and awareness of why some roads are safer than others. For road providers, the output, when used alongside existing approaches, can help in setting realistic targets for improvements.

3.3 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 can be identified as a black spot, if the recorded number of crashes exceeds the critical number of crashes (as calculated for a defined level of confidence).

3.4 Bayes Method

In the Bayes method, the local expected number of crashes on a specific site is estimated as a weighted mean of the recorded number of crashes at the location and the general expected number of crashes for similar sites. 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.

Empirical Bayes Method (EB) offers a method which merges the estimates using a predictive model and observed crash frequencies in order to obtain a more reliable estimate of expected average crash frequency. The EB Method is a key tool which can be used to compensate for regression-to-the-mean bias. Crash frequencies vary naturally from one time period to the next. When a site has a higher-than-average frequency for a particular time period, the site is likely to have lower crash frequency in subsequent time periods. Utilising Bayes Method ensures that this natural decrease in crash frequency following a high observed value is not mistaken for the effect of a project or for a true shift in the long-term expected crash frequency.

The steps in applying the EB Method are:

1. Verification of applicability
2. Determining the accessibility of the data (whether observed crash frequency data are available for the project or facility, on the time period for which the predictive model was applied and, if so, obtaining those crash frequency data)
3. Allocating individual crash instances to specific roadway segments.
4. Approximately calculating the expected crash frequency by combining the predicted and observed crash frequencies for the observed time period.
5. Calibrating the estimated value of expected crash frequency to a future time period, if appropriate.

The observed crash data should be utilised once at least two years of observed crash history data is available for the section being evaluated. In estimating the expected crash frequency for an existing section in a future time period where no improvement is planned, only the traffic volumes should differ between the before and after periods, while the rest of the data set should remain the same.

3.5 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.
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 locate critical failures. Therefore, it was found that the techniques used in statistical quality control could be developed for the study of traffic crashes.

First step of Quality Control model is the division of the road facility into several 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 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.

Results describe 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.

3.6 RAP Star Rating and Fatality Estimation

Star Ratings are based on road attribute data, and provide a simple and objective measure of the level of safety built into the roads, for each of four types of road user: vehicle occupants, motorcyclists, pedestrians and cyclists.

The Star Ratings reflect risk contributed by each of the road attributes that are coded – the higher the risk, the lower the rating. The risk is calculated on the basis of research evidence

iRAP considers more than 90 proven road safety countermeasure treatments to generate affordable and economically tested Safer Road Investment Plans (SRIP) that will reduce road user risk, improve a road’s Star Rating and will save lives. Road improvement options range from low-cost road markings and pedestrian refuges to higher cost intersection upgrades and full highway duplication. In order to prioritise work on the network, the Fatality and Serious Injury estimation map (FSI estimation map) can be produced and utilised to identify the number of fatal and serious injuries on sections. Segments which have greater rate of FSI can then be identified and can subsequently be prioritized for most effective countermeasure implementation.

In the continuation of the chapter, a process for implementing Star Rating, fatality estimation and SRIP protocols is described, from the selection of priority sections, to survey and coding, through ViDA software outputs.

1. **Network selection**

The first step in the procedure is the identification of the roads on which the Star Rating and SRIP protocols should be applied to. A number of possibilities are feasible, each having respective benefits and shortcomings. The procedures are applicable to:

Entire road network: obvious benefit of examining the entire network is enabling the risk prioritization over the span of the entire network. Furthermore, strategic goals can be set more easily, and examining the entire network would provide a good foundation for monitoring improvements.

A certain subset of the network: even though there are obvious benefits to examining the entire network, this is not always feasible due to economic, political or other barriers. Identification of a logical network subset can also be performed, enabling the examination of a targeted part of the network. This network subset can be identified per road type or a performance element (e.g. rural roads, all motorways, roads with certain AADT, etc.). Crash density and crash risk rates can also be used for determining the network subset.

If crash risk or crash density parameters are chosen, the network should be partitioned into sections which are long enough that statistically reliable results can be obtained. A time period for accidents should be established (ideally three or more years) in order to make sure that a section is consistently hazardous.

Individual sections: individual section can also be examined once the section is pinpointed as a priority section for examination due to high risk, financing prospects for the specific section emerge, or if major works are already planned for the area, which means that improvements can be made upon the section for a marginal cost. However, if individual section approach is used, it will not be possible to prioritise investment across the network, and therefore optimal impact might not be possible to achieve.

2. **Road Survey**

In order to perform the Star Rating protocol on the observed road network, it is necessary to perform road survey and record georeferenced video files of the observed road sections. The road surveys are carried out by accredited suppliers, therefore ensuring that the data is collected to standard and risks associated with the collection are removed or reduced. More
information about the process is available on https://www.irap.org/knowledge-base-for-manuals/category/irap-survey-manual/

3. Road Coding

Recorded survey videos are uploaded into coding software and then segmented into 100-meter road segments which are used for performing road attribute coding and post-coding process. In the coding process, 50 attributes that are relevant to road safety outcomes are coded every 100 m along the road section. Coding needs to be undertaken by accredited personnel who are adequately trained and experienced and there are accredited coding teams available in several countries. iRAP requires all coding to be scrutinised through a quality assurance (QA) process, whereby at least 10% of the network is reviewed and any problems or inaccuracies are identified. The QA process runs throughout the project, and it is important that the first sample is reviewed early in the coding task.

4. Supporting data

To complement coding data, it is necessary to collect the data on existing speed limits, operating speeds, as well as the data on vehicle flow, motorcyclist percentage, the peak hour flows for cyclists and pedestrians. At an overall project level, three sets of information are required: crash data for a period of three years prior to survey, economic parameters, and countermeasure costs.

5. Processing the data in ViDA

After the coding process is completed, data is stored in a CSV format and then uploaded into ViDA web application. Finally, the prepared dataset is calibrated and processed using model algorithms that are computed using ViDA in order to create Star Rating, FSI estimation map and Safer Roads Investment Plans (SRIP).

6. Star ratings

Star Ratings road provide a simple and objective measure of the level of safety intended for individual road users which is ‘built-in’ for the road per vehicle occupants, motorcyclists, bicyclists and pedestrians categories. Five-star roads are the safest while one-star roads are the least safe. Broadly speaking, every extra star rating results in a halving of crash cost in terms of the number of people who are killed and seriously injured. Through the Risk Worm chart, it is also possible to see specific parts of the segments which are identified as the most critical ones. Star Ratings can be completed without reference to detailed crash data. The Star Ratings road can be generated for the roads the current condition (Before Star Rating) and following the implementation of a Star Rating Investment Plan (After Star Rating).

