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WP2. Road Infrastructure Safety Management methodology – Network Wide Road Safety Assessment

T2.3 Network Wide Road Safety Assessment Fundamentals - Implementation of a systems approach to RISM at strategic, regional, and local levels

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1 ABOUT THE EUROSAP-NWRSA PROJECT

The main objectives of the **European Road Safety Partnership - Network Wide Road Safety Assessment** project are for students to gain knowledge and improve the competence and skills of road authorities, auditors, and road safety inspectors, as well as lecturers and experts (teaching staff) in the area of Network Wide Road Safety Assessment (NWRSA) as part of Road Infrastructure Safety Management (RISM).

To achieve this goal, international cooperation within the project will be necessary to increase the quality of education, allow for the exchange of knowledge between partners, and implement and disseminate innovative solutions.

Achieving the project's main objective will increase the possibilities of solving such a socially significant problem as road safety. The main aim will be achieved through the implementation of sub-objectives:

1) Prepare the methodological basis and develop didactic and training materials for six courses, including competence certification.
2) Building a knowledge base of stakeholders and professionals in RISM for European Union countries.
3) The participants of the pilot training courses verified, evaluated and recommended the prepared didactic and training materials and methodologies.
4) Disseminate information about the project and its results using digital tools.

Work package 2

Work package No. 2 is the first element in the implementation of the planned project. It will be the basis for the implementation of works under the following packages: WP3, in which the didactic-training materials will be created, which will then be subject to verification and evaluation as part of WP4 (pilot training).

Two main goals of WP2 are:

5) preparation of the methodological basis for the development of the didactic-training materials for 6 courses under WP3, along with the development of competency certification
6) building two knowledge databases on stakeholders and specialists in the RSIM for the EU countries

The main goal to be achieved through the implementation of specific goals:

7) development of techniques for the implementation of the training and teaching process with the use of supporting tools,
8) development of recommendations for/to the necessary NRWSA supporting tools,
9) development of a method for assessing the level of knowledge, along with its verification, for NRWSA specialists, necessary to obtain a certificate of competence,
10) preparation of a survey collecting detailed information about specialists and stakeholders in the field of the RSIM, along with conducting research,
11) elaboration of the survey results on specialists and stakeholders, preparation of input data for knowledge bases.

2 ROAD INFRASTRUCTURE SAFETY MANAGEMENT TOOLS

There are several well-established Road Infrastructure Safety Management Tools available to the road safety engineer and prescribed by the EU Directive 2019/1936, such as (see also Figure 2.1):

- **Network Wide Road Safety Assessment (NWRSA)**
  Evaluating accident and impact severity risk, based on: a) primarily, a visual examination, either on site or by electronic means, of the design characteristics of the road (in-built safety); and b) 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 (Mandated by the EU Directive 2019/1936).
- **Road Safety Impact Assessment (RSIA)**
  A strategic comparative analysis of the effects of building new roads or a substantial modification to the existing network on the safety performance of the road network. RSIA is carried out at the initial planning stage before the infrastructure project is approved to indicate the road safety considerations, which contribute to the choice of the proposed solution.
- **Road Safety Audit (RSA)**
  A formal safety performance examination of planned roads by an independent audit team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users.
- **Road Safety Inspection (RSI)**
  A systematic review of existing roads with the intention to identify any potential hazards, faults or deficiencies that may lead to serious accidents.

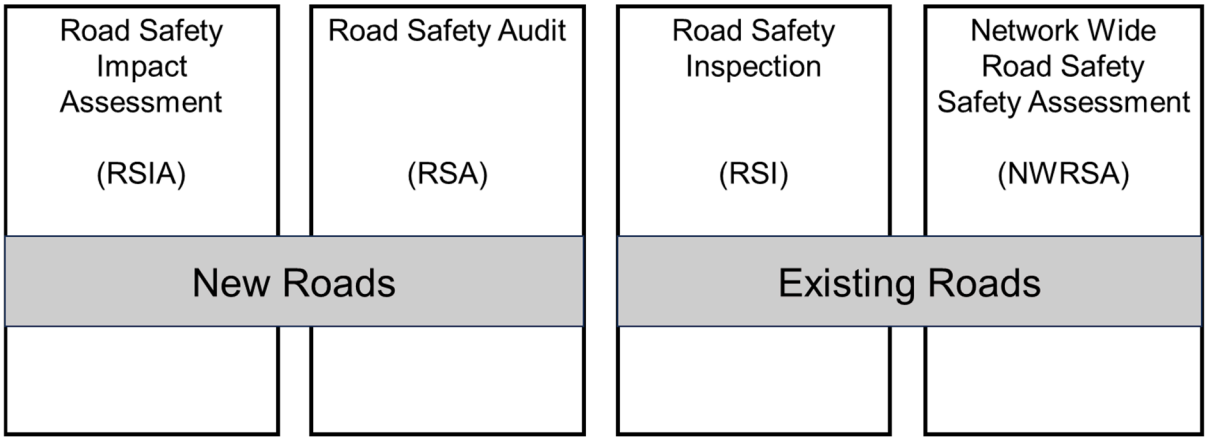


Figure 2.1 Road Infrastructure Safety Management Tools (Based on EU Directive 2019/1936).

3 NETWORK WIDE ROAD SAFETY ASSESSMENT

As prescribed by the EU Directive 2019/1936, NWRSA combines two approaches and consists of a proactive part: “a visual examination, either on site or by electronic means, of the design characteristics of the road (in-built safety)” and a reactive part “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”. The two approaches are both applied over the same network, and the resulting combined assessment builds on integrating the findings from the two approaches, providing the final road network rating and ranking. Particular emphasis is placed on the needs of vulnerable road users.

3.1 Proactive Safety Methods Based on Road Characteristics

3.1.1 IRAP Star Ratings

iRAP Star Rating method is used for proactive road safety network wide assessments, road safety impact assessments, inspections and audits. Star Ratings are an objective measure of the level of safety which is ‘built-in’ to the road through more than 55 road attributes that have a known influence on road safety risk for vehicle occupants, motorcyclists, bicyclists, and pedestrians.

Star Ratings reflect the risk as it relates to an individual road user. 1-Star roads have the highest risk, and 5-Star roads have the lowest risk. One of the main benefits of the Star Rating method is that the risk level can be produced without reference to detailed crash data, as shown in the examples within Figure 3.1 and Table 3.1.

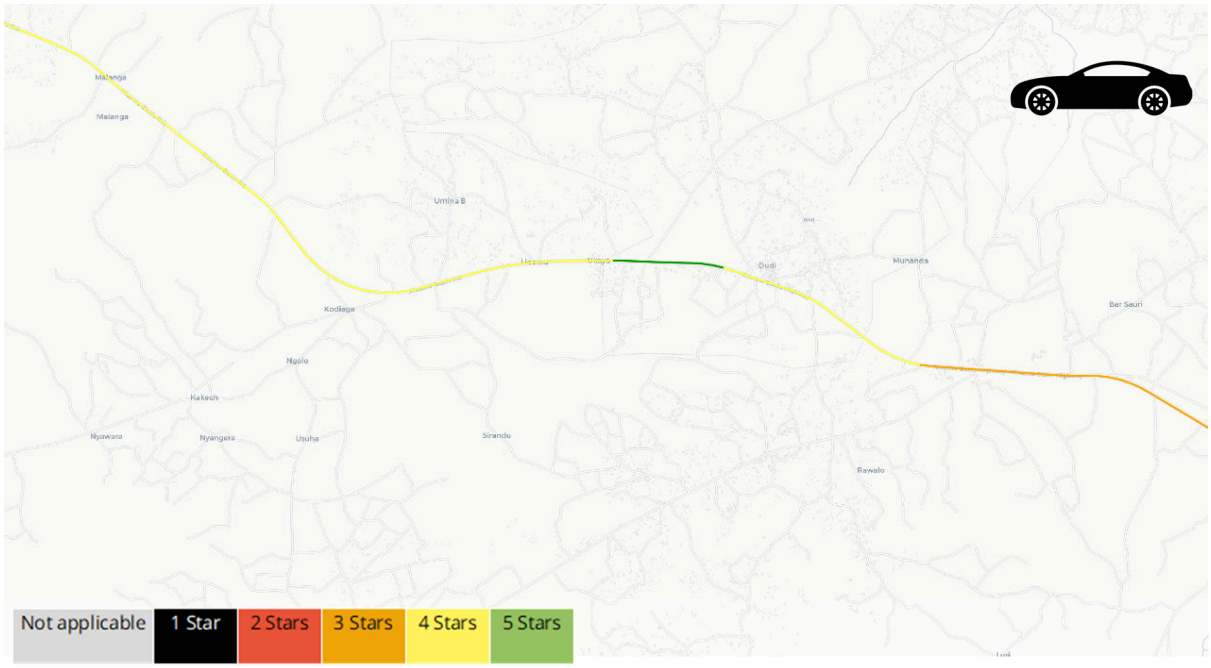


Figure 3.1. An example Star Rating map depicting the risk level for vehicle occupants

Table 3.1. Star rating of roads – what makes a road safe?
Source: Global Status Report on Road Safety 2018, www.irap.org

Star Rating				
★☆☆☆☆	No sidewalk, no safe crossing, 60 km/h traffic	No cycle path, No safe crossings, poor road surface, 70 km/h traffic	No motorcycle lane, undivided road, trees close to road, winding alignment, 90 km/h traffic	Undivided road with narrow centreline, trees close to road, winding alignment, 100 km/h traffic
★★★☆☆	Sidewalk present, pedestrian refuge, street lighting, 50 km/h traffic	On-road cycle lane good road surface, street lighting, 60 km/h traffic	On-road motorcycle lane, undivided road, good road surface, >5m to any roadside hazards, 90km/h	Wide centreline separating oncoming vehicles, >5m to any roadside hazards, 100 km/h traffic
★★★★★	Sidewalk present, signalized crossing with refuge, street lighting, 40 km/h	Off-road dedicated cycle facility, raised platform crossing of major roads, street lighting	Dedicated separated motorcycle lane, central hatching, no roadside hazards, straight alignment, 80 km/h traffic	Safety barrier separating oncoming vehicles and protecting roadside hazards, straight alignment, 100 km/h traffic

The Star Ratings model also support FSI Estimations and Investment Plans, all of which are integrated in iRAP's online platform, ViDA. Specifications and manuals which were used when doing Star Rating Assessment procedures described within this pilot report are freely available at www.irap.org/specifications. There are also a range of tools available that can help the

reader understand the method, including the Star Rating Demonstrator for small assessments of one or more locations.

3.1.1.1 Star Rating process

iRAP has a number of road safety protocols:

1. Risk Maps use detailed crash data to illustrate the actual number of deaths and injuries on a road network (reactive method).
2. Star Ratings provide a simple and objective measure of the level of safety provided by a road's design (proactive method).
3. Safer Roads Investment Plans draw on approximately 90 proven road improvement options to generate affordable and economically sound infrastructure options for saving lives.
4. Performance Tracking enables the use of Star Ratings and Risk Maps to track road safety performance and establish policy positions.

The focus of this chapter is on elaborating the application of **second** and **third** protocol – Star Ratings and Safer Roads Investment Plans, which go hand in hand.

Star Ratings Star Ratings and Safer Roads Investment Plans can be used as part of a systematic, proactive approach to road infrastructure risk assessment and renewal based on research about where severe crashes are likely to occur and how they can be prevented. Figure 2.2 illustrates the process used to undertake these protocols.

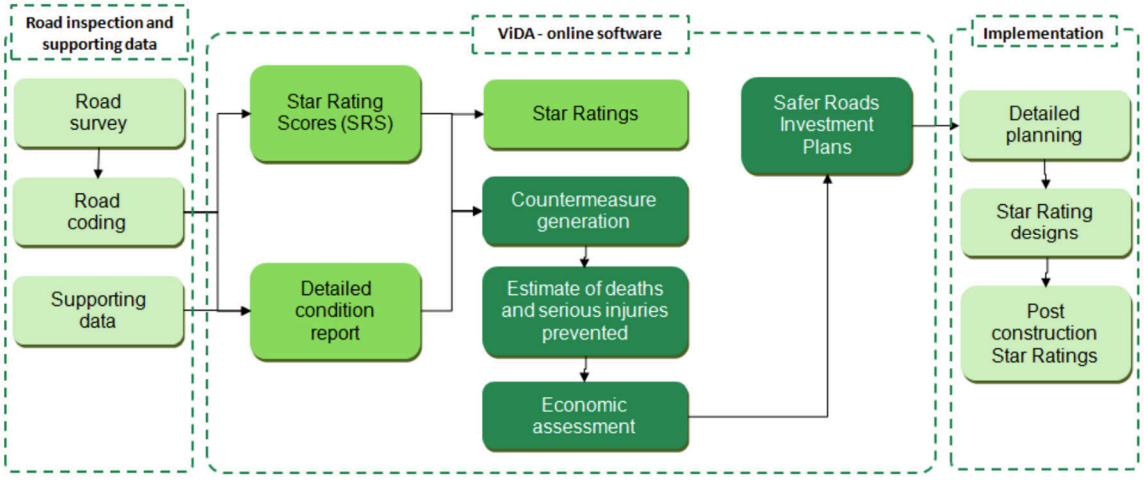


Figure 2.2. The iRAP Star Rating and Safer Roads Investment Plan process. Source: www.irap.org

3.1.1.2 Algorithms

In order to attribute Star Rating to a road section, Star Rating Score (SRS) needs to be calculated. The SRS is a unit-less indicator, which depicts the infrastructure's safety capacity and it is calculated for an individual road segment per individual user type. Road user types that are considered are the car occupants, the motorcyclists, the bicyclists and the pedestrians, who may be involved in road accidents. For each road user type per road segment, respective SRS is calculated as follows:

$$SRS_{n,u} = \sum_c SRS_{n,u,c} = \sum_c L_{n,u,c} * S_{n,u,c} * OS_{n,u,c} * EFI_{n,u,c} * MT_{n,u,c} \quad (1)$$

where:

n is the number of a road segment, “u” the type of road user and “c” the crash type that the road user type “u” may be involved in. The following variables are taken into consideration:
L: The Likelihood that the “i” crash may be initiated,
S: The Severity of the “i” crash,
OS: the degree to which risk changes with the Operating Speed for the specific “i” crash type,
EFI: the degree to which a person’s risk of being involved in the “i” type of crash is a function of another person’s use of the road (External Flow Influence),
MT: the potential that an errant vehicle will cross a median (Median Traversability).

SRS is only produced if a flow of the particular road user is recorded. For example, if no pedestrians are present, then no SRS is produced. SRS are also not produced when major road works are being undertaken. Per road user specific SRS equations used in iRAP Star Rating model are described in greater detail within *iRAP Method Fact Sheet #6: Star Rating Score equations.*

3.1.1.3 Star Rating Bands

Star Ratings are determined by assigning Star Rating Scores (SRS) to respective bands. Separate bands are used for motorised road users (vehicle occupants and motorcyclists), bicyclists and pedestrians because their scores are calculated using different equations. That is, motorised road user scores are based on head on, run-off road and intersection crashes; pedestrian scores are based on walking along and across the road crashes; and bicyclist scores are based on riding along the road and intersections crashes. Star Ratings are determined by assigning Star Rating Scores (SRS) to the bands as shown in Figure 3.3.

Star Rating	Star Rating Score				
	Vehicle occupants and motorcyclists	Bicyclists	Pedestrians		
			Total	Along	Crossing
5	0 to < 2.5	0 to < 5	0 to < 5	0 to < 0.2	0 to < 4.8
4	2.5 to < 5	5 to < 10	5 to < 15	0.2 to < 1	4.8 to < 14
3	5 to < 12.5	10 to < 30	15 to < 40	1 to < 7.5	14 to < 32.5
2	12.5 to < 22.5	30 to < 60	40 to < 90	7.5 to < 15	32.5 to < 75
1	22.5 +	60+	90 +	15 +	75 +

Figure 3.3. Star Rating Bands table.