7. FSI estimation

Fatal and Severe Injury (FSI) crash reporting map can display estimated number of fatal and serious injuries on observed network. This map can help to prioritise the implementation of countermeasures by identifying specific locations or road sections where the potential to save lives is greatest. The FSI reports can be access from the ViDA reports ribbon. Once selected, users can select between the following options:

User group enables you to choose the FSI map to be displayed for an individual road user group or all the road user groups combined.
SRIP implementation enables you to choose Before or After Star Ratings. Before is the Star Rating before countermeasures from the SRIP are implemented (existing road). After is the Star Rating after SRIP countermeasures are implemented.

Banding type enables you to choose between the Relative bands and the Absolute bands. Relative bands display the FSI estimations in 10 percentile groups. Absolute bands display the FSI estimations relative to the Risk Mapping bands.

8. Star Rating Investment Plan

SRIPs identify ways in which fatal and serious injuries (FSIs) can be prevented in a cost-effective way. A SRIP is a high-level plan and should be used to understand the scale and potential or investing in road safety along with the types of interventions, and detailed planning would still be needed. ViDA calculates the casualty reduction expected from around 90 countermeasures (treatments designed to improve safety such as crash barriers, central cross hatching and shoulder rumble strips also known as raised rib line) and does so every 100 m along an inspected road, comparing this against the cost of implementing the treatment, to produce an economic appraisal. Greater value can be achieved through implementing treatments along a whole section, rather than individual site treatments. The output is a SRIP, which can be implemented at the individual section, regional or national (portfolio) level to assess the appropriateness and effectiveness of individual options for improvement. These can be refined to allow economic appraisal of a locally acceptable treatment programme. The appraisal period is normally 20 years, allowing the cost of implementing each measure to be evaluated against the expected casualty savings over the same time period. ViDA provides Present Values (PVs) and Benefit Cost Ratios (BCRs) for appraisal of each proposed countermeasure. Fatal and Serious Injury (FSI) estimation maps can also be generated, which display how fatal and serious injuries can be reduced on a network over the period of time.

3.7 PRACT - Predicting Road Accidents - a transferable methodology across Europe

PRACT is a research project funded by the National Road Authorities of Germany, Ireland, UK and the Netherlands within the Conference of European Directors of Roads (CEDR) Transnational Research Programme Call 2013: Safety, which was completed within May of 2016. This transferable methodology across Europe aims at developing an European accident prediction model structure that could be applied to various European road networks with suitable calibration.

The key aim of the project was to develop a procedure that will enable Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) to be transferred towards conditions different to the conditions upon which they were developed. The project focuses in particular on motorways and two-way two-lane rural roads.

Base SPFs were developed for different European countries using generalized linear models with negative-binomial distributions. A set of CMFs was developed under this project and decisions regarding which CMFs will be developed were based upon a questionnaire survey across European countries where each country could state its needs.

Since PRACT model is based on the HSM predictive method and a primary purpose of the project was the development and modification of CMF’s for transferability within the Europe,
a summary of HSM predictive method with a step-by-step implementation guide is described within the appendix of this document. PRACT models and crash modification factors are available as an alternative means for European countries to the use of HSM.
4. Performing network wide safety assessment

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

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

For the purpose of increasing statistical reliability of the data, all injury crashes, in a 4-year assessment period (2014-2017), were considered in order to implement the Poisson test, as well as the RAP Crash Risk Mapping. On the contrary, RAP Star Rating and Fatality Estimations are a proactive methodology based on road inspection.

4.1 Poisson Test

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 apply the Poisson test across the Greek TEN-T network, 10km long road sections were integrated into one sample. When applying the Poisson test for the entire 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 crashes (around 68%) are recorded on the 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.

Consecutively, the following parameters were 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, were considered to be crash-prone sections. Identified hazardous road sections across the examined TEN-T network are presented in the Table 1.

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

Table 1: Poisson Test – Hazardous road sections across the Greek TEN-T Network
4.2 RAP Crash Risk Mapping

The TEN-T network in Greece was divided into road sections, in a manner where each road section has at least 20 injury crashes within a 4-year assessment period. In order to adapt the road sections to this principle, some road section lengths were also increased. In addition, the subdivision of the network into sections was performed, so that the road design within each road is uniform as much as possible, and the traffic flow consistent.

The road sections for Egnatia motorway, along with the allocated crashes, are shown in the Table 2.

<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 3 lists the road sections for NRAC, along with the corresponding traffic crashes.

<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>

Table 4 shows the “Risk Bands 2020” thresholds. These express upper and lower limits of fatality rates used for categorising the road sections into risk categories (low, low-medium, medium, medium-high, and high risk) and are based on a standard 3-year data period.

<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 adjusted thresholds for each risk banding, the upper and lower limits for fatal (F) crashes from the Table 4 are multiplied by the scaling factor. The scaling factor is defined as the ratio of fatal and serious crashes and fatal crashes (FSI:F). 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 5.

### Table 5: Scaling Factor Calculation

<table>
<thead>
<tr>
<th>Route Description</th>
<th>Assessment Period: 2014-2017 Crash Severity</th>
<th>All Injury</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sindos I/C-Kipi</td>
<td>131</td>
<td>27</td>
<td>18</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Chania-Sitia</td>
<td>61</td>
<td>34</td>
<td>11</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>192</td>
<td>61</td>
<td>29</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>Scaling Factor = All Injury/Fatal</td>
<td>3,1475</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The upper and lower boundaries for different risk categories based on crashes per kilometre (crash density) needs to be calculated. The scaling factor (FSI/F) is used to multiply the crash rates, as shown in Table 6:

### Table 6: Calculating risk band thresholds for crash density (Risk Bands 2020)

<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;0.09</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>0.09 - &lt;0.16</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>0.16 - &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 different risk categories based on crashes per vehicle kilometres travelled, based on a 3-year data period, the scaling factor (FSI/F) is used to multiply the crash rates, as shown in Table 7:

### Table 7: 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 - &lt;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>
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 budget effectively.

At the simplest level collective crash risk maps show the density, or total number, of crashes on a road over a given length. Collective risk is expressed as the number of all injury crashes per kilometre 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 8 and Table 9) present the collective risk for each of the Egnatia motorway and NRAC sections, respectively. The collective risk was determined according to the adjusted thresholds presented in the Table 6.

**Table 8: 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 9: 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 road sections of Egnatia motorway (equivalent to approximately 30 km or 5% of the considered TEN-T network) are classified as medium-high- or high-risk sections.

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:

1. 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; and

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

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

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

Before calculating the individual risk for each road section, the Average Annual Daily Traffic, regarding the assessment period (2014-2017) is allocated to each individual section. Tables 10 and 11 show the individual risk for each of the Egnatia motorway and NRAC sections. The individual risk was determined according to the adjusted thresholds presented in the Table 7.

### Table 10: 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*km*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 11: 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*km*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 can be seen that 10 out of 12 RAP Crash Risk Mapping sections (equivalent to 536 km or 85% of the TEN-T network) were rated as medium or high risk.
4.3 RAP Star Rating and Fatality Estimations

The assessment of the road safety requires the Road Safety Inspection 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 an accident occurrence or its severity. The RAP Star Rating and Fatality Estimation utilizes video-based inspections, with the characteristics of the road infrastructure elements are recorded for each 100m road length. Following the survey, Star Rating Score (SRS) is calculated. The SRS is a unit-less indicator which depicts the infrastructure’s safety capacity for each road user type, and it is calculated for 100-m road segments. Road user types that are included are the vehicle occupants, motorcyclists, bicyclists and pedestrians who may be involved in road accidents. For each road user type and for 100-m road segmentation, the respective Star Rating Score is calculated.

Based on the coded and supporting data, the ViDA online software produces Star Ratings and Fatality Estimations of the surveyed network. For this example, the Star Rating was produced for vehicle occupants, motorcyclists and pedestrians only. Bicyclists were not included due to non-existent flows on these sections.

Figures 5 and 6 depict the levels of risk for vehicle occupants, motorcyclists and pedestrians, on Egnatia Motorway and on North Road Axis of Crete, respectively.
Figure 5: Star Ratings-Level of risk before countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, Egnatia Motorway
Figure 6: Star Ratings - Level of risk before countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, North Road Axis of Crete
Tables 12 and 13 display the Star Rating distribution for vehicle occupants, motorcyclists and pedestrians across Egnatia Motorway and North Road Axis of Crete, respectively.

Table 12: Star Ratings distribution for vehicle occupants, motorcyclists and pedestrians for the Egnatia Motorway - before countermeasure implementation.

<table>
<thead>
<tr>
<th>Star Ratings</th>
<th>Vehicle Occupant</th>
<th>Motorcycle</th>
<th>Pedestrian</th>
<th>Length (km)</th>
<th>Percent</th>
<th>Length (km)</th>
<th>Percent</th>
<th>Length (km)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Stars</td>
<td>2.00</td>
<td>1.50</td>
<td>0.00</td>
<td>2.00</td>
<td>0.29%</td>
<td>1.50</td>
<td>0.22%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>4 Stars</td>
<td>4.90</td>
<td>0.40</td>
<td>0.00</td>
<td>4.90</td>
<td>0.72%</td>
<td>0.40</td>
<td>0.06%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>3 Stars</td>
<td>573.80</td>
<td>0.50</td>
<td>0.00</td>
<td>573.80</td>
<td>84.11%</td>
<td>0.50</td>
<td>0.07%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>2 Stars</td>
<td>85.10</td>
<td>12.47%</td>
<td>682.20</td>
<td>85.10</td>
<td>12.47%</td>
<td>682.20</td>
<td>100.00%</td>
<td>682.20</td>
<td>100.00%</td>
</tr>
<tr>
<td>1 Star</td>
<td>16.40</td>
<td>2.49%</td>
<td>494.20</td>
<td>16.40</td>
<td>2.49%</td>
<td>494.20</td>
<td>72.44%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>Not applicable</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00%</td>
<td>682.20</td>
<td>100.00%</td>
</tr>
<tr>
<td>Totals</td>
<td>682.20</td>
<td>100.00%</td>
<td>682.20</td>
<td>100.00%</td>
<td>682.20</td>
<td>100.00%</td>
<td>682.20</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Table 13: Star Ratings distribution for vehicle occupants, motorcyclists and pedestrians for the North Road Axis of Crete - before countermeasure implementation.

<table>
<thead>
<tr>
<th>Star Ratings</th>
<th>Vehicle Occupant</th>
<th>Motorcycle</th>
<th>Pedestrian</th>
<th>Length (km)</th>
<th>Percent</th>
<th>Length (km)</th>
<th>Percent</th>
<th>Length (km)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Stars</td>
<td>2.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.00</td>
<td>0.70%</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>4 Stars</td>
<td>5.90</td>
<td>0.00</td>
<td>0.00</td>
<td>5.90</td>
<td>1.91%</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>3 Stars</td>
<td>36.00</td>
<td>5.70</td>
<td>237.50</td>
<td>36.00</td>
<td>12.84%</td>
<td>5.70</td>
<td>1.56%</td>
<td>237.50</td>
<td>80.63%</td>
</tr>
<tr>
<td>2 Stars</td>
<td>41.40</td>
<td>24.10</td>
<td>234.10</td>
<td>41.40</td>
<td>14.41%</td>
<td>24.10</td>
<td>8.39%</td>
<td>234.10</td>
<td>81.48%</td>
</tr>
<tr>
<td>1 Star</td>
<td>287.30</td>
<td>70.14%</td>
<td>287.30</td>
<td>287.30</td>
<td>70.14%</td>
<td>70.14%</td>
<td>25.14%</td>
<td>287.30</td>
<td>71.48%</td>
</tr>
<tr>
<td>Not applicable</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00%</td>
<td>49.40</td>
<td>17.15%</td>
</tr>
<tr>
<td>Totals</td>
<td>287.30</td>
<td>100.00%</td>
<td>287.30</td>
<td>100.00%</td>
<td>287.30</td>
<td>100.00%</td>
<td>287.30</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

When observing Figures 5 and 6 as well as tables 12 and 13, it can be seen that that almost entire examined network has a Star Rating of 3 or less for Vehicle occupants, Motorcyclists and Pedestrians (where applicable).

4.4 Understanding the results of network wide safety assessment

The RAP protocols measure the risk of roads that are in operation using two protocols (Star Rating and Crash Risk Mapping).
Star Rating uses a proactive methodology which depends on a visual assessment of « in-built safety » of roads.

Crash Risk Mapping protocol utilizes a reactive methodology utilizing reported crashes and traffic flow. Many authorities have their own frameworks of crash mapping, but the RAP protocols were statistically designed to permit ‘performance tracking’. The most regularly utilized mapping is the map showing the risk individual users face as they make a switch from one road to another. Nonetheless, mapping of crash density and crash costs is also used.