3.1.1.4 Smoothed Star Rating

A Star Rating Score (SRS) is calculated for each segment of road for vehicles occupants, motorcyclists, pedestrians and bicyclists. These scores are then allocated to Star Rating bands to determine the segment specific Star Rating. However, for the purposes of producing a wholesome road map, length of such segments can be too detailed. Hence, Star Ratings are smoothed (or averaged) over longer lengths in order to produce more meaningful results. The effect of smoothing is illustrated in Figure 3.4 below, which shows unsmoothed Star Rating Scores (SRS) in grey and smoothed SRS in white:

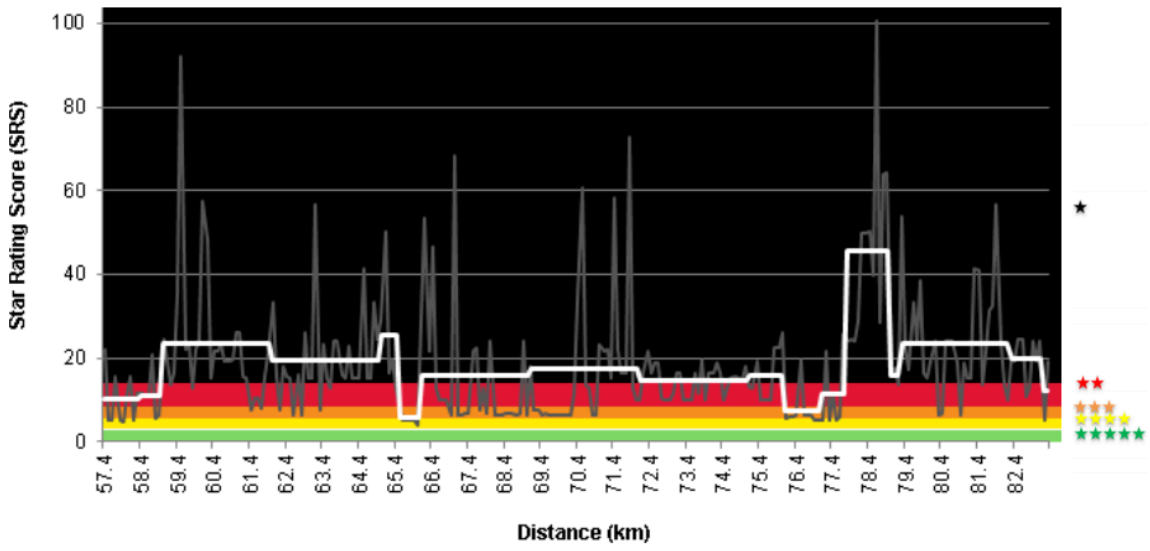


Figure 3.4. Smoothed SRS example

Smoothed Star Ratings are used in Star Rating maps, when presenting aggregated Star Rating results for a road network or in longer-term performance tracking.

3.1.1.5 Interpreting the iRAP Star Rating results

The iRAP Star Rating System serves as a comprehensive evaluation tool for road segments, providing a clear indication of safety levels across various sections of a road. Each 100-meter segment of a road undergoes assessment, receiving a star rating ranging from 1 to 5 based on safety parameters. Approximately, each star stands for:

- 5 Stars (colour coded as **Green**): Indicates an exemplary safety standard, signifying a low probability of severe accidents.
- 4 Stars (colour coded as **Yellow**): Represents a high safety standard, with a likely reduced likelihood of serious crashes.
- 3 Stars (colour coded as **Orange**): Denotes a moderate safety level, suggesting room for potential safety enhancements.
- 2 Stars (colour coded as **Red**): Highlights areas of concern, indicating a higher risk of crashes with severe consequences and necessitating safety improvements.
- 1 Star (colour coded as **Black**): Signifies a critical need for safety enhancements, reflecting a substantial risk of severe crashes.

The final output of the assessment is presented through Star Rating Maps and tables, where road segments are distinctly color-coded based on their awarded star rating, providing a clear and comprehensive visual representation of road safety across different sections. The determination of the star rating involves a thorough process of aligning calculated safety ratings (called Star Rating Score, or SRS for short) to predefined 5 rating bands (Stars). These bands vary for 4 different road user categories as displayed in Figure 3.5.

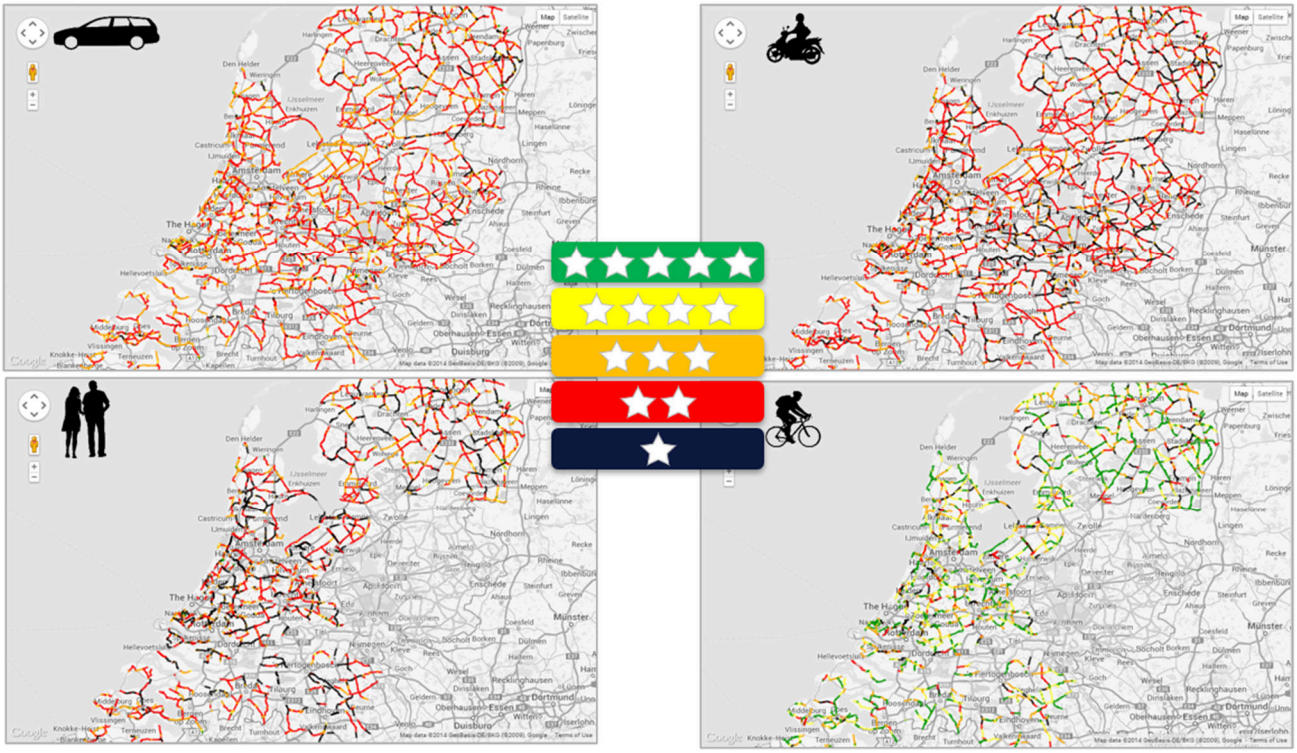


Figure 3.5. An example of a difference in risk between different user groups over the same network. Source: www.irap.org

3.1.1.6 The relationship between visual inspection of the road and Star rating

The iRAP proactive evaluation of road safety on a network wide scale necessitates segmenting the road network into 100-meter sections for a detailed analysis. Each segment undergoes a thorough examination, resulting in an assignment of a **Star Rating Score (SRS)**, reflective of the identified risk level which is based on recorded road attributes.

The analysis process encompasses visual observation and documentation of road infrastructure elements known to influence the likelihood and severity of crashes. The method employed for this task encompasses two distinct types of inspection: drive-through and video-based. The former involves live recording (dubbed “coding”) of infrastructure elements on the field, while the latter utilizes a vehicle equipped with recording apparatus, enabling an in-office virtual drive-through of the network for subsequent analysis within a special coding software (example of the software displayed in Figure 3.6).

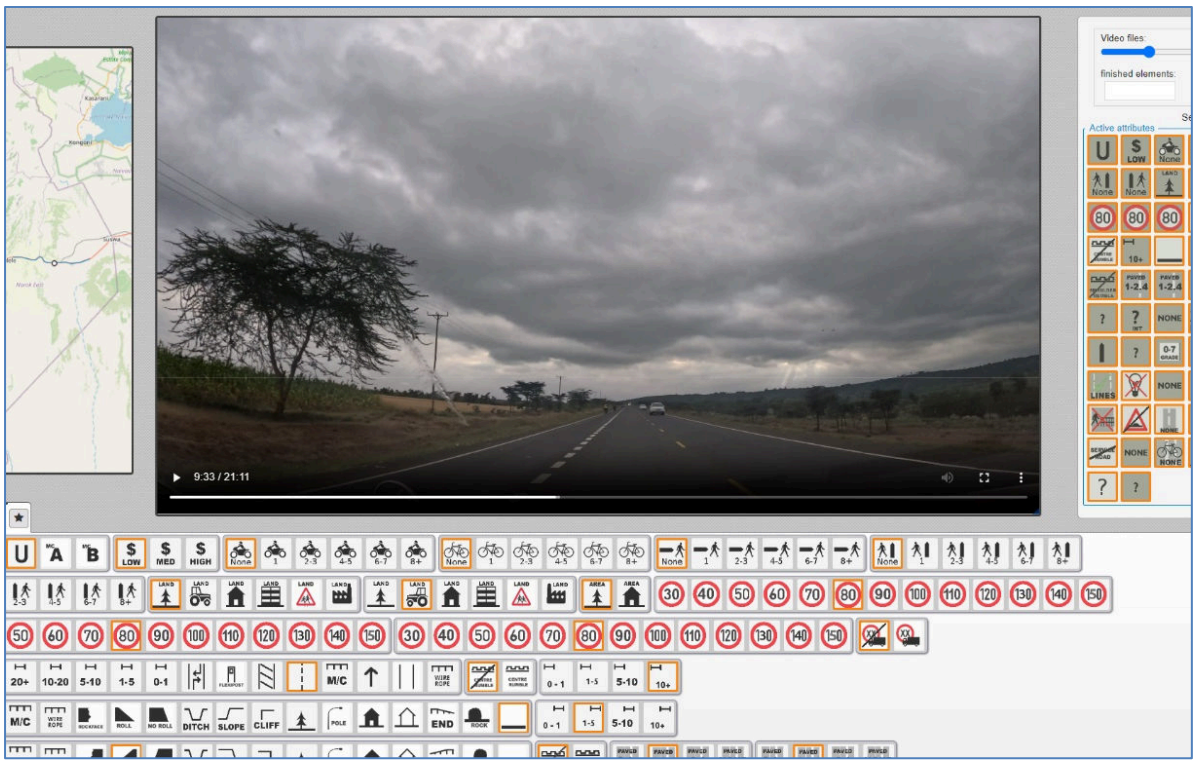


Figure 3.6. Example of a coding toolkit software interface for recording road infrastructure attributes (FPZ WebGIS coding tool)

For each road user type and road segment, the Star Rating Score (SRS) is calculated using a comprehensive formula, incorporating variables such as:

- Likelihood of a crash initiation
- Severity of a potential crash
- Influence of operating speed on risk for specific crash types
- External Flow Influence, indicating how one user's road usage can affect the risk for others
- Median traversability, assessing the likelihood of a vehicle crossing into oncoming traffic

The recording of road infrastructure is a critical component in evaluating road safety, as it directly feeds into the calculation of the SRS. Each aspect of the road's design and features is analysed for its influence on safety by iRAP's ViDA software. This comprehensive data analysis forms the basis of the SRS, a quantitative measure that reflects the safety conditions of a specific road segment. Following the SRS calculation, the results are then classified into star rating bands, ranging from 1 to 5 stars, based on how high the SRS score is. This relationship between recorded road attributes and star rating score is depicted on Figure 3.7.

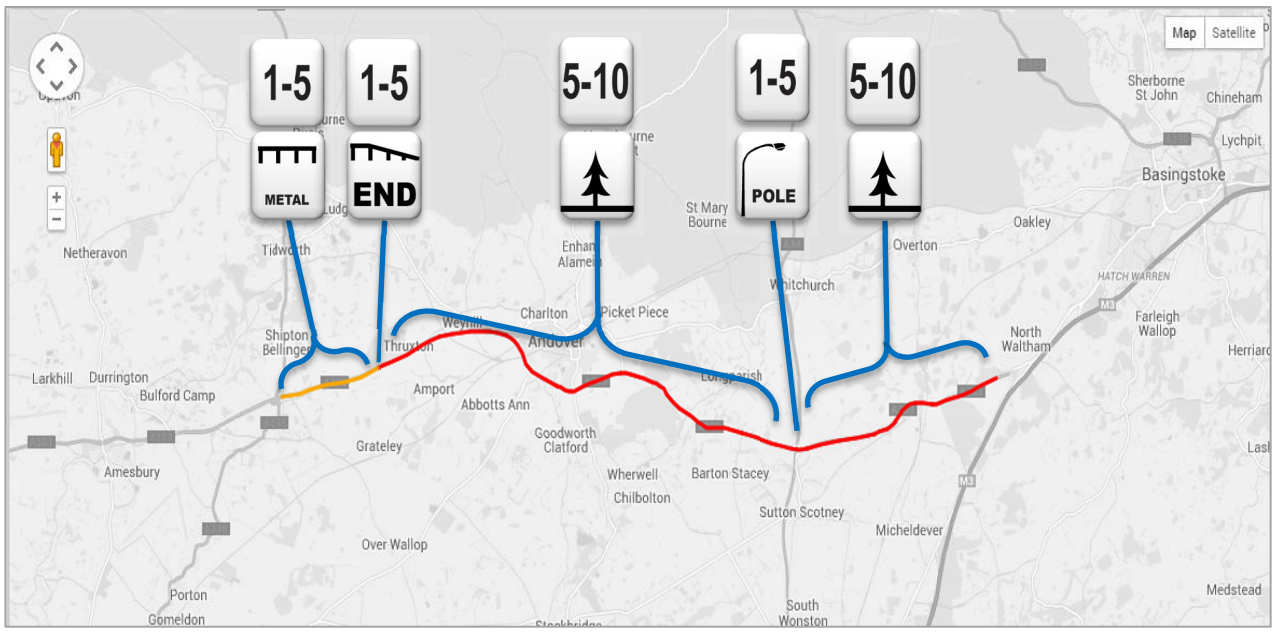


Figure 3.7. Relationship between coded infrastructure attributes and Star Rating score. Source: www.iRAP.com

3.1.1.7 About Safer Road Investment Plan (SRIP)

The Safer Road Investment Plan (SRIP) represents a strategic approach aimed at enhancing road safety over a defined period, typically spanning 20 years. Within this framework, a systematic analysis is conducted to identify and prioritize infrastructural modifications and safety interventions that yield the highest impact in terms of reducing road traffic injuries and fatalities. The SRIP encompasses a range of potential countermeasures, addressing various aspects of road safety from the improvement of road geometry, the installation of safety barriers, to the enhancement of road markings and signage. The ultimate objective of the SRIP is to facilitate informed decision-making, ensuring that investments in road safety are both effective and cost-efficient, ultimately contributing to a safer road network for all users. The SRIP layout example which is used within this report (as well as within iRAP's ViDA software) is shown in Table 3..