Both protocols, consistent with safe system design and European targets, centre around on fatal and serious injuries. Crash numbers in high performing nations are, often, statistically too small to be a reliable input for network wide assessment methodologies. The quality of detailed crash data (locations; crash type etc.) is an issue in numerous nations. Nonetheless, using aggregated recorded crash numbers as a statistical control with the Star Rating data, allows for estimation of changes in the risk of death and serious injury rates. This thus allows ‘bank friendly’ monetary assessment of safety investment in a way which is comparable with other appraisals.

The basic output of the RAP method is the Safer Roads Investment Plan. The SRIP presents all the countermeasures proved able to provide the greater safety capacity and maximize the benefit over spent cost of the planned investments. The cost of each countermeasure is compared to the value of life and serious injuries that could be saved and Benefit to Cost Ratio (BCR) is calculated for each countermeasure proposed.

The SRIP for the Egnatia Motorway part of the network would save 259 fatalities and serious injuries over the analysis period of 20 years. The cost of these countermeasures adds up to approx. 16.087.900 €, while for North Road Axis of Crete, 9008 fatalities could be saved, and the countermeasure cost would be approx. 2.093.218.775 €. The total BCR is 4 and 11 for Egnatia and NRAC, respectively. Figures 7 and 8 present top countermeasures of the SRIP in terms of saved lives and serious injuries (FSI) for Egnatia Motorway and North Road Axis of Crete, respectively.
Figure 8: SRIP countermeasures for North Road Axis of Crete

The Star Rating results after adopting all the proposed countermeasures for Egnatia Motorway and North Road Axis of Crete are presented in the Figures 9 and 10.

Figure 9: Star Rating after implementing the SRIP, Egnatia Motorway
It is clear that the SRIP would improve the Greek road network safety significantly. For vehicle occupants, the improvement is most noticeable, with about 43% of the network being awarded with 5 star rating. There are improvements in the motorcyclists' and pedestrians' safety as well. However, effect of the SRIP on these user groups is relatively lower than for the vehicle occupants. Bicycle rating was not performed since bicycle traffic is negligible in Greek rural roads. Maps depicted on Figures 11 and 12 display the level of risk on Egnatia Motorway and North Road Axis of Crete for vehicle occupants, motorcyclists and pedestrians, respectively.
Figure 11: Star Ratings - Level of risk after countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, Egnatia Motorway
Figure 12: Star Ratings-Level of risk after countermeasure implementation for vehicle occupants, motorcyclists and pedestrians, North Road Axis of Crete

Figures 13 and 14 present predicted fatal and serious injury reductions on Egnatia Motorway and North Road Axis of Crete after implementing the proposed SRIP.
FSI estimation map focuses on where to address the countermeasures primarily to save the most lives and serious injuries by identifying FSI rates for segments of observed network. It is clear that the predicted casualty reduction is evenly spread throughout the network, with a number of critical sections where focus should be prioritized first because the predicted countermeasures are expected to be most effective in those locations.

In a case of the Greek example, following a network-wide road assessment approach it is concluded that a significant proportion (8%-86%) of the considered network should be re-examined or explored in more detail, in order to recognize and suppress possible infrastructure risk factors. This advocates the utilization of cost-effective mass action plans, hence, prompting large scale improvement of the road safety level.
5. Conclusion

The main objective of network-wide road assessment is to support national road safety strategies and to provide an additional layer of relevant information alongside already existing approaches. Network assessment typically covers roads outside towns and cities, where deaths and serious injuries are mostly concentrated. Not all roads carry the same risk; and examining the statistics from a wide range of countries show that around 50% of total fatalities occur on as little as 10% of total roads. Therefore, network-wide road assessment enables the identification of the safest and most hazardous road sections within observed region or country.

Document provides an overview of selected proactive and active network wide road assessment methodologies in Chapter 3, and a step-by-step guide for each methodology is provided in Chapter 4.

In the case of Greek Ten-T network assessment, presented in Chapter 4 as an example, following Network-wide road assessment methodologies were conducted in order to examine the road safety level on chosen sections of the road:

- Poisson Test
- RAP Crash Risk Mapping
- RAP Star Ratings

Following a network-wide road assessment approach it is concluded that a significant proportion (8%-86%) of the considered network should be re-examined or explored in more detail, in order to recognize and suppress possible infrastructure risk factors. This advocates the utilization of cost-effective mass action plans, hence, prompting large scale improvement of the road safety level.
Appendix A – Road Safety Audit

Road Safety Audit (RSA) is defined as a formal, independent evaluation of the safety performance of a new road or proposed road design. The aim 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.

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

It is essential to follow the steps in the audit process as closely as possible with the purpose of ensuring that the audit is both formal and methodical. It should be mentioned that the described process is the same no matter on the type and scale of project, but the amount of effort required for each step can vary.

1. Initiating the Audit

After the process initiation, independent audit team will be formed with one leader. Major projects will require a minimum of at least two experts, and at least one of them must have road safety engineering experience. It is always useful to have people on the team who have good knowledge of the local travel patterns, traffic problems, and accident history. Audits at different stages might require experts with different skills. For example, at the Detailed Design stage it is helpful to have someone who has sufficient design experience to check the details of signs, safety barrier, street lighting, etc., and at the Pre-Opening stage it is usual to include a traffic police officer with local knowledge.

2. Providing the Background Information

The Client should instruct the Designer to provide all relevant information to the Audit team. This information should include, at minimum:

- a project description
- an account of the design principles and standards that were used (e.g., design speed, standards for radius of horizontal curves, superelevation, stopping sight distance, overtaking sight distance, percentage of route where safe overtaking sight distance is possible, etc.)
- a description of any departures from Road Design Manual standards and the reasons for them
- traffic data
- accident data
- full set of design plans showing details of the horizontal and vertical alignment
- signing and marking plans (essential for Detailed Design and Pre-Opening Stage audits)
- a copy of the previous audit reports (if any) and an account of any changes since the previous audit (if any).

3. Studying the Plans and Inspecting the Site

The Auditors will examine the plans and additional relevant material in order to better understand the proposal. It is vital for the audit team to visit the site in order to examine it for undocumented issues and envision the upcoming proposals and their impacts. A night-time check-up is also highly desirable, as it can often reveal unforeseen issues.

4. Holding a Commencement Meeting with the Designer and Client

The purpose of this meeting is to exchange information between the Designer, Auditor and the Client. It is an opportunity for the Auditors to clear up any doubts about what is planned and to find out the reasoning behind specific design decisions. There is also merit in getting the Designer’s initial reactions to the problems that have been identified so far. It will often be necessary for the Client or his representative to explain the purpose and workings of the audit process to the Designers. Sometimes it can be both convenient and beneficial to combine the commencement meeting with the site inspection.

5. Undertaking the Audit

There are numerous methods of organising the audit effort, and this is often a matter of the individual approach of the audit team leader and his team members. However, one method which is generally efficient is for each team member to do their own audit parts then meeting afterwards in order to discuss their findings and to prepare the team report.

Auditors should bear in mind to:

- consider the needs of all road users (including pedestrians (especially children), cyclists, and motorcyclists) in all weathers and lighting conditions
- be thorough and comprehensive
- be realistic and practical (though they should not be too concerned about costs)
- keep to road safety aspects
- check compliance with standards and guidelines whilst remembering that compliance with guidelines does not always guarantee that the road will be safe.

It has been found that the use of checklists is a valuable tool in ensuring that nothing is forgotten during the audit. Novice auditors may wish to record their findings against every item in the checklist while more experienced auditors may prefer to just read through the checklist before they start auditing.

6. Writing the Audit Report

The audit report should set out unambiguously what the problems are and make proposals on corrective action. The findings and recommendations should be described under three headings:
- Observation – refer briefly to the problem feature, and locate it precisely (specify the chainage, or indicate on a copy of the scheme drawing)
- Reason for concern – explain briefly why the feature increases the accident risk
- Suggested response – give a clear indication of what needs to be done, but do not to be too specific or provide a detailed design; that is the job of the Designer.

It is also helpful to indicate whether a response is Essential, Highly Desirable, or Desirable.

The audit report should be thorough and comprehensive, but also concise. The report should ideally only detail the specific safety concerns of the examined segment. Checklist below provides further detail on what should be included:

a) Introduction – details of:
   - who requested the audit
   - names of persons in the audit team
   - designs and documents submitted
   - constraints, e.g., no signing plans available
   - when the audit was done – date of site visit
   - dates of meetings
   - the technical terms used in the report

b) Safety concerns regarding general aspects of the design such as design speed, cross-section, superelevation, failure to manage speeds through trading centres, inadequate signing, etc. Each concern should be explained under the headings: Observation, Reason for concern, and Suggested Response.

Specification whether a response is Essential, Highly Desirable, or Desirable can also be implemented.

c) Safety concerns regarding features at specific locations, such as an awkward bend, or a dangerous junction. Each concern should be explained under the headings: Observation, Reason for concern, and Suggested Response.

Specification whether a response is Essential, Highly Desirable, or Desirable can also be implemented.

d) Concluding section
   The audit team leader should sign and date the report.

7. Holding a Completion Meeting

Once the Designer’s report has been received the Client will request the audit team leader to attend the Completion Meeting together with the Designer. The purpose of the Completion Meeting is to enable the Client to get further information or clarification about the audit findings and to assess with the Designer what remedial actions should be taken.
Appendix B – 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) is recognised as one of the most distinguishable and valuable road safety evaluation techniques for roads which are already constructed and in operation for years. 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 to propose (where possible) suitable treatments to eliminate or reduce risk.

There are four key steps in the RSI process:

- Preparatory work such as a review of the existing documents, collection of accident data, etc.
- Site visit including discussions with people responsible for the road
- Creation of the RSI report
- Implementation of the proposed measures, monitoring

Throughout a Road Safety Inspection, all elements that can have an impact on the safety of the inspected section are examined. Checklists should be used as the basis for the assessments and site visits.

1. Preparations for a Road Safety Inspection

Available accident data should be, if available, analysed as part of a Road Safety Inspection. The accident data for the examined section should be considered for a time period of 3 to 5 years if there is no specific reason which limits the evaluation to a shorter period of time (construction works, etc.). For each road type, the number of accidents resulting in personal injury or fatality should be determined along with their locations as accurately as the data allows. If property damage accidents are available, they can be incorporated in the evaluation as well.

Technical traffic data must also be taken into account when performing RSI. These data sets can include the volume of traffic and the composition of traffic. If statistical traffic data sets are available, they should also be included. Traffic development projections (if available) should also be taken into account.

In certain instances, additional data such as speed measurements, following distance measurements, and the like may be practical to consider for RSI. Sight distance measurements, driving and accident simulations, driving dynamics evaluations, inclination measurements, light measurements, mobile road condition inspections, and mobile road mapping can be used as needed.
The design documents for the relevant road section should be checked if available during a road safety inspection to serve as a supplementary source of information. It must be noted that technical drawings, longitudinal sections, and cross sections are not always available for roads which were built a while ago and work that has been completed since the original construction of the road is often difficult to find. Aerial photos and drone recordings can be used for the evaluations, if available. Safety assessments that have already been completed on the section such as road safety audits should also be included if possible.

### 2. Inspection of the Section

The complete section must be inspected in person during RSI. This site visit allows the section and traffic situation on the section to be accurately assessed. The participation of authorities, the road maintenance agency, public experts, etc. in the site visit is reasonable because segment specific issues can be discussed directly on the section. The entire section must be viewed by travelling in both directions. If required (depending on the causes of accidents, etc.), multiple site visits can be appropriate during relevant conditions (e.g. day/night, dry/wet conditions, etc.). The inspected section must be recorded by a video or photographs. An on-site meeting should be held by RS inspectors, including the police, road maintenance agency, etc. before or after the site visit. In this meeting, the section to be inspected should be discussed systematically on the basis of the checklists. The checklists and the results of the various evaluations (e.g. accidents, traffic activity, etc.) serve as the basis for the site visits.

The structure and content of the checklists ensures that all necessary criteria are considered and checked during the site visit. Additional criteria can be added to the checklist if it is required.

### 3. Creation of the Report

The report for an RSI can be broken down into the following parts:

- **General information**
  The general information provides an introductory summary, describing the key features of the inspected section, as well as including an overview of data used to assess the inspected section for the purposes of an RSI (length of the section, traffic volume, permitted speeds, etc.). Section must at least include general details, overview map, used documents (list of the documents and data used in the RSI) and information concerning performed meetings and site visits.

- **Completed checklist and accident evaluation**
  The checklist contains important criteria for the respective road category. It should be indicated whether each item is safety relevant (yes/no). Comments can also be entered. The checklist records that all aspects were accounted for by the RS inspectors during the RSI.

- **List of measures**
  In the list of measures, known problems and safety shortcomings are recorded and remedial measures for individual shortcomings are proposed. To provide a clear and concise depiction of the measures, these are shown in a table format where each deficiency or measure is shown on a separate row in portrait format. The exact locations of the problem areas must be defined and the corresponding deficiency, the
road safety problem, proposed measures, and the expected improvement after the implementation of the proposed measures must be indicated. A numbering of the deficiencies makes referencing easier. A photo of the deficiency should be included for each measure for better clarity. Additional illustrations (such as collision diagrams and the like) and explanations can also be included. The problems and measures should be stated as briefly as possible in the table for reasons of clarity. If more detailed explanations are needed, these can be referenced in the table and the explanation added after the table.