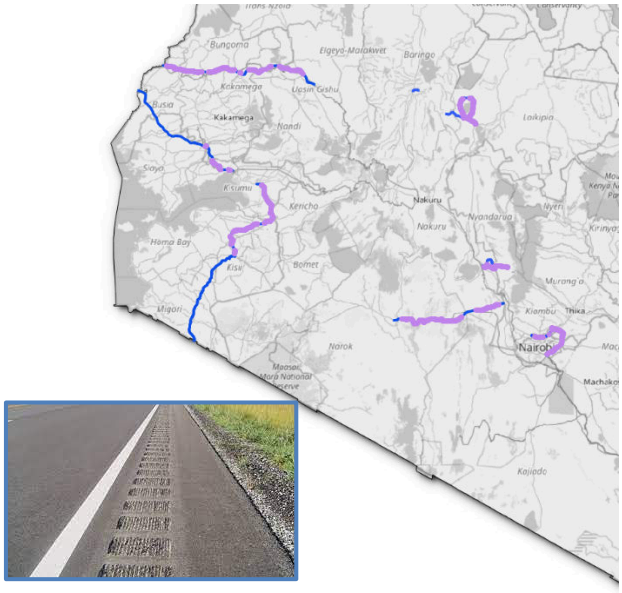
Table 3.2. Layout of a SRIP table.

Total FSIs Saved	Total PV of Safety Benefits	Estimated Cost	Cost per FSI saved	Program BCR
Number of fatal and serious injury saved by all project countermeasures	Benefit of all countermeasure values	Estimated cost of all counter-measures	Number of fatal and serious injury saved by the implementation	Benefit to cost ratio of a coun-termeasure

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Name of a countermeasure	Total length or number of sites for	Number of fatal and serious injury	Benefit of a countermeasure value	Cost of the road upgrade	Cost per average life	Benefit to cost ratio of a

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
	countermeasure implementation	saved by the countermeasure			or serious injury	countermeasure

An example countermeasure overview displaying location of shoulder rumble strips implementation, along with corresponding SRIP attributes is shown in Figure 3.8.



Countermeasure	Length / Sites	FSIs saved	Estimated Cost	Program BCR
Shoulder rumble strips implementation	304.30 km	6,233	191,398,035	81

Figure 3.8. Example of countermeasure overview displaying location of shoulder rumble strips implementation, along with corresponding SRIP attributes. Source: www.iRAP.com

3.1.2 IASP

In the framework of the European project “Identification of Hazard Locations and Ranking of Measures to Improve Safety on Local Rural Roads” (IASP) (Cafiso et al., 2007), a new surrogate safety measure, the Safety Risk Index (SRI), was defined to supplement crash investigation studies in the safety evaluation of two-lane rural highways using data from SIs and design consistency models.

The SRI formulation was defined by combining the risk components related to (Cafiso et al., 2007):

1. the exposure of road users to road hazards **Ef:** depending on the length of the segment under consideration (L) and the average annual daily traffic (AADT),

2. the probability of a vehicle being involved in a collision, **AFf**: that is the severity of crashes basing on both roadside hazards, identified by Safety Inspection (SI), and the ratio between the 85th percentile of free flow speed and the posted speed,
3. the resulting consequences should a crash occur, **ASf** that depends on the defects in road features affecting safety, which are assessed by SIs, Design Consistency and Design Standards Checks.

$$SRI = Ef \times AFf \times ASf \qquad (2)$$

In general, SIs relate to the main safety issues that can be effectively detected by means of inspections and which are consistently present along two-lane rural roads (Accesses, Cross sections, Delineation, Markings, Signs, Pavement, Roadside, Sight distance). In field SIs are carried out by a visual survey of the road using a checklist purposely set up for the successive SRI evaluation. Checklists used in SI procedures are filled in for both directions of the road, with a constant step (e.g. 200 meters) using well defined procedures and criteria for identifying and ranking safety issues with 'high level problem', 'low level problem' or 'no problem'. SIs are carried out involving three operators: the driver of the vehicle and two inspectors positioned in the front and rear seats.

Design Consistency and Standards Checks refer to the safety evaluation of the horizontal alignment based on design standards for tangents and the Safety Criteria proposed by Lamm (Lamm et al., 1999) for curves. To validate the procedure, comparisons were made between SRI scores and the expected frequency of severe (fatal and injury) crashes on a sample of road segments. More specifically, using crash data collected over a five-year period of accident history on the road sample, a crash prediction model was developed using the segment length and the AADT as explanatory variables, including an empirical Bayes correction technique (EB). Comparison between R scores and EB frequency estimates pointed out a significant linear correlation that can be used to validate the SRI model and to predict the number of crashes basing on SRI values as well.

3.1.2.1 Exposure Factor

The exposure factor measures the exposure of road users to road hazards and is assessed as follows:

$$Exposure\ Factor = L \times AADT \qquad (3)$$

where L is the length of the segment under consideration (in kilometres) and AADT is average annual daily traffic (in 1,000 vehicles per day).

3.1.2.2 Accident Frequency Factor

The accident frequency factor depends on the safety features of the segment, which are assessed by two analysis methodologies:

- RSIs and
- Design consistency evaluations and design standard check.

The accident frequency factor is obtained by

$$Accident\ Frequency\ Factor = RSI\ AF \times GD\ AF \qquad (4)$$

where RSI AF is the RSI accident frequency factor, and GD AF is the geometric design accident frequency factor.

With scores assigned to each inspection unit (segment 200 m long) during the survey, a weighted score of each safety issue j (WSj) ranging from 0 to 1 is computed as follows:

$$WS_J = \frac{1}{2\ x\ n\ x\ m_j} x \sum_{i=1}^{m_j} \sum_{k=1}^{2xn} S_{ik} \quad (5)$$

where:
Sik = score of detailed safety issue i in inspection unit k,
N = number of inspection units that form section under consideration,
m_j = number of detailed issues associated with issue j, and
2 = factor to take both directions into account.

For each safety issue j the related accident frequency factor (AFj) is computed as follows:

$$AF_j = 1 + WS_j\ x\ \Delta AF_j \quad (6)$$

where ΔAFj is the estimated relative increase in accident risk due to issue j and Pj is the proportion of accident typologies affected by issue j.

The cumulative influence of all safety issues j is assessed by the RSI accident frequency factor, computed as follows:

$$RSI\ AF = \prod_{j=1}^{l} AF_j \quad (7)$$

where l is the number of safety issues, equal to 8 in the IASP model.

Based on existing literature, the relative increase in accident risk due to each issue was estimated (see Table 3.3). Many studies have been performed to estimate the safety impact of various types of engineering improvements. Many existing accident modification factors (AMFs) are derived from before-and after analysis of actual countermeasure implementation. Indeed, such before-and-after studies, as opposed to cross-sectional and regression-type analysis, will produce the best AMF estimates, but only if conducted properly. Unfortunately, many current studies reflect changes in crash experience resulting from improvements at sites that had experienced unusually high accident rates in the before treatment period. The selection bias inherent in this approach often results in significantly exaggerated AMF estimates because of the phenomenon of regression to the mean. The most accurate AMFs have been developed in rigorous before-and-after studies that incorporated the current best study design and statistical analysis methods. Currently, the empirical Bayes (EB) methodology represents the best available approach. Change in accident risk (ΔAFj) is related to the AMFj of the safety issue by

$$\Delta AF_j = AMF_j - 1 \quad (8)$$

Explanations of the relative increase in accident risk estimates for each safety issue are briefly reported in the Table below.

Table 3.3. Safety Effects of Issues.

Safety Issue	Related Accidents	ΔAF (%)
Accesses	All	135
Cross section	Run off the road Head-on Sideswipe	15–100 f(AADT)
Delineation	All	30
Markings	All	20
Pavement	All	10
Roadside	Run off the road	0
Sight distance	All	50
Signs	All	20

A consistent highway design ensures that successive elements are coordinated in such a way as to produce harmonious and homogeneous driver performance along the road. Practice highlights that an alignment with inconsistencies requires drivers to handle speed gradients in order to drive safely on certain alignment elements. On this basis, the importance of identifying inconsistencies on highways and their significant contribution to road safety is emerging as an important feature in highway design. Design consistency evaluates an overall safety module defining three design classes: poor, fair, and good. This safety module combines the following three safety criteria:

- Design consistency, related to the difference between the operating speed, represented by the 85th-percentile speed (V85), and the design speed (Vd) of the observed roadway section;
- Operating speed consistency, related to the difference in V85 between two successive geometric elements; and
- Driving dynamic consistency, determined by the difference between side friction assumed (fRA, which depends on the design speed) and side friction demanded (fRD, which depends on the operating speed) on one individual curve.

To evaluate the safety module, good design is classified by the weighting factor of +1, fair design is described by the factor 0, and for poor design the factor −1 is used. Summing up the weighting factors for the individual safety criteria, the calculated average value xrepresents an evaluation for the safety module as follows: if x ≥ 0.5, design class is good; if −0.5 < x < 0.5, design class is fair; if x ≤ −0.5, design class is poor.

Table 3.4. Design Consistency Criteria.

Safety Criterion	Design Class		
	Good	Fair	Poor
I	$\lvert V_{85i} - V_d \rvert \le 10$ km/h	10 km/h $< \lvert V_{85i} - V_d \rvert \le 20$ km/h	$\lvert V_{85i} - V_d \rvert > 20$ km/h
II	$\lvert V_{85i} - V_{85i+1} \rvert \le 10$ km/h	10 km/h $< \lvert V_{85i} - V_{85i+1} \rvert \le 20$ km/h	$\lvert V_{85i} - V_{85i+1} \rvert > 20$ km/h
III	$f_{RA} - f_{RD} \ge +0.01$	$-0.04 \le f_{RA} - f_{RD} < +0.01$	$f_{RA} - f_{RD} < -0.04$

$f_{RA} = 0.6 \times 0.925 \times (0.59 - 4.85 \times 10^{-3} \times V_d + 1.51 \times 10^{-5} \times V_d^2)$
$f_{RD} = V_{85}^2/(127 \times R) - e$

The GD AF is assessed by the following formula:

$$GD\ AF = 1 + WS_{GD}\ x\ \Delta AF_{GD}\ x\ P_{GD} \quad (9)$$

where:
WS_{GD} = weighted score of safety issue GD,
ΔAF_{GD} = estimated relative increase in accident risk due to issue GD,
P_{GD} = proportion of accidents affected by issue GD.

For a section of v geometric elements, WS_{GD} is computed through a weighted mean of GDS_I:

$$WS_{GD} = \frac{\sum_{l=1}^{v} GDS_l\ x\ L_l}{\sum_{l=1}^{v} L_l} \quad (10)$$

where:
v = number of geometric elements that form section under consideration,
L_I = length of geometric element I, and
GDS_I = geometric design score of element I.

Each GDS_ (ranging from 0 to 1) was estimated by analyzing the increase of the accident rate with respect to:

- Poor, fair, and good design class for the curved elements and
- A check in terms of minimum or maximum length, which failed Italian design standards for tangents. The state of the art indicates an increase in accident risk on poor curved segments as compared with tangents (ΔAFDCS) equal to 700%.

Table 3.5. Geometric Design Scores GDSI.

Curved	Elements	Tangents		Related Accidents
Good	0.2	Overall standards check	0.0	Run off the road
Fair	0.5	Minimum length	0.1	Partially (50%):
Poor	1.0	Maximum length	0.1	Head-on
				Same direction and opposite direction sideswipe

3.1.2.3 Accident Frequency Factor

Accident severity is intended as a measure of the ratio between the number of severe accidents (injury or fatal) and the total number of accidents. Two factors were considered significant:

- Operating speed and
- Roadside hazard.

The accident severity factor for the segment is computed with the following formula:

$$Accident\ Severity\ Factor = \left(\frac{V_{85}}{V_{base}}\right) x\ RSI\ AS_{roadside} \quad (11)$$

where:
V_{85} = average 85th percentile of speed along segment (weighted to element length),
V_{base} = base operating speed for two-lane local rural highways (assumed equal to legal speed limit of 90 km/h), and

RSI $AS_{roadside}$ = roadside accident severity factor of segment.

The road safety inspection accident severity factor of the roadside safety issue (RSI $AS_{roadside}$) is equal to

$$RSI\ AS = RSI\ AS_{roadside} = 1 + WS_{roadside} \times P_{roadside} \times \Delta AS_{roadside} \quad (12)$$

where:
$WS_{roadside}$ = weighted score of roadside safety issue;
$P_{roadside}$ = proportion of accidents related to roadside issue, equal to proportion of run-off-the-road accidents; and
$\Delta AS_{roadside}$ = estimated relative increase in accident severity due to issue j; this value was assumed equal to 2 considering maximum increase in proportion of injury accidents due to roadside hazard.

Considering that RSI $AS_{roadside}$ evaluates roadside items including embankments, bridges, dangerous barrier terminals and transitions, trees, utility poles, and rigid obstacles and ditches, a weighted mean of the roadside issue ($WS_{roadside}$) is computed as follows:

$$WS_{roadside} = \frac{\sum_{k=1}^{2xn} max_i(score_{ik}\ x\ weight_i}{2\ x\ n\ x5} \quad (13)$$

where $score_{ik}$ is the score of roadside safety item i in the inspection units k (0, 0.5, or 1), and weight i is the relative weight of roadside safety item i.

Table 3.6. Relative Weights of Roadside Safety Items.

Detailed Safety Issue	Relative Weight
Embankments	3
Bridges	5
Dangerous terminals and transitions	2
Trees, utility poles, and rigid obstacles	2
Ditches	1

3.1.3 Road Safety Models of Various Countries

The document "PPR770 Road Safety Models" by Transport Research Laboratory (Fletcher et al., 2015) provides a comprehensive review of various road safety models and methodologies used globally to improve road safety.

The document evaluates different road safety models, focusing on their effectiveness, data requirements, ease of use, and suitability for various road types, particularly rural roads. It aims to guide road safety practitioners in selecting the most appropriate models for their needs. The document emphasizes the importance of selecting the right model based on the specific needs, resources, and data availability of the road authority. It highlights the strengths and limitations of each model, providing a valuable resource for improving road safety practices.

3.1.3.1 High-Risk Rural Roads Guide (HRRRG)

Developed by the New Zealand Transport Agency, provides methods to identify high-risk road sections and a list of countermeasures and focuses on rural roads and uses crash data and road features for risk assessment.

Model:	**High-Risk Rural Roads Guide**
Country:	New Zealand
Developer:	NZTA
First released:	2011
Model type:	Risk-based and crash history
Format:	Text-based guidelines which references several established road safety models

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
££	£££	£	★★★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	X	✓	-	✓

Figure 3.9. Summary of High-Risk Rural Roads Guide model.

3.1.3.2 Manual for Selecting Safety Improvements on High Risk Rural Roads (HRRR).

Developed by the Federal Highway Administration (USA), assists in understanding the effectiveness of various safety improvements. Suitable for low-volume rural roads and includes economic appraisal.

Model: **Manual for Selecting Safety Improvements on High Risk Rural Roads**
Country: United States of America
Developer: Federal Highway Administration Office of Safety
First released: 2014
Model type: High-risk roadway features and severe crash history
Format: Guidance manual

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£	£	£	★★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	✓	✓	-	-

Figure 3.10. Summary of Safety Improvements on High Risk Rural Roads model.

3.1.3.3 Systemic Safety Project Selection Tool

Developed by the Federal Highway Administration (USA), focuses on network-wide safety analysis and proactive risk management. Uses minimal data and provides guidance for economic appraisal.

Model: **Systemic Safety Project Selection Tool**
Country: United States of America
Developer: Federal Highway Administration Office of Safety
First released: 2013
Model type: High-risk roadway features and severe crash history
Format: Guidance manual

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£	££	£	★★★★	★★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	✓	✓	-	-

Figure 3.11. Summary of Systemic Safety Project Selection Tool.

3.1.3.4 Users' Safety on Existing Roads (SURE)

Developed in France and Germany, uses economic potential for improvement to prioritize road sections. Focuses on identifying and treating road design deficiencies.

Model: **Users' Safety on Existing Roads (SURE)**
Country: France (Germany)
Developer: Service d'Etudes Techniques des Routes et Autoroutes, Highways Department, Road Safety and Traffic Directorate, France
First released: 2004
Model type: Reactive with some inspection
Format: Guidance

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	£££	£££	★★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	✓	X	✓	-

Figure 3.12. Summary of SURE model.

3.1.3.5 Route Analysis Tool

Developed by North Yorkshire County Council and Jacobs (UK), uses statistical methods to identify longer road sections with high crash occurrences. Suitable for rural roads and complements hotspot analysis.