- Summary

The evaluation is then reviewed together with the key results of the road safety inspection. The annex to the report should contain the minutes of all conducted meetings, all available accident maps, collision diagrams, and the monitoring table if applicable.

4. Documentation, Exception Report, and Monitoring

The findings of the RSI are reviewed by the RS inspectors and road maintenance agency, and are then documented in an RSI report. At this point, the inspection is concluded for the RS inspectors. A monitoring table can help the road maintenance agency (commissioning party) track the implementation of the individual proposed measures. The RS inspectors can list all measures in abbreviated form and with their locations in the monitoring table. The road authority can indicate whether the implementation of the measure is planned, by whom and by when the measure will be implemented, and a rough estimate of the costs of the measure. This information allows the implementation of the measure to be checked quickly. The exception report is a key part of the road safety inspection. In the exception report, the road maintenance agency (commissioning party) must state whether a proposed remedial measure will be implemented. If a measure will not be implemented, sufficient justification for this must be provided in the exception report. Schedules for possible solutions and their implementation must also be created.
Appendix C – AASHTO Highway Safety Manual Predictive Method

The Highway Safety Manual (HSM 2010) provides a predictive method for estimating expected average crash frequency (including by crash severity and collision types) of a network, facility, or individual site. The estimate can be made for existing conditions, alternatives to existing conditions (e.g., proposed upgrades or treatments), or proposed new roadways. The predictive method is applied to a given time period, traffic volume, and constant geometric design characteristics of the roadway. The predictive method provides a quantitative measure of expected average crash frequency under both existing conditions and conditions which have not yet occurred. This allows proposed roadway conditions to be quantitatively assessed along with other considerations such as community needs, capacity, delay, cost, right-of-way, and environmental considerations.

The predictive method can be used for evaluating and comparing the expected average crash frequency of situations such as:

- Existing facilities under past or future traffic volumes;
- Alternative designs for an existing facility under past or future traffic volumes;
- Designs for a new facility under future (forecast) traffic volumes;
- The estimated effectiveness of countermeasures after a period of implementation; and
- The estimated effectiveness of proposed countermeasures on an existing facility (prior to implementation).

In the predictive method the roadway is divided into individual sites that are either homogenous roadway segments or intersections. A facility consists of a contiguous set of individual intersections and roadway segments, each referred to as “sites.” Different facility types are determined by surrounding land use, roadway cross-section, and degree of access. For each facility type a number of different site types may exist, such as divided and undivided roadway segments or signalized and unsignalized intersections. A roadway network consists of a number of contiguous facilities. The predictive method is used to estimate the expected average crash frequency of an individual site. The cumulative sum of all sites is used as the estimate for an entire facility or network. The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecast. The estimate relies upon regression models developed from observed crash data for a number of similar sites. The predictive method provides an 18-step procedure to estimate the “expected average crash frequency” (by total crashes, crash severity, or collision type) of a roadway network, facility, or site. Steps are shortly described in the continuation of this subchapter (Taken from HSM 2010):

**Step 1** - Defining the limits of the roadway and facility types in the study network, facility, or site for which the expected average crash frequency, severity, and collision types are to be estimated. The predictive method can be undertaken for a roadway network, a facility, or an individual site. Site is either an intersection or homogeneous roadway segment.

**Step 2** - Defining the period of interest. The predictive method can be undertaken for a past period or a future period. All periods are measured in years. Years of interest will be determined by the availability of observed or forecast AADTs, observed crash data, and
geometric design data. Whether the predictive method is used for a past or future period depends upon the purpose of the study.

**Step 3** - For the study period, determining the availability of annual average daily traffic volumes should be done. For an existing roadway network, checking the availability of observed crash data in order to determine whether the EB statistical method is applicable should also be done within this step. Where an existing site or alternative conditions to an existing site are being considered, the EB Method is used. The EB Method is only applicable when reliable, observed crash data are available for the specific study roadway network, facility, or site. At least two years of observed crash data are desirable to apply the EB Method.

**Step 4** - Determining geometric design features, traffic control features, and site characteristics for all sites in the study network.

**Step 5** - Dividing the roadway network or facility under consideration into individual roadway segments and intersections. Using the information from Step 1 and Step 4, the roadway is divided into individual sites, consisting of individual homogenous roadway segments and intersections. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to no less than 160 meters will minimize calculation efforts and not affect results.

**Step 6** - Assigning observed crashes to the individual sites (if applicable). Step 6 only applies if it was determined in Step 3 that the site-specific EB Method was applicable. If the site-specific EB Method is not applicable, Step 6 should be skipped. In Step 3, the availability of observed data and whether the data could be assigned to specific locations was determined.

**Step 7** - Selecting the first or next individual site in the study network. If there are no more sites to be evaluated, steps 8-14 should be skipped. In Step 5 the roadway network within the study limits is divided into a number of individual homogenous sites (intersections and roadway segments). At each site, all geometric design features, traffic control features, AADTs, and observed crash data are determined in Steps 1 through 4. For studies with a large number of sites, it may be practical to assign a number to each site. The outcome of the HSM predictive method is the expected average crash frequency of the entire study network, i.e., the sum of all of the individual sites for each year in the study. This value will be the total number of crashes expected to occur over all sites during the period of interest. If a certain crash frequency is desired, the total can be divided by the number of years in the period of interest. The estimate for each site (roadway segments or intersection) is undertaken one at a time. Steps 8 through 14, described below, are repeated for each site.

**Step 8** - For the selected site, selecting the first or next year in the period of interest should be done. The individual years of the evaluation period may have to be analysed one year at a time for any particular roadway segment or intersection because Safety Performance Function (SPFs) and some CMFs (e.g., lane and shoulder widths) are dependent on AADT, which may change from year to year.

**Step 9** - Determining and applying the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features. (SPF) are adjusted to site specific conditions (in Step 10) using crash modification factors (CMFs) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor. The SPFs, CMFs, and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predicted average crash frequency for the selected year of the selected site. The resultant value is the predicted average crash frequency for the
selected year. The SPF estimates the predicted average crash frequency for a site with the base conditions (i.e., a specific set of geometric design and traffic control features).

**Step 10** - Multiplying the result obtained in Step 9 by the appropriate CMFs in order to adjust the predicted average crash frequency to site-specific geometric design and traffic control features. Each SPF is applicable to a set of base geometric design and traffic control features, which are identified for each site type.

**Step 11** - Multiplying the result obtained in Step 10 by the appropriate calibration factor. Calibration of SPFs to local conditions will account for differences. A calibration factor is applied to each SPF in the predictive method.

**Step 12** - If there is another year to be evaluated in the study period for the selected site, returning to Step 8 is needed. Otherwise, Step 13 should be next. This step creates a loop through Steps 8 to 12 that is repeated for each year of the evaluation period for the selected site.

**Step 13** - Applying site-specific EB Method (if applicable). Whether the site-specific EB Method is applicable is determined in Step 3. If the site-specific EB Method is applicable, Step 6 EB Method criteria is used to assign observed crashes to each individual site.

**Step 14** - If there is another site to be evaluated, returning to Step 7 should be done, otherwise, Step 15 should be next. This step creates a loop for Steps 7 to 13 that is repeated for each roadway segment or intersection within the study area.

**Step 15** - Applying the project level EB Method (if the site-specific EB Method is not applicable). This step is applicable to existing conditions when observed crash data are available but cannot be accurately assigned to specific sites.

**Step 16** - Summing all sites and years in the study to estimate total crashes or average crash frequency for the network. Regardless of whether the total or the total average number of crashes is used, a consistent approach will produce reliable comparisons.

**Step 17** - Determining if there is an alternative design, treatment, or forecast AADT to be evaluated. Steps 3 through 16 of the predictive method are repeated, as appropriate, not only for the same roadway limits, but also for alternative geometric design, treatments, or periods of interest or forecast AADTs.

**Step 18** - Evaluating and comparing results. The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency within defined network or facility limits over a given period of time for given geometric design and traffic control features and known or estimated AADT. The predictive method results may be used for a number of different purposes. Example uses include:

- Screening a network to rank sites and identify those sites likely to respond to a safety improvement;
- Evaluating the effectiveness of countermeasures after a period of implementation; and
- Estimating the effectiveness of proposed countermeasures on an existing facility.
Appendix D – About IRAP Methodology

iRAP was established to help tackle the devastating social and economic cost of road crashes. Without intervention, the annual number of road deaths worldwide is projected to increase to some 2.4 million by 2030. The majority of these will occur in low-income and middle-income countries, which already suffer nine out of ten of the world’s road deaths. Almost half of those killed will be vulnerable road users – motorcyclists, bicyclists and pedestrians. Large as the problem is, making roads safe is by no means an insurmountable challenge; the requisite research, technology and expertise to save lives already exists. Road safety engineering makes a direct contribution to the reduction of road death and injury. Well-designed intersections, safe roadsides and appropriate road cross-sections can significantly decrease the risk of a motorised vehicle crashes occurring and the severity of crashes that do occur. Footpaths, pedestrian crossings and bicycle paths can substantially cut the risk that pedestrians and bicyclists will be killed or injured by avoiding the need for them to mix with motorised vehicles. Motorcycle lanes can minimise the risk of death and injury for motorcyclists.

By building on the work of Road Assessment Programmes (RAP) in high-income countries (EuroRAP, AusRAP, usRAP and KiwiRAP) and with the expertise of leading road safety research organisations worldwide, including ARRB Group (Australia), TRL (United Kingdom), MRI Global (United States) and MIROS (Malaysia), iRAP has developed globally consistent protocols to assess and improve the safety of roads:

▪ Crash Risk Maps use detailed crash data to illustrate the actual number of deaths and injuries on a road network.
▪ Star Ratings provide a simple and objective measure of the level of safety provided by a road’s design.
▪ FSI estimation maps focus on where to address the countermeasures primarily to save the most lives and serious injuries by identifying FSI rates for segments of observed network.
▪ Safer Roads Investment Plans draw on approximately 90 proven road improvement options to generate affordable and economically sound infrastructure options for saving lives.
▪ Performance Tracking enables the use of Star Ratings and Crash Risk Maps to track road safety performance and establish policy positions.
Appendix E – How EuroRAP addresses the RISM

Article 1 (2) - This Directive shall apply to roads which are part of the trans-European road network, to motorways and to other primary roads, whether they are at the design stage, under construction or in operation.

EuroRAP provides general advice and support on the use of RAP protocols and systems in Europe. EuroRAP also provides advice on procurement and identification of suppliers, and on strategies for subsequent analyses of survey data, including maintenance-related information.

The requirements of the revised Road Infrastructure Safety Directive (RISM) are very familiar to EuroRAP members and accredited suppliers which have carried out RAP assessments in Europe. In fact, RISM’s minimum legal requirements are less demanding than those of EuroRAP. Members have already carried out RAP assessments in most European countries. Assessment to date have either been performed by EuroRAP national programmes leads as national initiatives and/or within European Commission projects. The EC CEF SLAIN project supports and encourages the main changes to the Road Infrastructure Safety Management Directive 2008/96/EC and assesses the readiness of Europe’s infrastructure for automation in 4 Member States (Spain, Italy, Croatia, Greece).

Article 5 (2) - Network-wide road safety assessments shall evaluate accident and impact severity risk, based on: primarily, a visual examination, either on site or by electronic means, of the design characteristics of the road (in-built safety); and an analysis of sections of the road network which have been in operation for more than three years and upon which a large number of serious accidents in proportion to the traffic flow have occurred.

Star Rating and FSI estimation is a safety ranking method that is primarily based on road inspection data and is therefore, an assessment of the in-built safety of roads. In addition to road inspection data, SR uses traffic volume and accident data to determine the risk on the assessed roads. These three data sources are imported into algorithms which classify the road in one out five categories, known as “stars”. Developed SRs can assess roads while considering the safety needs of different road user, e.g., motorized vehicles and pedestrians. EuroRAP can support road infrastructure managers in advising on applications of the RAP Star Rating and FSI estimation protocol.

When fully developed, Vision-based ADAS technologies such as Mobileye’s will leverage EuroRAP’s expertise in infrastructure-based safety measures and provide real-time automated assessments through mass vehicle fleet sourced data.

Article 5 (3) - “Member States shall ensure that the first network-wide road safety assessment is carried out by 2024 at the latest. Subsequent network-wide road safety assessments shall be sufficiently frequent in order to ensure adequate safety levels, but in any case, shall be carried out at least every five years”

EuroRAP can help road infrastructure managers in Member States by providing support for their first network-wide road safety assessment by 2024 and at least every five years.

By looking at currently implemented national programmes and the EC supported projects, SLAIN included, it can be concluded that Star Rating assessment has already been carried out in the majority of EU countries. There are, at the date of writing this document, various projects in 20 countries across the European continent.
The CEF EC project SLAIN is active in Croatia, Greece, Italy and Spain and includes work supported by the motor industry on ‘roads that cars can read’.