Model: **Route Analysis Tool**
Country: United Kingdom
Developer: North Yorkshire Council and Jacobs
First released: 2012
Model type: Reactive – Crash analysis based
Format: MS Access/GIS

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	££	£££	★★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	X	X	X	X

Figure 3.13. Summary of Route Analysis Tool model.

3.1.3.6 PTV Visum Safety

Developed by PTV Group (Germany), integrates with traffic management software to identify and analyze crash hotspots. Provides network safety management and risk assessment for future scenarios.

Model: **PTV Visum Safety**
Country: Worldwide
Developer: PTV Group
First released: 2014 (Version assessed)
Model type: Mix of risk-based and crash history
Format: GIS based transport planning software with safety module

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	£££	£££	★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	✓	X	✓	X

Figure 3.14. Summary of PTV model.

3.1.3.7 Safety Analyst

Developed by the Federal Highway Administration (USA), implements analytical procedures for highway safety management. Supports network screening, diagnosis, countermeasure selection, and economic appraisal.

Model: **Safety Analyst**
Country: United States of America
Developer: Federal Highway Administration and participating state and local agencies, currently sold and supported by the American Association of State Highway and Transportation Officials (AASHTO)
First released: 2008
Model type: Proactive, Network screening and project prioritisation
Format: Software

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	££££	£££££	★★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	✓	✓	✓	✓

Figure 3.15. Summary of Safety Analyst model.

3.1.3.8 HiSafe

Developed by Digiwest (USA), companion software to the Highway Safety Manual, provides crash reduction estimates and economic appraisal for safety treatments.

Model:	**HiSafe: Companion Software to the Highway Safety Manual**
Country:	United States of America
Developer:	Digiwest, LLC
First released:	2010
Model type:	Reactive, Accident Predictive Models
Format:	Software

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	££	££££	★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	X	✓	✓	X

Figure 3.16. Summary of HiSafe model.

3.1.3.9 Interactive Highway Safety Design Model (IHSDM)

Developed by the Federal Highway Administration (USA), evaluates the effects of geometric design on highway safety. Includes modules for crash prediction, design consistency, and policy review.

Model:	**Interactive Highway Safety Design Model (IHSDM)**
Country:	United States of America
Developer:	Federal Highway Administration
First released:	2000 (current version 2014)
Model type:	Proactive, Crash Prediction Models for Identifying Site Specific Improvement Potential
Format:	Software

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	££	£	★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	X	X	X	X

Figure 3.17. Summary of IHSDM model.

3.1.3.10 NetRisk Rating Tool

Developed by ARRB Group (Australia), provides a rapid assessment of road infrastructure risk. Suitable for local road authorities and complements other safety models.

Model: **NetRisk Rating Tool**
Country: Australia
Developer: ARRB Group & Roads Alliance
First released: 2006
Model type: Risk-based
Format: Microsoft Excel based software with purpose-built form which can be imported into video rating

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	££	£££	★★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	-	X	X	X

Figure 3.18. Summary of NetRisk model.

3.1.3.11 RANKERS

Developed by CIDAUT and ERF (Europe), provides a Road Safety Index and a Countermeasure Catalogue. Focuses on non-urban roads and promotes proactive safety management.

Model: **RANKing for European Road Safety (RANKERS)**
Country: Europe
Developer: CIDAUT & ERF
First released: 2008
Model type: Risk-based with an applied factor for crash history
Format: Suite of reports containing two tools, one of which benefits from specialised road inventory software

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	£££	££	★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	X	✓	-	X

Figure 3.19. Summary of RANKERS model.

3.1.3.12 Road Infrastructure Safety Assessment (RISA)

Developed by the New Zealand Transport Agency, evaluates road infrastructure risk and prioritizes sections for improvement. Suitable for rural sealed roads and includes risk assessment and crash prediction.

Model: **Road Infrastructure Safety Assessment (RISA)**
Country: New Zealand
Developer: New Zealand Transport Agency
First released: 2007
Model type: Risk based model
Format: Microsoft Excel based software (macro-enabled)

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££	££££	££	★★	★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	X	-	X	X

Figure 3.20. Summary of RISA model.

3.1.3.13 Australian National Risk Assessment Model (ANRAM)

Developed by ARRB Group (Australia), combines risk rating and crash history to identify high-risk sections. Suitable for high-volume roads and includes economic appraisal.

Model: **Australian National Risk Assessment Model (ANRAM)**
Country: Australia
Developer: ARRB Group, funded by Austroads
First released: 2013
Model type: Risk-based and crash history
Format: Microsoft Excel based software (macro-enabled)

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££££	££££	££££	★★★★	★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	✓	✓	✓	X

Figure 3.21. Summary of ANRAM model.

3.1.3.14 Safety Network Evaluation Tool (SafetyNet)

Developed by Abley and NZTA (New Zealand), combines multiple safety performance indicators into one rating. Provides a comprehensive approach to prioritizing high-risk sections.

Model: **Safety Network Evaluation Tool (SafetyNet)**
Country: New Zealand
Developer: Abley & NZTA
First released: 2012
Model type: Mix of risk-based and crash history
Format: Web-based tool, input data is uploaded if recent data is not already contained on the website

Costs			Star Ratings	
Data	Human Resources	Software / licencing	Comprehensiveness	Suitability for UK local authority rural roads
£££££	£££	£	★★★★	★★★

Key processes of a road safety model				
Prioritisation of high-risk sections	Identification of road safety deficits	Generation of potential treatments	Economic appraisal	Monitoring and evaluation
✓	-	X	X	X

Figure 3.22. Summary of SafetyNet model.

3.1.4 EC NWA proactive method

The EC NWA proactive approach[1] is based on the assessment of the safety condition of road infrastructure.

The first step of the EC NWA proactive approach is the classification of roads into:

- Motorways
- Primary roads without a physical median
- Primary roads with a physical median

For each road segment, input data must be collected and assigned, ranging from simple geometric characteristics (e.g., road width and horizontal curve radius) to more complex operational features (e.g., traffic volume).

After completing the collection of input data, Reduction Factors (RF) are assessed for each road segment. These factors are calculated from Crash Modification Factors (CMF) and are then used to compute the final safety rating for each road segment. Details on the calculation method and the conversion from CMF to RF are thoroughly explained in the EC NWA Handbook.

The safety rating serves as the basis for classifying a road segment into one of three safety classes:

- **High risk (class p3)**
- **Medium-high risk (class p2)**
- **Low risk (class p1)**

The impact of each parameter on traffic safety is based on relevant international research, which allows for an assessment based on the parameters and characteristics of the road infrastructure without the need for accident data.

Table 2.7 shows an example of calculated Reduction Factors (RF) used in the EC NWA proactive approach.

Table 2.7. Example of Reduction Factors (RF) for the Lane Width Parameter Source: "Network Wide Road Safety Assessment - Methodology and Implementation Handbook," European Commission

AVERAGE LANE WIDTH (ALW)	CRASH MODIFICATION FACTOR (CMF)	REDUCTION FACTOR (RF)
ALW ≥ 3.40 m	1.000	1.000
3.15 m ≤ ALW < 3.40 m	1.025	0.976
ALW ≤ 3.15 m	1.050	0.952

[1]https://road-safety.transport.ec.europa.eu/eu-road-safety-policy/priorities/infrastructure/road-infrastructure-guidelines_en

3.23 presents the flowchart of the EC NWA proactive approach, serving as a comprehensive visual guide for conducting the procedure.

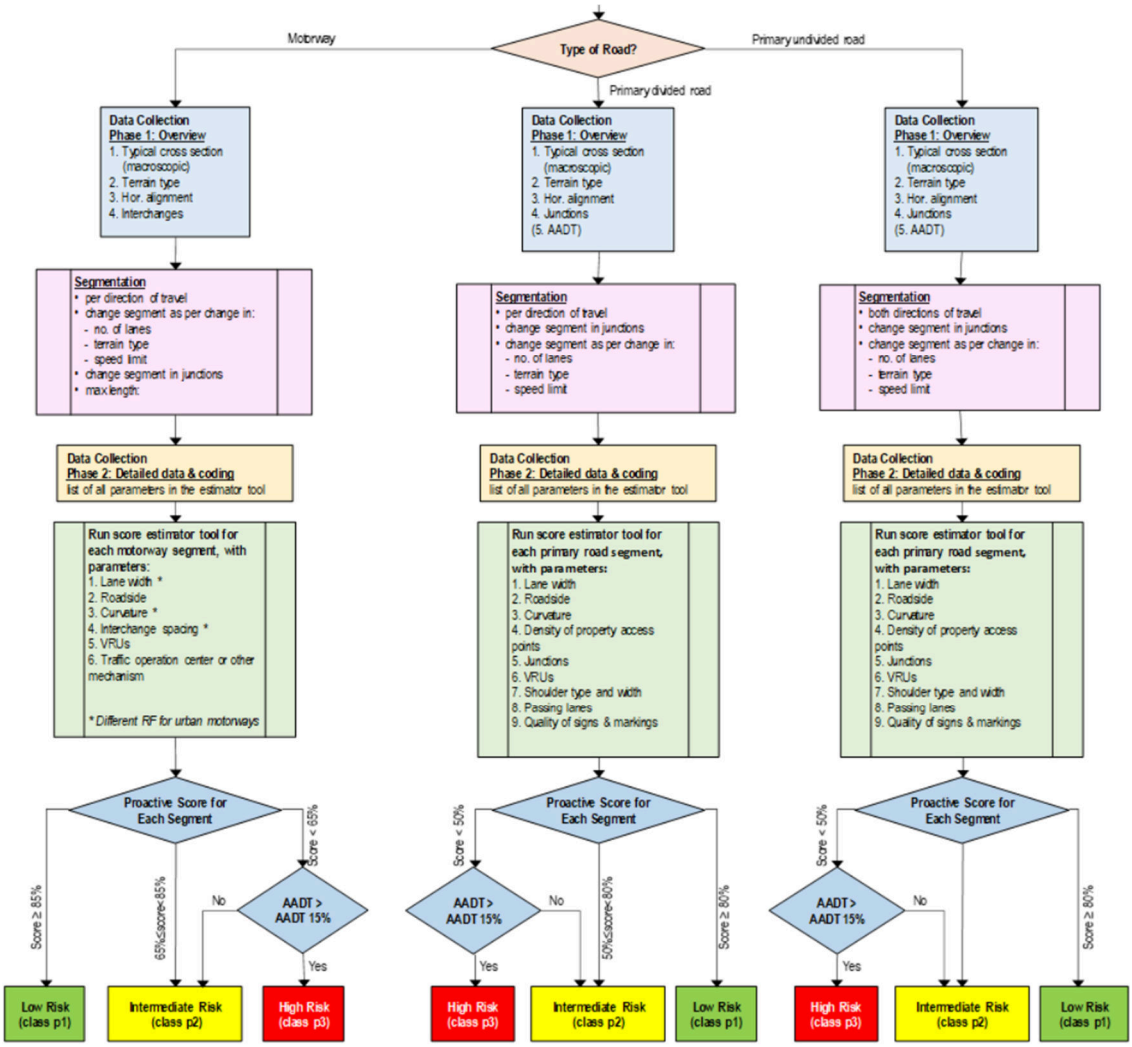


Figure 3.23. Flowchart of the EC NWA Proactive Approach Source: "Network Wide Road Safety Assessment - Methodology and Implementation Handbook," European Commission

3.1.4.1 Segmentation of the road network – EC NWA proactive

The segmentation process in the EC NWA proactive approach involves dividing roads into smaller sections—segments. For all types of roads included in the EC NWA method (motorways and primary roads), two alternative segmentation approaches are considered:

3.1.4.1.1 Approach 1 - Approximately Homogeneous Road Segments

Maximum lengths of road segments range from **2 to 5 km**.

When defining approximately homogeneous segments, the following characteristics are considered:

- **AADT** (Average Annual Daily Traffic)

- **Number of traffic lanes**
- **Speed limit**
- **Type of terrain**

Approach 1 - General Notes:

- The road consists of the **road axis and nodes**. Nodes can be part of a segment unless there is a significant change in traffic volume.
- **Road tunnels are excluded** from segmentation. Defined road segments should end before the tunnel entrance and start after the tunnel exit.
- **Toll station zones are excluded** from segmentation. Defined road segments should end before the start of the toll station expansion and start after the road resumes its usual cross-sectional profile beyond the toll station.
- The NWA Proactive approach **applies to bridges and viaducts** as well as to other road segments.
- Segmentation on motorways and primary roads with a physical median is conducted **per direction of travel**. The start/end points of a segment in one direction do not have to coincide with those in the other direction.
- If a new segment needs to be defined near a node, it should be done at the **end of the acceleration lane** or at the **beginning of the deceleration lane**.
- Significant changes in **AADT** should be used to define two different segments. These changes are expected in the area of nodes, from the deceleration lane to the acceleration lane. The point where one segment ends and another begins should be the dividing point of the node's acceleration/deceleration lane.
- If the **number of traffic lanes changes** (e.g., from two to three or from four to three), a new segment should be defined. Additional lanes at the node are not considered in segmentation.
- If the **speed limit changes** along the axis, different segments should be defined. Minor variations in the speed limit (e.g., for lengths less than 200 m) are not considered.

Recommendations for the maximum length of a homogeneous segment are:

- **Rural motorways**: L ≤ 5 km
- **Urban motorways**: L ≤ 3 km
- **Primary roads**: L ≤ 2 km

3.1.4.1.2 Approach 2 - Fixed-Length Road Segments

Segments are defined according to a **fixed distance**.

The fixed length of segments should be **from 400 to 600 m**, as longer segments would combine non-homogeneous road characteristics.

3.1.4.2 EC NWA Proactive Approach - Requirements and Recommendations

3.1.4.2.1 Motorways

Significant data that need to be collected for the EC NWA proactive approach on motorways include:

Lane Widths

- Calculate the **average lane width** for each direction of travel.

- Measurement techniques **differ** for edge lanes and traffic lanes.
- Use **length-weighted averages** for segments with varying lane widths.

For assessing lane width, it is recommended to first analyze existing high-resolution satellite images or georeferenced aerial photographs, as well as CAD/GIS databases containing the road inventory. For more precise measurements, laser distance meters or precise GPS tools can be used. It is important to note that lane width is **not a criterion for segmentation**; therefore, collecting high-precision data in different segments is not necessary in all cases.

Lateral Obstacles and Objects

- Required data: **width of the roadside area** and **type of lateral obstacle and object**.
- Segments should be changed when there is a change in the width of the roadside area or the type of lateral obstacle.

Data can be obtained from CAD or GIS databases with the road inventory, as well as from satellite images. For a more detailed evaluation, field surveys can be conducted using video cameras and/or GPS devices to measure or mark the start and end points of different types of lateral obstacles. The widths of **hard shoulders** and **acceleration/deceleration lanes** at nodes are not considered.

Road Curvature

- Collect data on the presence of **horizontal curves** and their **radii**.
- **Transition curves** are not considered.

Data can be obtained from existing road inventory databases and analyzed satellite images to identify approximate radii of horizontal curves. For more precise measurements, CAD data, GIS mapping, or laser rangefinders in the field can be used to measure the radii and lengths of horizontal curves. Transition curves are not considered when collecting data.

Nodes

- Data include the **locations of node ramps** and the **distances between acceleration and deceleration lanes**.

Data can initially be obtained from CAD/GIS road inventory databases. Analyses of aerial or satellite images can also provide information on the presence of nodes. For precise data, on-site GPS or laser mapping can be used to measure the distances between acceleration and deceleration lanes.

Conflicts Between Vulnerable Users and Motorized Traffic

- Collect data on the presence and location of **non-motorized traffic flows** (pedestrians, cyclists, etc.).

Assessments of potential conflict zones between vulnerable users and motorized traffic can be obtained from existing traffic studies and technical reports, as well as from satellite images. For a more detailed insight, field surveys can be conducted. Non-motorized traffic may be present only in rest or parking areas, so collecting data in other areas is not necessary.

Traffic Management Centers

- Collect data on **ITS-supported mechanisms** for providing real-time information to drivers about traffic accidents.

3.1.4.2.2 Primary Roads

Significant data that need to be collected for the EC NWA proactive approach on primary roads include:

Lane Widths

- Calculate the **average lane width** for each direction of travel.
- Compute the **average lane width** overall.
- **Hard shoulders** and **merging lanes at intersections** are not considered.

Initial data can be obtained from existing road inventory databases, CAD/GIS databases, and satellite images. For more precise measurements, laser distance meters or precise GPS tools can be used.

Lateral Obstacles and Objects

- Required data: **width of the roadside area** and **type of lateral obstacle and object**.
- Segments should be changed when there is a change in the width of the roadside area or the type of lateral obstacle.

Initial data can be obtained from CAD/GIS databases and satellite images. For a more detailed evaluation, field surveys are recommended.

Road Curvature

- Record the **radius of all horizontal curves**.
- Data on the **speed limit** for the horizontal curve with the smallest radius are required.

Data can be obtained from existing road inventory databases and satellite images. For more precise measurements, CAD/GIS mapping or laser distance meters are used.

Density of Road Access Points

- Density is calculated as the **number of road access points per kilometer**.

Data can be obtained from existing road databases and aerial or satellite images.

Intersections

- Determine the **type and length** of each intersection.
- Consider different types of intersections, with typical dimensions for each.

Data can be obtained from CAD/GIS databases and aerial or satellite images. For more precise measurements, GPS or laser mapping techniques are used.

Conflicts Between Vulnerable Users and Motorized Traffic

- Required data include **pedestrian crossings**, facilities for **pedestrians and cyclists**, and **speed limits**.
- Additional data are needed if there are **at-grade intersections** with lower-category roads.

Assessments of potential conflict zones between vulnerable users and motorized traffic can be obtained from existing traffic studies and technical reports, as well as from satellite images. For a more detailed insight, field surveys need to be conducted.

Type and Width of Shoulders

- Measure the **total width** and **type of shoulder** (paved/unpaved).
- For shoulders of different types, calculate a **length-weighted average**.

Data can be obtained from existing road inventory databases and aerial or satellite images.

Passing Lanes

- This parameter is collected for **two-lane roads without a physical median**.

Data can be obtained from existing road management databases and aerial or satellite images.

Horizontal and Vertical Signage

- Assess the **presence**, **quality**, and **condition** of horizontal and vertical traffic signage.

Initial assessments can be made using existing road management databases. For a more detailed insight, field surveys need to be conducted.

3.1.5 Germany

Currently, Germany does not employ any proactive NWRSA methods. To comply with the EU Directive 2019/1936, a new combined reactive-proactive method was developed by Schüller. Niestegge and Butz (2021) in a project funded by the German Federal Highway Research Institute (BASt):

Reactive and proactive parts of the method each yield a number of points and based on that number, the overall evaluation of the road segment is determined in one of 5 levels of priority.

Focussing on the proactive part, there are eight categories, each of which can receive an evaluation at three levels (red, yellow, green). The categories are:

- Obstacle free roadside
- Horizontal design
- Vertical design
- Sight distances
- Cross sections
- Intersections
- Quality of the road surface
- Facilities for pedestrians and cyclists (only on links not in intersections).

Each of the three levels has defined design parameters, which have to be matched to achieve the level rating. Figure 3.24 gives an example of the levels for the category “Cross sections”.

	Road with < 6 m on rural roads OR Motorway without side strops or with side strips< 2,50 m
	Average lane width < 3,35 m OR Lane width > 3,75 on two-lane rural roads
	All other cross-sections

Figure 3.24. Example of the level classification for the category "Cross section" in the planned German proactive method.

The levels in the individual categories are assigned different point values to differentiate between the different importance of the categories. For example, in the category “Obstacles in the road side” red is given 5 points, yellow 3 and green 0-1 while in the category “Quality of the road surface” the points are 3,1,0. The final point score for the proactive part is based on the highest mark between all categories. (Schüller, Niestegge & Butz 2021).

3.1.6 Poland

In Poland, on May 28, 2024, the Regulation on the Assessment of Accident Risks and Accident Severity and Road Safety Categories came into force (Polish regulation by the Minister for Infrastructure). The Polish method is based on the “*Network Wide Road Safety Assessment Methodology and Implementation Handbook”* (EU, 2023).

The regulation specifies:

1) the method and manner of conducting the risk assessment referred to in Article 24ma (1) of the Law of March 21, 1985, on public roads, from now on referred to as “risk assessment”,
2) the method of submitting the risk assessment report to the minister in charge of transportation,
3) the content and presentation of the results of the risk assessment in the risk assessment report,
4) categories of road safety.

Risk assessment shall be carried out separately for:

1) motorways and expressways or sections thereof;
2) other roads or sections thereof:
   a) with two main carriageways,
   b) with one main carriageway.

The proactive method is based on analysing the technical parameters of the road and its surroundings. Based on the parameters, each road segment is assigned to one of the safety classes: 1) safe; 2) moderately safe; 3) unsafe. The possibility of no evaluation has also been introduced.

A proactive risk assessment for motorways and express-ways is carried out by subdividing the sections, taking into account the following parameters: (1) urban and suburban sections; (2) traffic volume; (3) number of lanes; (4) speed limit; (5) terrain; (6) recommended segment lengths. For the remaining roads, the segmentation is carried out taking into account the following parameters: (1) traffic volume, (2) number of lanes, (3) speed limit, (4) terrain, and (5) recommended segment lengths. A detailed description of how the road network is divided into sections is provided in the regulation.

For each segment, the impact of the following parameters of the road and its surroundings on the risk of road accidents is assessed:

1 for motorways and express-ways:
   a. width of lanes,
   b. road surroundings,
   c. road layout in plan,
   d. distances between junctions,
   e. conflict points with pedestrian and bicycle traffic,
   f. functioning of the traffic management system or intelligent transport systems.
2 for other roads:
   a. width of lanes,
   b. road surroundings,

c. road layout in the plan,
d. the density of exits,
e. parameters of intersections,
f. conflict points with pedestrian and bicycle traffic,
g. width and type of shoulders,
h. presence of overtaking lanes,
i. vertical and horizontal markings.

In order to facilitate the work, a spreadsheet was developed to estimate the risk in each section.

3.1.7 Sweden

The description below is based on Lundberg & Ekman (2022), Ekman & Lundberg (2023) and Lundberg & Ekman (2024).

The Swedish Transport Administration (STA) assesses all roads with a traffic flow above 2000 AADT with a proactive approach. The aim of the assessment is to illuminate whether intersections or links are in line with the Vision Zero safety philosophy of Sweden. The proactive approach with a few but utterly important parameters for traffic safety has been used for about 10 years. The assessment uses data from the National Road Database and is based on the following parameters:

- posted speed limit,
- the quality of the roadside area
- the presence of a middle-barrier.

A large share of the fatalities on rural undivided roads are head-on collisions, even at rather low flow. Since speed has an impact both on the likelihood for a collision and the consequence of the accident. it is an important parameter in the assessment. While peed is not of primarily concern on motorways, it is an important parameter when classifying rural, undivided roads. Without speed as a parameter on rural undivided roads, almost all roads would receive the same classification.

The assessment results are according to the following classification:

- Green – Good level of safety
- Yellow – Acceptable level of safety
- Red – Low level of safety

The safety level of the road infrastructure is assessed for both protected (motorised vehicles) and unprotected road users (pedestrians and bicyclists) and there is a model for links and intersections / crossing points. The four models are for:

- motor vehicles on links
- motor vehicles at intersections
- pedestrians and bicyclists on rural links
- pedestrians and bicyclists crossing the street

Link model for motor vehicles

When dividing the road into segments, there must be a difference in a parameter critical for safety ranking. According to the experience of the STA, a homogenous segment can be longer than 2-5 km, which is very common in Sweden.

The rural link model considers the posted speed limit, the quality of the side area and the presence of a middle-barrier. In general, roads with a middle-barrier and safe side areas are considered safe at all legal speed limits. They have the highest class and are green.

If there is no middle-barrier the speed limit needs to be below 90 km/h and supported by speed cameras, and the side area needs to be good in order to reach the “green” standard. Undivided two-lane roads with speeds of 80 km/hand more have the lowest class and are red.

The example in Figure 3.25. shows how a road link is assessed depending on if there is middle separation, or a grooved centre line, and how the side area looks like. To be noted that it is a general assessment of a link – along it may be several parts with different class, both higher and lower.

Road type/ speed limit	Very good	Good	Fair	Low
Two-lane road 		**Median barrier** Centre line rumble strips and automatic speed sureviellance using cameras **Roadside zone** Principally side barriers or a 5-metre safety zone	**Median barrier** Centre line rumble strips when AADT over 2000 **Roadside zone** Principally side barriers or a 4 - metre safety zone	

Figure 3.25. Example of classification of a link for motor vehicles (Lundberg & Ekman, 2024).

Motor vehicles at intersections

The assessment covers intersections withe the primary road over 2000 AADT and secondary road over 100 AADT. Motorway interchanges are conflict free and are therefore considered safe. Roundabouts provide interactions at low speed and are always of a very good class.

Distinction is made between three- versus four-legged intersections. The posted speed at the intersection together with the likelihood for speeding determines the safety level. The likelihood of speeding is distinguished in three levels. If there is a physical speed reduction countermeasure or a safety camera, it is assumed that the speed limit is kept. If the speed limit is local the speed compliance is generally low. Local is defined as a short stretch (less than 400 meters) with a lower speed limit. In between there are the “normal” situations with a constant speed limit and no speed reducing countermeasures. Three- and four-way intersections with a speed limit above 80 km/h are always low class

The classification of the intersections is based on the type of the intersection and the posted speed limits and has been validated with accident statistics. For an example, see Figure 3.26.

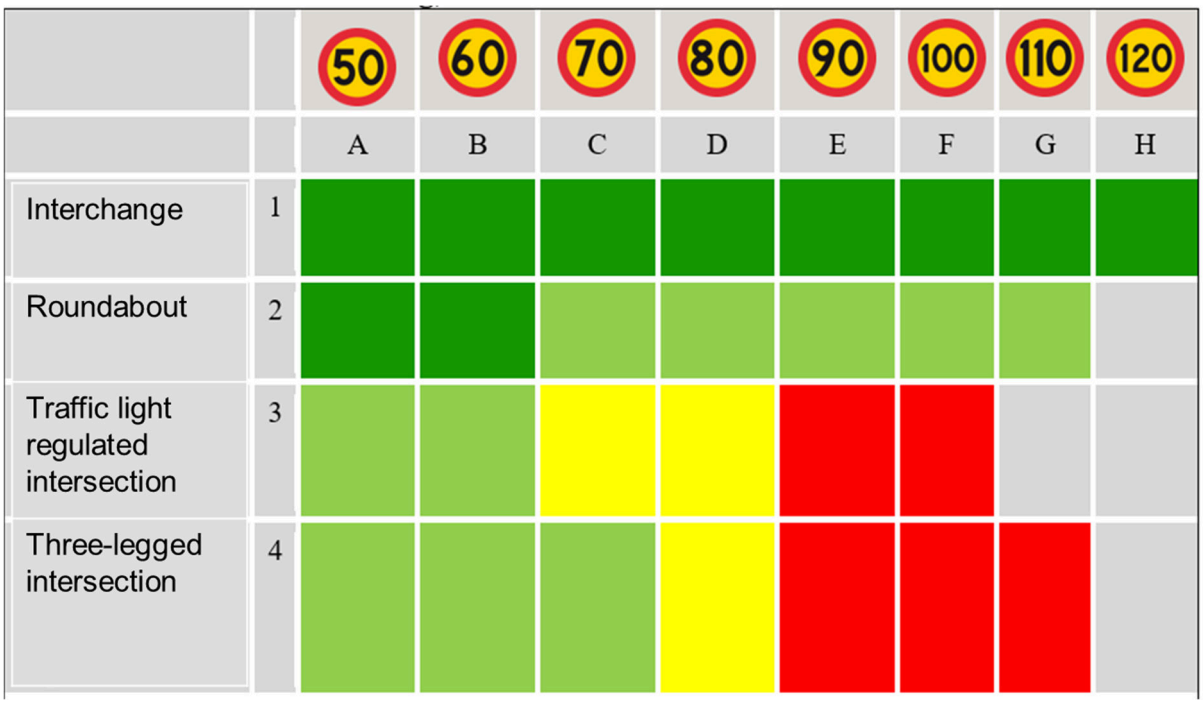


Figure 3.26. Classification of intersections for motor vehicles (Lundberg & Ekman, 2024).

Link model for pedestrians and bicyclists in rural areas

The model is intended for roads in rural areas. It is primarily sensitive for the protection against being hit by a motor vehicle. If there is a separated bicycle path it is considered safe. If the pedestrians and bicyclists are mixed with car-traffic, the level of safety is determined by three factors:

- Available space in the cross-section for pedestrians or bicyclists
- Speed limit on the road
- Traffic volume.

If the speed limit is above 80 km/h the link is always classified as “red”. If the road is narrow and there is no space for pedestrians or bicyclist and the ADDT is above 1500 it is classified as “red” if the speed limit is above 40 km/h.

Crossings for pedestrians and bicyclists

Passages via a bridge or a tunnel are considered safe. For other crossings where the pedestrians or bicyclists have to interact with cars, the safety is determined by the presence of speed reducing countermeasures. The effect of the speed reducing countermeasure determines the level of safety:

- “Green” – 85 percentile of car speed below 30 km/h
- “Yellow” – 85 percentile of car speed below 40 km/h
- “Red” – 85 percentile of car speed above 40 km/h

Results

The results are available on a publicly accessible map highlighting hazardous locations for car-drivers, pedestrians and bicyclists respectively. It is a good tool to prioritise traffic safety countermeasures and Investments. It is also used as part of the Swedish safety performance indicators that are used in the plans for reaching the Swedish traffic safety goals for 2030.

Maintaining the data

With time, several parameters can change and even minor changes can alter the classification. For not having to do the classification all over again necessisates a system that keeps track of any parameter changes. It is vital that the tool is updated regularly. The link models for cars are manually updated annually with support from a map with data on changes during the last year that might influence the classification. It means that only the sections that have changed since last year have to be reassessed. For the other three models, all classification is derived automatically from the national road-database. It means that the classification is always up to date.

3.2 Reactive Methods Based on Accident Data

3.2.1 Best Practice in Network Safety Management

The State-of-the-art approaches for Network Safety Management (NSM) the best currently known method from a theoretical point of view. It presumes that all relevant data about accidents, traffic volume, road design, traffic control and surrounding environment are available, have sufficient quality, unambiguously located on the road network and interoperable with each other (Elvik, 2007). The state-of-the-art approach also requires that there are comprehensive resources with regard to money, time, personnel and professional expertise to implement it. However, this is rarely the case, hence the second-best approach is the best practice approach which is constrained to limited data regarding quantity and quality. It is better to use best practice approaches rather than refrain from doing anything just because the demand for carrying out the State-of-the-art method cannot be satisfied (Sorensen & Elvik, 2007).

Sorensen and Elvik (2007) identified the following four criteria for the best approach to identify hazardous road sections from a theoretical point of view:

- It should control for **random fluctuations** in the number of accidents by relying the expected number of accidents and not the recorded number of accidents.
- It should control for **systematic variation**, hence account for as many as possible of the factors relating to road design, traffic control, traffic volume, known to influence road safety by use of accident prediction models.
- It should control for **local risk factors**; it should identify sections at which local risk factors related to road design, and traffic control make a substantial contribution to the higher expected number of accidents than the 'normal' expected number for similar sections.
- **Severity** should be taken into consideration in a systematic way, if road safety policy seeks to prevent the most severe accidents.

Elvik (2007) emphasises the absolute importance of the employment of the Empirical Bayes method, since model-based methods take systematic variation and partially random fluctuations into consideration. Hazardous road sections should be identified in terms of the **expected number of accidents**, not the recorded number of accidents. That is because an abnormally high recorded number of accidents could be largely the result of random variation and does not necessarily mean that a section has a high expected number of accidents. Hence, the best way of identifying hazardous road sections is that for each type of section to estimate the 'normal', predicted number of accidents and then combine this with the accident record for the section in question, yielding an estimate of the site-specific expected number of accidents. A road section would be considered hazardous if the site-specific expected number of accidents was (substantially) higher than the 'normal', predicted number of accidents for similar sections (Sorensen & Elvik, 2007).