**Article 5 (4) - In carrying out the network-wide road safety assessment, Member States may take into account the indicative elements set out in Annex III.**

EuroRAP inspections and road safety assessments focus on more than 50 different road attributes that are known to influence the likelihood of a crash and its severity. These features include intersection design, road markings, roadside hazards, footpaths and bicycle lanes - all fully in line with ANNEX IIa – Indicative elements of targeted road safety inspections and ANNEX III – Indicative elements of network-wide road safety assessments.

EuroRAP Specifications and methodology/Road Attributes are available and free of charge:

- Specifications (coding on the right /coding on the left)
  
  http://www.irap.org/specifications/

- Methodology (Factsheet number 3 - Road Attributes)
  
  https://www.irap.org/methodology/

EuroRAP can contribute and provide guidance to road authorities regarding RAP protocols and carrying out systematic network-wide road safety assessments and safety ratings.

**Article 5 (6). On the basis of the results of the assessment referred to in paragraph 1, and for the purpose of prioritisation of needs for further action, Member States shall classify all sections of the road network in no fewer than three categories according to their level of safety.**

The Star Rating methodology categorises the safety of road sections from 1-5 Stars. EuroRAP can support stakeholders in the classification of all sections of the road network in no fewer than three categories according to their level of safety.

Star Rating can be used on a variety of road types and allows individual sections or road networks to be assessed and compared on the same basis. Star Ratings are based on road inspection data and provide a simple and objective measure of the level of safety ‘built-in’ to the roads for vehicle occupants, motorcyclists, pedestrians and bicyclists. 5-star roads (green) are the safest, and 1-star (black) are the least safe. Broadly speaking, every extra star rating increase results in a halving of crash cost in terms of the number of people who are killed and seriously injured.

**Article 6 - Periodic road safety inspections**

The RAP Star Ratings, Road Safety Audits and Road Safety Inspections align on a number of topics, which can be derived from their definitions.

- The RAP approach includes an objective, evidence-based measure of the safety performance of the road for all road users that can guide policy, standards and performance tracking. The RAP assessments also include fatality and serious injury estimations and high-level Safer Road Investment Plans that optimise lives saved per unit of investment.

- A road safety audit is defined as a formal and independent technical check of a road scheme design and construction, to identify any unsafe features or potential hazards and to provide recommendations for rectifying them during all stages, from planning to

- “A road safety inspection (RSI) is a systematic, on-site review of an existing road with the aim of identifying hazardous conditions, faults and deficiencies that may lead to serious crash outcomes.” (https://roadsafety.piarc.org/en/planning-design-operation-risks-issue-identification/proactive-identification)

The inclusion of the Star Rating of a Design as part of the Road Safety Auditors assessment of a road design is encouraged and Auditors can be accredited to undertake these vital objective measures of safety performance in Europe and worldwide – see https://www.irap.org/accreditation-irap/ for further details”.

EuroRAP can support road infrastructure managers by providing advice on applications of the RAP Star Rating protocol including training and procurement. It can advise on ‘bank friendly’ policy and investment goals.

With falling serious crashes over time, the value of using historic crashes alone to guide interventions is falling. Furthermore, some countries do not record reliable data, typically having issues with locations or injury severity. Consequently, the estimation of risk from assessment of in-built safety and economic appraisal of risk countermeasures is also needed to allocate future road safety investments most effectively.

Once Star Rating is carried out, FSI estimations can be produced which then enables a Safer Road Investment Plan (SRIP) to be generated. SRIPs undertake ‘what if’ economic modelling and suggest high return programmes of engineering countermeasures. This evaluation is recognised by Investment and Development Banks worldwide and is set to be more than sufficient to comply with RISM requirements for prioritisation.

The economic benefits are estimated to provide countries with the confidence to invest in the evidence-based road upgrades that will play a key role in reaching the UN SDG target to halve road deaths and injuries.

Because each road – and the community it serves – is unique, every Safer Road Investment Plan is different. By assessing and optimising the 90 key attributes that are universal to all roads, a clear network-level plan that will maximise the lives saved per unit of investment can be created, based on the road users of that road network. In this way the road owner can have a full appreciation of the business case and have confidence that the interventions will deliver results.

Article 6 (b)- Member States shall ensure that the needs of vulnerable road users are considered in the implementation of the procedures set out in Articles 3 to 6a.

The RAP Star Rating protocol include a rating for pedestrians and cyclists where these are relevant. There is an intense interest in the further application of these measures into urban areas and continuous improvement programmes are currently in hand. The Directive however refers to extra-urban roads.

High-risk roads where large numbers of users are killed or seriously injured are inspected and affordable programmes of safety engineering are identified. As the percentage of vulnerable road users, like pedestrians and two-wheelers among the road deaths is high in
those countries, RAP focuses on measures to improve road design especially for these users. EuroRAP can provide guidance on providing road safety assessments considering the needs of vulnerable road users for Article 5 (2).

**Article 6 (c) – Member States shall pay specific attention, in their existing and future procedures for road markings and road signs, to readability and detectability for human drivers and automated driver assistance systems.**

As part of the CEF project - SLAIN (2019-2021), EuroRAP has performed road safety assessments in 4 member states which will aim on readability and detectability of road markings and road signs for human drivers and automated driver assistance systems. These results will be published in 2021.

**Article 6 (d) - The Commission shall publish a European map of the road network within the scope of this Directive, accessible online, highlighting different categories as referred to in Article 5(6).**

EuroRAP, in cooperation with relevant stakeholders, can prepare the European map of the road network accessible online for free on the user friendly ViDA software https://vida.irap.org/, highlighting different categories as referred to in Article 5(6). In the context of the EC CEF SLAIN project Activity 5, this activity can support preparing the European map of the road network.

**Article 10- In order to improve the safety of Union roads, the Commission shall establish a system for the exchange of information and best practices between the Member States, covering, inter alia, training curricula for road safety, existing road infrastructure safety projects and proven road safety technology.**

Substantial training and increased awareness will be needed to breed familiarity on Road Safety and the RISM directive. The EC CEF SLAIN project Activity 6 will publish more than 100 case studies online on a website which can be used for exchange of information and best practices between stakeholders. EuroRAP can support the activity with training curricula for road safety as well provide training to stakeholders for National / regional support on road safety and investment plans.

**Article 11a- Reporting**

EuroRAP can support Member states in reporting based on a common methodology. The report shall also cover the list of provisions of national updated guidelines, including the improvements in terms of technological progress and of protection of vulnerable road users.