The expected number of accidents is estimated by using the empirical Bayes method. According to the empirical Bayes method, the expected number of accidents on a specific site is estimated by weighing the registered number of accidents at the site and the predicted number of accidents for all similar sites estimated by accident prediction models. The method is illustrated in Figure 3.27 represented by the following formula (Sorensen & Elvik, 2007):

$$E(N,R) = w*N+(1-w)*R \qquad (14)$$

where:
E(N,R) = The expected number of accidents at a specific site
N = the expected number of accidents estimated by accident model
R = the registered number of accidents at the site

w (weight) = 1/(1+Var(N)/N)

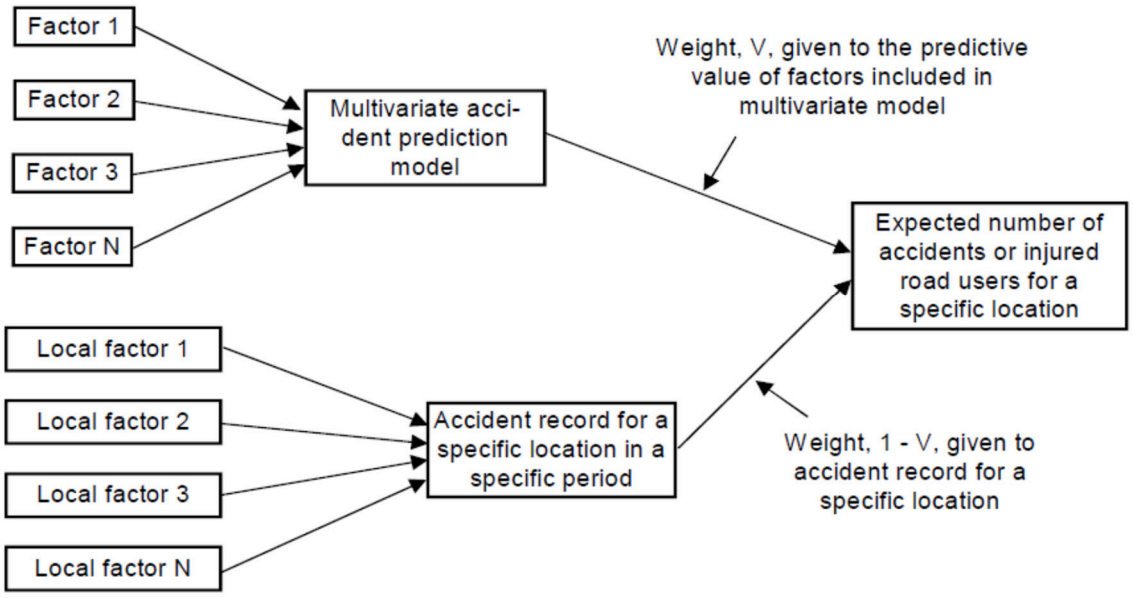


Figure 3.27. Illustration of the empirical Bayes mathod, where information about the predicted, "normal" and registered number of accidents is combined for estimation of the expected number of accid ents for a specific location (Sorensen & Elvik, 2007).

The scope of the safety analysis of road networks is commonly the entire road network of a jurisdiction (state or region). However, it also may be done by route. NSM comprises several hundreds or even thousands of kilometres of road. Due to design parameters and traffic volumes there will be a great variation among the roads submitted to analysis.

The stages of the Network Safety Management process based on accident data is shown in Figure 3.28.

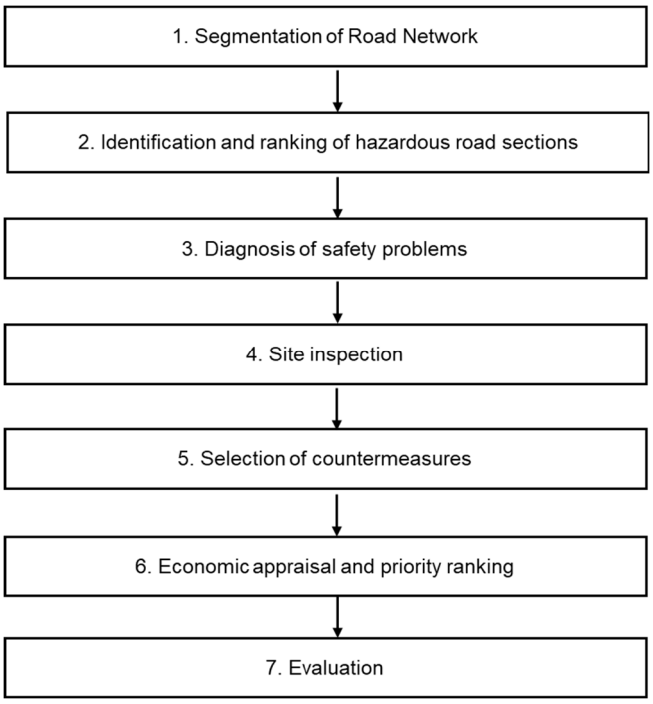


Figure 3.28. Stages of the accident-based Network Safety Management process.

3.2.1.1 Stage 1 – Segmentation of Road Network

In most countries, roads are classified and numbered with numbered sections. Each of these sections are, ideally, homogeneous with respect to design, traffic volume, but they might differ among themselves with respect to length and factors influencing the accident outcome. For the purpose of NSM, the functional classification of the roads is of importance. Motorways, rural main roads, rural secondary roads, urban main roads, urban secondary roads are treated as separate categories. The sections (study units) are typically defined based on the speed limits. The network can then be split/classified into different further subset, such as single carriageway sections, dual carriageway sections and motorway sections (TII, 2017).

Suitable sets of study units of the road network should be defined. A choice must be made in respect to homogeneity of each unit, i.e., traffic and road design parameters should be the same throughout the section. Relevant traffic and road design parameters are (Sorensen, 2006):

- Road category, type and function,
- Cross section – number of lanes, lane width, shoulder, presence of side strips or bicycle lane,
- Presence of oncoming traffic,
- Presence and type of intersections,
- Road alignment horizontally and vertically,
- Speed limit,
- Roadside buildings,
- Traffic type and AADT.

The selection of parameters depends on data availability, which varies from country to country. To collect new data may be necessary, but it could be resource demanding.

The criterion of homogeneity of each unit would sometimes request to use rather short sections as elementary units. Using very short units (below 50 m) has the disadvantage that it reduces the variation in accidents, meaning that almost all units will have 0 accidents and a few will have 1 accident. The shortest length of an elementary unit should be not less than the braking distance at the prevailing speed level of the section, since braking distance is often present in accident contributory factors. On the other hand, using too long sections as elementary units would necessitate to smooth the data pertaining to shorter subsections, which would imply loss of information. Consequently, the choice of the length of the elementary unit for the analysis must be a compromise. Sorensen (2007), in his best practice review of NSM of a number of countries, recommends that the road system should be divided in homogenous road sections with varying length between 2 and 10 kilometres. It might be impossible to divide the road network into homogenous sections that all have a length between 2 and 10 kilometres, hence a small percentage of the sections will be shorter than 2 kilometres.

Motorways typically are homogenous on longer sections than non-motorways, hence the selection length of study units of motorways can beneficially be longer.

To rationalize division of the road network, work can start with first making the division based on braking points, such as intersections, villages, or other salient “points”, thereafter it is controlled if the defined road sections are homogenous.

The selected units of interest should be clearly defined and numbered. This allows theoretical probability distributions for accidents to be fitted to the empirical distribution of recorded accidents at these units and allows statistical criteria of deviancy to be formulated (Sorensen and Elvik, 2007).

Geo-located accident data for the road network during the latest 3-5 years should be obtained from the national accident database. Only accidents with fatality and injury should be considered since damage only accidents are unreliable due to heavy underreporting.

3.2.1.2 Stage 2 – Identification and ranking of hazardous road sections

3.2.1.2.1 Linking accidents to the individual road sections

Accidents should be allocated to each section. Accident location is critical for linking an accident to a specific road section. Various ways can be used to locate accidents on the road network, such as GPS location, road code, road section numbering, and road name and address. If the information regarding the location of an accident is not adequate to allocate it to the correct part of the road, it is recommended that the available information in the accident record be analysed to try to allocate it.

3.2.1.2.2 Identification and ranking of hazardous road sections

Identification of hazardous road sections should be made by model based methods. Model based methods are the best to make reliable identification of sites with local risk factors related to road design and traffic control, because systematic variation and partially random fluctuation are taken into consideration. The safety potential can be calculated as the absolute difference between the registered and the general expected or - if not accident models are used - average number of accidents, and thus indicates the obtainable reduction of accidents (Sorensen and Elvik, 2007).

The road network is to be divided into different categories and for each category an accident prediction model has to be developed. The basic form of

$$E(\lambda) = \alpha \cdot Q^{\beta} \cdot e^{\sum \lambda_i \cdot x_i}$$

accident prediction models is a multivariate regression model (Sorensen and Elvik, 2007):

(15)

where:
E(λ): The estimated expected number of accidents
Q: Traffic volume
x_i: Variables denoting risk factors
α,β,λ_i: regression coefficients

Some of the independent variables are discrete variables (such as road standard, road layout, speed limit, and road environment), while regression variables are continuous variables (like traffic volume).

If there are no accident models developed for the road types in question, the second best method is to calculate the "normal", i.e. the average number of accidents of various severity for each type of road with similar characteristics.

Accident severity should be integrated into the analysis by weighing accidents with different severity. The objective of weighting the accidents is to identify those accidents that make the most significant contribution to Injury Severity Density (ISD). ISD is a construct of the number of accidents at a road section, weighted by the societal costs of the injury accidents by severity degree. Accidents with fatalities and severe injuries are weighted more than accidents with slight injuries. The weight should be based on the socioeconomic cost per accident by severity type. Sorensen (2007), in his best practice review of NSM of several countries, found a significant variation in how accidents with different severity categories are weighted relative to each other in the different reviewed countries. In England, accidents with serious injuries were weighted ten times more than those with slight injuries, and fatal accidents were weighted 90 times more than those with slight injuries (O´Flaherty, 1997).

If these costs are not yet established in the country in question, efforts should be made to estimate them for future use!

For pedagogical reasons, we use here the following Injury Severity Density weights based on the English figures (O´Flaherty, et al., 1997):

$$ISD = 90*FA+10*SER+SLI \quad (16)$$

where:
FA = Fatal accident
SER = Accident with severe injury as highest severity outcome
SLI = Accident with only slight injury

The output of linking accidents to the individual road sections is a list of all road sections (including their length and attributes) completed with numbers of fatal, severe injury and slight injury accidents, as well as ISD and ISD/km.

3.2.1.2.3 Assessing the "normal" value of ISD/km for each type of section

To estimate the "normal" value of ISD/km for a specific type of section, the mean value of ISD/km of the section type in question can be used. If there was no systematic variation among sections, this mean value would also be the ISD/km value that we would predict to occur at each section of the given type.

3.2.1.2.4 Analysis of variation of ISD/km

The distribution of ISD/km should be analysed with respect to variance. The objective of the analysis is to determine the amount of systematic variation in the ISD/km. If there is little systematic variation, there is little hope to be able to point out hazardous locations. On the other hand, if there is substantial systematic variation, it implies the existence of units with deviating level of hazard.

Since the ISD value is a construct of accident numbers at a given section, it is assumed to be Poisson distributed. In order to ascertain systematic variation in the ISD value between sections, the actual distribution of ISD over all sections can be compared with a Poisson distribution with the same mean value of the ISD value per section. In the Poisson distribution, the variance is equal to the mean, hence, the size of random variance in the ISD equals the expected value of ISD. The total variation in the ISD values in a sample of study units can be decomposed into random variation and systematic variation:

$$\text{Total variance} = \text{Random variance} + \text{Systematic variance} \qquad (17)$$

Thus, there is systematic variation in the ISD/km value whenever the variance exceeds the overall mean of ISD/km values (m). This is usually referred to as over-dispersion. One way to identify over-dispersion (and thereby systematic variation) is to look at the ratio:

$$\alpha = m \,/\, Var(x) \qquad (18)$$

If α is less than 1, we have an indication that there is systematic variation in the data. The smaller α gets, the more significant is the systematic variation. In those cases, we have reason to assume that a high ISD/km value is (partly) an indication of true hazardousness not only the result of random variation of ISD/km.

The proportion of variance, attributable to systematic variation, can be estimated as

$$S = (Var(x) - m) \,/\, Var(x) \qquad (19)$$

3.2.1.2.5 Estimating the expected value of ISD/km for each section

The best estimate of the expected value of ISD/km for a studied unit is obtained by combining two sources of information:

a) the ISD/km value based on recorded accidents (R) for a given section,
b) the "normal" value of ISD/km (N) (i.e. the mean value) for the same type of sections.

The best estimate of the expected value of ISD/km for a given section is then:

$$E(N,R) = w*N+(1-w)*R \qquad (20)$$

$$\text{where } w = 1/(1+Var(N)/N) \qquad (21)$$

The parameter w thus determines the weight given to the "normal" value of ISD/km for the type of sections in question, when combining it with the ISD/km value of a particular section based on recorded accidents, to estimate the expected value of ISD/km for that particular section.

Intuitively, we understand that:

- If there is much systematic variation in the data, the mean value (N) is not very informative concerning the expected value of ISD/km for a specific section, whereas,
- If there is much random variation in the data, the specific ISD/km value based on recorded accidents at a section (R) is not very informative compared to the larger data source of all sections (N).

The output of this activity is an added column to the list of all road sections with the expected values of ISD/km for each section.

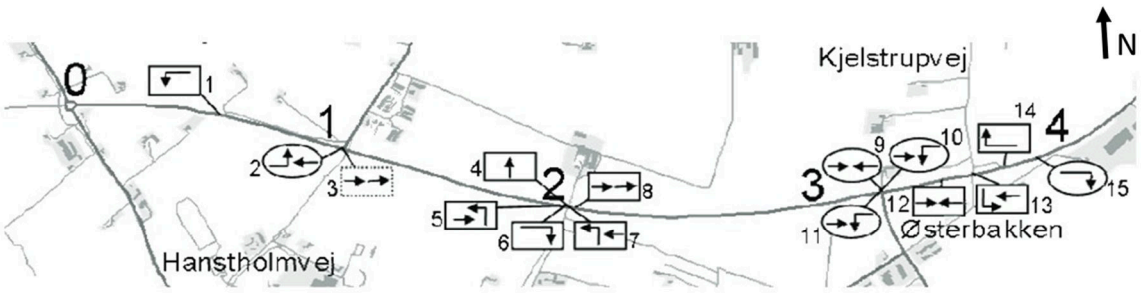
3.2.1.2.6 Identifying hazardous sections

The difference between the section-specific expected value of ISD/km (**E**) and the "normal" value of ISD/km (**N**) for similar sites **E-N** can be interpreted as an effect of local risk factors for the section, causing it to have a higher expected number of accidents than similar sections. This tells us which sections are most hazardous within their type.

The output from this step is a list of sections that are the strongest candidates for further investigation. An identified section does not necessarily imply that it has an existing safety concern. Identified sections are candidates for detailed analyses to identify appropriate countermeasures and assess whether those countermeasures are economically justified. Rather, the identification of a section indicates that it experiences a sufficiently high value of ISD/km that there may be an opportunity for a cost-effective safety improvement at that section. Identified sections are candidates for detailed analyses to identify appropriate countermeasures, and assessment whether those countermeasures are economically justified. Conducting detailed engineering studies of candidate sections for intervention is an expensive process, hence, only a limited set of sections can be investigated during a given year.

3.2.1.3 Stage 3 – Diagnosis of safety problems

For each specific section identified as candidates for further investigation, an extended collision diagram should be created. An extended collision diagram combines a traditional collision diagram and information from general accident data, such as accident severity, time (of day, week day, month and year), and circumstances (weather, light, road condition). For an example see Figure 3.29.



No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year	03	03	03	02	03	04	04	04	02	02	04	02	03	03	03
Month	5	9	10	10	9	9	10	10	1	8	5	6	12	10	5
Day	7	1	5	6	2	1	3	1	4	5	5	7	6	6.	6
Hour	6	12	22	02	05	23	11	22	18	10	9	4	11	01	05
Type	012	410	198	031	660	032	650	140	241	410	410	241	660	011	023
Weather	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Rain	Rain	Rain	Dry	Dry	Rain	Dry
Road	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Wet	Wet	Wet	Dry	Wet	Wet	Wet
Light	L	L	D	D	D	D	L	D	D	L	L	L	L	L	D
Alcohol	Yes	Yes	Yes	Yes	-	Yes	-	-	-	-	-	-	-	-	-

Figure 3.29. An example of an extended collision diagram for a 4 km long section with 15 accidents. The large numbers indicate km. Rectangles accidents with severe injuries, ellipses indicate fatality accidents. L = Light, D = Darkness. (Sorensen, 2007).

The extended collision diagram in Figure 3.29 shows that driving intoxicated may have contributed to most of the accidents on the western part of the section. Most accidents in the middle section occurred in September and October, when darkness may have contributed to these accidents. Wet road conditions might have contributed to five accidents in the eastern part of the section.

Each specific section should be reviewed by a suitably qualified review team to ensure that all data used in identifying the section during the initial desktop review is correct. The review includes an examination of the collisions on the section to help establish if any particular collision pattern is present. Collision patterns may help establish any deficiencies within the road environment that may be counteracted by engineering measures. The review should provide a preliminary diagnosis for the specific section, identifying safety issues related to road deign and traffic engineering, considering human factors. When the review has been undertaken, the review team may decide if a site visit is required (TII, 2017a).

The output from this activity is a list of the most hazardous sections under examination, their extended collision diagrams and preliminary initial diagnoses.

In addition, a broader macro view (route scale – typically 100 km) of the road network can be compiled from the details found within individual sections (TII, 2017a). Displaying the spatial distributions of particular collision types can help highlight any local concentrations within the network that may have been missed if patterns were only looked for at the micro scale. A typical output of this macro analysis is presented in Figure 3.30.

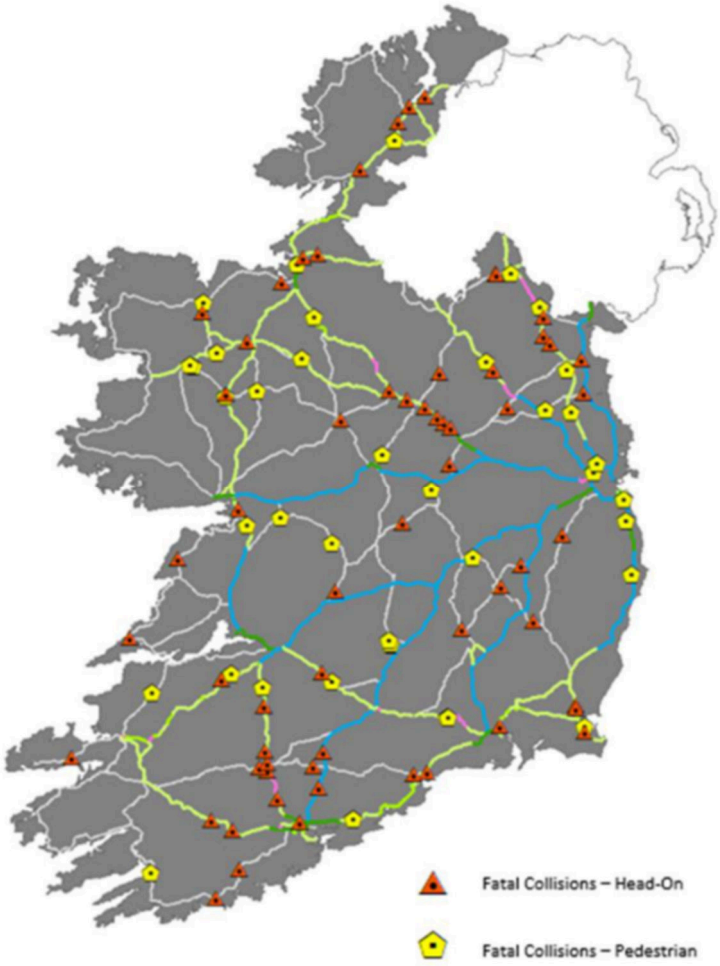


Figure 3.30. Spatial distribution of fatal head-on and fatal pedestrian collisions on the Irish national road network 2012-2016 (TII, 2017).

The output from this activity is a map of the studied road network highlighting with yellow colour all road sections having significantly higher expected values of ISD/km than the mean value of ISD/km of all sections of the same type. The short-listed most hazardous road sections whose hazardousness could be verified by the diagnosis of safety problems should be red coloured.

3.2.1.4 Stage 4 – Site inspection

The following material should be taken for the site visit:

- The extended collision diagram with all relevant characteristics of the section (geometrics, traffic devices, etc.) and the list of accidents, annotated with season, time, etc., and any prevalent accident type.
- List of preliminary initial diagnoses.
- List of questions about the section that could not be answered in the office.
- List of potential countermeasures to be considered in the field.

The site inspection should concern not only the possible contributory factors to the registered accidents but also general problems that, by chance, have not been a contributory factor to the recorded accidents. It should be formalised by using a checklist.

The road inspection should be conducted by two persons; a traffic safety expert and an employee of the operating department of the road authority. The inspection should be carried out by car, driving along each direction and from relevant side roads. A stop should be made at the sites posing problems to examine the locations more closely.

After the site inspection, a final diagnosis should be made for the specific section, identifying safety issues related to road design and traffic engineering.

The output after the site visits is a short list of the most hazardous road sections whose hazardousness could be verified, accompanied by description of the safety problems for each section.

3.2.1.5 Stage 5 – Selection of countermeasures

Following the site visit to each selected section, a proposal for countermeasures is developed for each section involving technical and budgetary considerations. For each safety concern identified for the section under the diagnosis step, a list of potential countermeasures is established. If more than one concern was identified for the section in question, more than one potential countermeasure list should be made.

If there is a clear accident pattern and evidence for identified risk factors contributing to this pattern on the section in question, the most effective treatment should be identified. Cost-effective countermeasures have been composed by PIARC (2003), Elvik, et al. (2009), and SafetyCube (2023) https://www.roadsafety-dss.eu/#/.

When thinking about appropriate countermeasures, the following issues should be considered:

- Cost-effectiveness. Low-cost measures should be prioritised. Some measures may be effective, but may be unnecessarily expensive.
- Long-lasting, i.e. the initial effect does not wear off as drivers get used to them.
- Will not increase unsafety (not causing other types of accidents, or other undesirable nuisances).
- Will its implementation need considerable publicity campaign or heavy police enforcement?
- Can the necessity of its implementation be explained to decision makers?

The output from countermeasure selection should be a list of proposed countermeasures for each of the hazardous sections.

3.2.1.6 Stage 6 – Economic appraisal and priority ranking

The proposed countermeasures should be subjected to a socio-economic assessment. For each hazardous road section, costs and benefits should be addressed considering accident severity.

The proposed countermeasures for each specific road section should be ranked using the safety effectiveness estimates, and a set of countermeasures should be identified that provide maximum safety benefits within the given budget constraints.

To assess the proposed countermeasures, the economic criteria “net benefits” can be used. The net benefit approach assesses countermeasures by their safety benefits minus construction costs and it yields the most desirable alternative with the highest net benefit:

$$Net\ Benefit = Benefits - Costs \qquad (22)$$

For a countermeasure to be economically justified by this criterion, its net benefits should be greater than zero. The net benefits approach allows to maximize the net benefits across all countermeasures and sections and to take budgetary constraints into consideration.

For each section with any countermeasure with negative benefits, the “do-nothing” alternative is considered more favourable.

The output from the economic analysis is a list of sections with the net benefit for each proposed countermeasure.

3.2.1.7 Stage 7 – Evaluation

The effects of the implemented measures should be subsequently evaluated. Evaluation should control for local changes in traffic volume, long term trends in accident development and regression-to-the-mean effects. The best way to do this is to employ a before-after study. An accident based evaluation of the safety effects of the implemented measures can be carried out when having access to at least three year of accident data during the after period.

To control for effects of extraneous variables, such as changes in traffic pattern, vehicle mix, and long-term safety trends, the evaluation study - besides the site in question - should include similar sites for control concerning area type, design factors and traffic volumes. The registered number of accidents at the study site is to be compared with “normal” control sites where no measures were implemented. This approach assumes that the annual average number of accidents (during the after period of 3-5 years) recorded at the study site provides an estimate of the expected number of accidents at that site. The annual average number of accidents (during the same 3-5 years period) recorded at the control sites provides an estimate of the expected number of accidents at the study site during the after period given that no measures were implemented.

3.2.2 Accident modelling: an overview

3.2.2.1 Introduction

First, a note on terminology is needed to clarify some terms used in this ection. The term "accident prediction models" (APMs), which is often used interchangeably with "safety performance functions" (SPFs), typically refers to multivariate models fitted to accident data. These models estimate the statistical relationship between the number of accidents and various factors believed to be related to their occurrence. The term "predictive" can be somewhat misleading; "explanatory" might be a more accurate term. Prediction implies forecasting future events, while accident prediction models are based on historical data and thus can only describe and potentially explain past occurrences (Elvik, 2007). Other models, which will not be treated here, aim to predict accident severities given (i) a non-zero probability of an accident •, and (ii) exogenous conditions ••.

The choice of explanatory variables that potentially affect the safety performance of a site should be grounded on theory (Zhankun, et al., 2024). For example, a theoretical basis for selecting explanatory variables might involve using a causal model •. In practice, however, a theoretical foundation for identifying explanatory variables is rarely stated explicitly •••••. Instead, the choice of variables often relies primarily on data availability. While it is evident that any analysis is constrained by the available data, the selection of explanatory variables should ideally not be based solely on this factor. Instead, explanatory variables should:

- Reflect findings from previous studies that indicate a major influence on the number of accidents;
- Be measurable in a valid and reliable manner;
- Avoid being endogenous, meaning they should not depend on other explanatory variables included in the model or on the dependent variable.

Historically, two statistical methods have been used to develop accident prediction models: conventional linear regression and generalized linear regression (GLM) (•. Recently, however, generalized linear regression has become the predominant method for developing collision prediction models. Research by Jovanis and Chang (1986), Hauer et al. (1988), and Miaou and Lum (1993) have highlighted the limitations of conventional linear regression for modeling discrete, non-negative, and rare events such as traffic accidents•••. These studies demonstrated that the standard conditions for conventional linear regression - normal distribution of model errors, constant error variance, and a linear relationship between the response and explanatory variables - do not hold when modeling traffic accident occurrences.

3.2.2.2 The GLM approach

The GLM approach has the advantage of overcoming the limitations of conventional linear regression in accident frequency modelling. In particular, it allows also a Poisson or Negative Binomial error structure, distributions that are more pertinent to accident frequency modelling, to be assumed. The GLIM approach is described in the following •••.

Suppose Yi is a random variable that describes the number of crashes at a given location i in a given period of time. Then Yi is assumed to possess Poisson distribution and can be expressed as:

$$P(Y_i = y_i) = \frac{\lambda_i^{\,y_i} \cdot e^{-\lambda_i}}{y_i!} \qquad (23)$$

where $P(Y_i=y_i)$ is the probability of occurring *y* crashes on the roadway section *i* in a given period of time and l_i is the expected number of crashes on section *i (i.e. $E(y_i)$)*. In addition, the mean or expected value of Y_i is assumed to be equal to its variance. That is:

$$E(Y_i) = Var(Y_i) = \lambda_i \qquad (24)$$

where E(Yi) is the expected number of crashes on section i and Var(Yi) is the variance of observed number of crashes. For a given set of explanatory variables (highway geometrics, traffic and other data), λi can be estimated using the formulation:

$$\ln(\lambda_i) = \beta X_i \qquad (25)$$

where X is a vector of explanatory variables and β is a vector of parameters to be estimated.

However, in some cases, this method has limitations when applied to real world data due to the assumption of equal mean and variance. When the data are overdispersed or underdispersed (i.e. mean is note equal to the variance), the use of this method would overestimate or underestimate the parameters. Many previous studies have found that crash data tend to be overdispersed in many situations with the variance being significantly higher than the mean •. In such cases, any inferences made based on Poisson model estimations may lead to wrong conclusions. As a result of this, many researchers recommend using alternative methods in analysing crash data, especially when the data is overdispersed. One such method is to utilize a Negative Binomial (NB) distribution because it does not require the equal mean and variance assumption. In this method, the mean or expected value itself is assumed to be a random variable, which can be described by Negative Binomial distribution. In this case, l_i can be now written as:

$$\ln(\lambda_i) = \beta X_i + \varepsilon_i \qquad (26)$$

where εi is the unobservable error term with a gamma distribution. The variance of this distribution can be expressed as:

$$Var[Y_i] = \mu_i + k\mu_i^2 \qquad (27)$$

where μi is the expected number of crashes on section i and k is called the Negative Binomial dispersion parameter. The overdispersion occurs when the value of k is greater than 1 and when its value is zero, NB distribution reduces to Poisson distribution with which the variance is equal to the mean. The corresponding probability distribution under the NB assumption is given by:

$$P(Y_i = y_i) = \frac{\Gamma(y_i + 1/k)}{\Gamma(y_i+1)\Gamma(1/k)} \cdot \frac{(k\cdot\mu_i)^k}{(1+k\cdot\mu_i)^{(y_i+1/k)}} \qquad (28)$$

where Γ(.) is the gamma function. The Negative Binomial model can be estimated using a maximum likelihood method to obtain the model parameters or β values and the dispersion parameter *k*. This can be

carried out through maximization of the likelihood function L, where, N is the total number of sections:

$$L(y_i,\mu_i,\alpha)=\sum_{i=1}^{N}\left[y_i\cdot\log(\alpha\cdot\mu_i)-(y_i+1/\alpha)\log(1+\alpha\cdot\mu_i)+\log\left(\frac{\Gamma(y_i+1/\alpha)}{\Gamma(y_i+1)\Gamma(1/\alpha)}\right)\right] \quad (29)$$

The general form of the accident prediction model for road segments adopted is:

$$E(Y)=e^{a_0}\cdot L\cdot AADT^{a_1}\cdot e^{\sum_{j=1}^{m}b_j\cdot x_j} \quad (30)$$

where:
E(Y) = expected accident frequency (accidents/time period);
L = length of the segment under consideration (km);
AADT = Average Annual Daily Traffic (AADT) (veh/day);
x_j = Any of m- additional variables;
a_0, a_1, *and* b_j = model coefficients.

This model form was selected because it is generally accepted as the form that better describes the accident phenomenon ••Zhang, & Ivan, 2005).

In particular, it logically estimates zero accidents if one of the two exposure variables (AADT or L-in case of road segments) is equal to zero and it allows the non-linear relationship between traffic volume and accident frequency by means of a suitable calibration of the traffic volume coefficient.

In the case of road intersections, the length (L) is not a relevant variable, but the entering flows can be modelled separately for the conflicting traffic directions. In this case, the regression terms for the two flows must be estimated separately in the model.

3.2.2.3 Goodness of fit measures

Several measurements are usually used to assess the goodness-of-fit of the model and the significance of the model parameters •. These are the t-ratio for the model parameters, the scaled deviance (SD), and the Pearson $\chi 2$ statistics for the model overall. The SD, defined as the likelihood ratio test statistic, is estimated as twice the difference between the log-likelihoods of the studied model and the full or saturated model where the full model has as many parameters as the observations so that the model fits the data perfectly. Therefore, the full model, which possesses the maximum log-likelihood achievable under the given data, provides a baseline for assessing the goodness-of-fit of an intermediate model with specified parameters. McCullagh and Nelder **Error! Reference source not found.** showed that for negative binomial error structure the scaled deviance is as follows:

$$SD=2\sum_{i=1}^{n}\left[yi\ln\left(\frac{yi}{\hat{E}(yi)}\right)-(yi+k)\ln\left(\frac{yi+k}{\hat{E}(yi)+k}\right)\right] \quad (31)$$

where:
SD = scaled deviance;
y_i = observed number of accidents of the i[th] segment;

$\hat{E}(y_i)$ = predicted number of accidents of the i[th] segment;
k = negative binomial dispersion parameter;
n = number of the observations in the sample.

The Pearson χ^2 can be calculated by means of the following formula:

$$Pearson\ \chi^2 = \sum_{i=1}^{n} \frac{\left[y_i - \hat{E}(y_i)\right]^2}{Var(y_i)} \qquad (32)$$

where $Var(y_i)$ = variance of the i[th] segment.

In order to verify the goodness-of-fit of the model, these two measures must be compared with the value obtained from the χ^2 distribution with the model's degrees of freedom and for a given level of significance. The model can be considered significant, if both measurements are less than the χ^2 critical value.

The Akaike's Information Criterion (AIC) was also used as goodness of fit measure ••**Error! Reference source not found.**. The AIC value is calculated as follows:

$$AIC = -2 \cdot logL + 2 \cdot p \qquad (33)$$

where:
$logL$ = maximum log-likelihood of the fitted model;
p = number of parameters in the model.

The smaller the value of AIC, the better the model data fit. Therefore AIC can be used also to compare and rank different models calibrated on the same dataset.

Another measure of goodness of fit is R^2k. This measure was calculated as follows •**Error! Reference source not found.**:

$$R_k^2 = 1 - \frac{k_0}{k} \qquad (34)$$

where:
k_0 = the overdispersion parameter estimated in the negative binomial model with only a constant term;
k = the negative Binomial overdispersion parameter estimated in the full model.

R^2_k is simple to calculate, and it yields a value between 0 and 1. Since it is based explicitly on the overdispersion parameter, it is especially applicable in evaluating negative binomial models. The higher the R^2_k value, the better is the fit.

An adjusted R^2_k is a modification of R^2_k that adjusts for the number of explanatory terms in a model:

$$R_k^2 adj = 1 - (1 - R_k^2) \cdot \frac{(n-1)}{(n-p-1)} \qquad (35)$$

where:
n = total number of observations in the sample;
p = total number of the parameters in the model (not counting the

constant term).

A tool that can be adopted for the evaluation of the appropriateness of the model form chosen, is the cumulative residual analysis (•;••. The residual for each data observation of the sample is equal to the difference between the observed and estimated values of the dependent variable. A standardized residual for the i^{th} observation, e.g., road segment, (SR_i) is computed from the following equation:

$$SR_i = \frac{(y_i - \hat{y}_i)}{\sqrt{\hat{y}_i + k \cdot \hat{y}_i^2}} \qquad (36)$$

where:
y_i = observed number of accidents of the i^{th} segment;
$\hat{y}_i$ = estimated number of accidents of the i^{th} segment;
k = dispersion parameter

The cumulative standardized residual value for the j^{th} element is obtained as follow:

$$CSR_j = \sum_{i=1}^{j} SR_i \qquad (37)$$

for j = 1, ,…, m and with m equal to the total number of the observation.

Cumulative standardized residuals analysis is carried out by plotting CSR_i versus exposure values, computed as the product of AADT and the length for each homogeneous section. The more the points of the CSR curve stay close to the x-axis, avoiding significant increase or decrease of the shape, the closer the estimates are to the observations and the more limited the over/under-estimation phenomenon. Moreover, a CSR curve contained into the 2 standard deviation interval (e.g. 2s), indicates the appropriateness of the model form chosen •.

3.2.2.4 Empirical Bayes Estimation

Ultimately, a safety performance function provides an estimate of the expected number of accidents for a roadway element with a specific combination of characteristics. Typically, these characteristics include traffic volume and highway geometry. However, most safety performance functions do not account for all factors that contribute to systematic variations in accident counts. As a result, the estimates generated by a safety performance function represent average values for sites with a particular set of traits. Consequently, the expected number of accidents at a specific site will generally differ from the average value for other sites with similar general characteristics.

What is the best estimate of the long term expected number of accidents for a given roadway element, given the fact that some, but not all the factors affecting accident occurrence, are known? According to the empirical Bayesian method (Hauer, 1997), the best estimate of safety is obtained by combining two sources of information:

1. The accident record for a given site;
2. A safety performance function showing how and how much various factors affect accident occurrence.

As previously emphasized, safety performance functions are commonly calibrated using negative binomial regression in which a dispersion parameter that represents extra-Poisson variation is estimated. The negative binomial error structure is preferred to the conventional

normal distributed structure assumed in conventional regression modelling because crash data are non-negative counts. The Poisson distribution is a special case of the negative binomial but is only applicable when all entities with identical values of the independent variables can be assumed to have identical means, a near impossibility because of the practical difficulty of accounting for all effects in crash prediction models. Indeed, the size of the calibrated dispersion parameter is a measure of how well a model represents the data and can be thus used to compare competing models for the same data.

Actually, the primary use of the dispersion parameter is not in assessing goodness of fit but in empirical Bayes (EB) estimation (•, in which the posterior mean of an entity with a known crash history is estimated as a weighted average of the crash counts and an SPF prediction. The dispersion parameter is used to calculate the relative weights for each component and is such that the smaller the parameter, the better the model is and the greater the weight assigned to it relative to that assigned to the crash counts. Other types of models do not require the estimation of the dispersion parameters, but despite the effective accident frequency estimation, such analytical stochastic models cannot be easily transferred to different sites•.

To be more specific, let O be the observed number of accidents and E the normal, expected number of accidents estimated by a safety performance function. The best estimate (empirical Bayes estimate) EB of the expected number of accidents for a given site is given as follow:

$$EB = w \cdot E + (1 - w) \cdot O \tag{38}$$

The parameter (empirical Bayes calculation weight) *w* determines the weight given to the estimated normal number of accidents for similar sites when combining it with the observed number of accidents to estimate the expected number of accidents for a particular site. Usually, *w* is estimated as follow:

$$w = \frac{1}{1 + \frac{Var(E)}{E}} \tag{39}$$

where *Var(E)* is the variance of the expected number of accidents E estimated by a safety performance function and is given as:

$$Var(E) = E + k \cdot E^2 \tag{40}$$

where *k* is the value of the dispersion parameter characterizing the safety performance function and is estimated as the “shape parameter” of the negative binomial distribution adopted for calibration in the regression model.

These EB estimates are used in safety management applications in such application tools as the Highway Safety Manual • and SafetyAnalyst •, for which the two primary uses are:

- To estimate the safety of sites for network screening to prioritize them for safety investigation;
- The treatment evaluation to estimate the expected safety of a site had it not been treated.

It stands to reason, therefore, that the importance of precise estimation of the dispersion parameter should be established. This need is complicated by findings in a recent flurry of research papers that suggest that the dispersion parameter, contrary to earlier research, is not constant for a given data set but varies from site to site, depending on site characteristics such

as segment length. Therefore, the real question is: Does it matter that the dispersion parameter varies and, if so, does it matter how it varies? The question is especially topical since dispersion parameters in the Highway Safety Manual (HSM) and SafetyAnalyst either are constant or have a very simple form.

The varying form in the HSM and SafetyAnalyst is such that the dispersion parameter for certain classes of road segments is inversely proportional to segment length, as first suggested by Hauer • who argued logically that shorter segments have a higher accident frequency variance and consequently should have a higher dispersion parameter than longer segments, and that this variation should influence the long-term estimate of a segment's safety. Since this argument does not apply to intersection models, it is not surprising that dispersion parameters for these SPFs are constant in the HSM and Safety Analyst. However, others ••••) have suggested that other variables can affect the dispersion parameter, and thus this parameter may also vary for entities such as intersections and rail-highway crossings.

El-Basyouny and Sayed• proposed a method that accounts for variation in the dispersion parameter for urban arterials by estimating the variance of the prediction using a similar form to the one used for estimating the mean. In this approach, the dispersion parameter is calculated as the square of the model's prediction divided by the estimated variance. While this method offers considerable flexibility in estimating the dispersion parameter's variability, the chosen form for the variance is somewhat arbitrary, and the rationale for including factors beyond length has not been fully justified. Overall, the variable dispersion parameter improved the model's goodness of fit by accommodating more variability. However, when applied to the identification and ranking of accident-prone locations, the differences from using a constant dispersion parameter were minimal or limited.

3.2.2.5 Key points on accident modelling

Based on the existing literature, several key points about statistical accident modeling merit emphasis.

First, the generalized linear modeling (GLM) technique proves highly effective for calibrating safety performance functions. Unlike conventional linear regression, GLM addresses its limitations in accident frequency modeling by accommodating Poisson or Negative Binomial error structures, which are more suitable for such analyses •. Additionally, GLM allows for the application of advanced calibration techniques.

Second, the model form must account for the nonlinear relationship between accident frequency estimates and traffic volume. It should also ensure that the dependent variable can logically be zero when exposure variables are zero.

Third, the definition and selection of independent variables should encompass road geometric features, consistency measures, and road context-related characteristics.

Fourth, contemporary research not only focuses on the selection of independent variables but also on developing guidelines for defining and obtaining homogeneous segments. This includes methodologies for segmenting roadways into sections with uniform safety-related features, enhancing the accuracy and relevance of the safety performance functions••Zhang, & Ivan, 2005; •

3.2.3 Network Safety Management Practice in Denmark

Sorensen and Elvik (2007) describe NSM practice in Denmark as follows:

"The road system is divided into homogenous sections regarding annual average daily traffic, type of road, number of lanes, roadside buildings, speed limit and presence of bicycle lanes

and side strips. In order to make sure that the sections are homogenous, the sections may have different lengths. It is recommended that the lengths are between two and 10 kilometres.

The identification of hazardous road sections is based on the so called reduction potential index (RPI), which is estimated as the absolute difference between the recorded accident cost weighted density of accidents for the given road section, and the average accident cost weighted density of accidents for the category to which the road section belongs.

The calculation of recorded and average accident cost weighted density of accidents is based on density of accidents with severe personal injury, minor personal injury and damage to property, weighted according to the average accident costs for the three categories of accidents. The calculations of both the recorded and the average accident cost weighted density are done by use of a five years accident period.

Hazardous road sections are identified as sections with RPI larger than four. In the analysis stage, the identified road sections have to be analysed in order to ascertain whether they are true hazardous road sections, and, if so, why they are hazardous.

The accident analysis consists of a general accident analysis as well as an extended collision diagram. The extended collision diagram covers a traditional collision diagram, which has been amplified with information from the general analysis. This is done to allow the identification of local problems, which 'drown' in the average of the road section as such. Both results from the general accident analysis and the extended collision diagram have to be compared with the normal accident pattern for similar road sections. The accident analysis is to be supplemented by a road inspection and relevant analyses of traffic and road features.

Provided that the identified sections are found to be true hazardous road sections, proposals for countermeasures have to be made and assessed." (Sorensen and Elvik, 2007).

3.2.4 Network Safety Management Practice in Germany

Sorensen and Elvik (2007) describe NSM practice in Germany as follows:

"The road network is divided into road sections that more or less have the same traffic volume, the same cross section and the same type of environment. The road sections are around 10 kilometres and at least 3 kilometres long.

A distinction is made between three levels of accident severity. That is serious injury accidents, which includes fatal accidents, slight injury accidents and property-damage-only accidents. Four indicators of safety performance are used to identify hazardous road sections:

1. Accident density: Number of accidents per kilometre per year
2. Accident cost density: Societal cost of accidents per kilometre per year
3. Accident rate: Number of accidents per million vehicle kilometres
4. Accident cost rate: Societal cost of accidents per million vehicle kilometres

All these indicators are stated in terms of the recorded number of accidents during a period of three to five years. No attempt is made to adjust for possible random fluctuations.

To identify road sections with poor safety performance, accident cost density is used. As resources are limited, those sections where improvements can be expected to have the highest benefit-cost ratio should be treated first. Therefore, information is needed on the accident costs per kilometre and the safety potentials for possible remedial measures.

The safety potential (SAPO) is defined as the amount of accident costs per kilometre that could be reduced if a road section had a best practice design. The higher the safety potential the more societal benefits can be expected from improvements of the road. SAPO is calculated as the difference between the current accident cost density (ACD) and the basic accident cost

density (bACD), which represents the anticipated average annual number and severity of accidents, which can be achieved by a best practice design.

The sections of the road network are ranked according to the magnitude of the safety potential. Sections with a high rank are selected for more detailed engineering study designed to propose safety measures. It is recommended to present the results of the analysis in diagrams. The initial stages of this analysis are identical to the analysis of black spots with the exception that no sites visits are performed." (Sorensen and Elvik, 2007).

3.2.5 Network Safety Management Practice in Norway

Sorensen and Elvik (2007) describe NSM practice in Norway as follows:

"The Norwegian approach is performed for the national roads, which were divided into one-kilometre road sections. The identification method is based on the concept of injury severity density (ISD), which is defined by the formula:

$$ISD = \frac{33.20 \cdot FAT + 22.74 \cdot CRI + 7.56 \cdot SER + 1.00 \cdot SLI}{Km \cdot year} \quad (41)$$

where:
FAT = Fatally injured road users
CRI = Critically injured road users
SER = Seriously injured road users
SLI = Slightly injured road users

The levels of injury severity are based on official Norwegian road accident statistics, and the weights assigned to each level of injury severity are proportional to the societal costs of one injury of the stated severity.

In order to develop unbiased estimates of injury severity density for any road section, the empirical Bayes method was applied. In order to apply the empirical Bayes approach, multivariate models were fitted to explain the number of injured road users. The dependent variable in the models fitted was the number of injured road users of a given injury severity per kilometre during a period of eight years. Separate models were fitted for each level of injury severity. Annual average daily traffic, speed limit, the type and status of road, number of lanes and number of junctions per kilometre were used as explanatory variables in the models.

Hazardous road sections are identified as those 10% of all national roads that have the highest values for expected injury severity density, and where accidents resulting in fatalities or serious injuries have been recorded during the last eight years.

Once hazardous road sections are identified, an analysis of accidents is performed, using routinely available data only and not visiting each section. The objective of the accident analysis is to identify those accidents that make the greatest contribution to injury severity density. As part of the accident analysis, accidents were described according to type of accident, road surface condition, weather conditions and light conditions. The analysis of accidents was based on the recorded number of accidents, or, more precisely, on the number of injured road users, specified according to injury severity in each type of accident." (Sorensen and Elvik, 2007).

3.2.6 Network Safety Management Practice in Poland

In Poland, on May 28, 2024, the Regulation on the Assessment of Accident Risks and Accident Severity and Road Safety Categories came into force (Polish regulation by the Minister for Infrastructure).

The regulation specifies:

1) the method and manner of conducting the risk assessment referred to in Article 24ma (1) of the Law of March 21, 1985, on public roads, from now on referred to as "risk assessment",
2) the method of submitting the risk assessment report to the minister in charge of transportation,
3) the content and presentation of the results of the risk assessment in the risk assessment report,
4) categories of road safety.

The risk assessment shall be carried out separately for:

1) motorways and expressways or sections thereof.
2) other roads or sections thereof:
    a) with two main carriageways,
    b) with one main carriageway.

The reactive method is based on an analysis of the occurrence of road accidents.

Road sections:
If no road accident data are available for at least three years preceding the year the risk assessment is carried out for a given road section, the risk assessment shall only be carried out using the proactive method.
For the road sections referred to in § 2 item 2, located within a built-up area and tunnels with a length of 500 meters or less, the risk assessment shall be carried out using the reactive method only.

Motorways and expressways are divided into segments, considering urban and rural sections, interchange location, number of lanes, road shape in plan, and recommended segment lengths. Other types of rods are divided into segments, considering interchange or intersection location, number of lanes, annual average daily traffic, road shape in plan, and recommended segment lengths.

The recommended segment lengths for motorways and expressways are rural: 5 to 15 km, and urban: 3 to 7 km for dual carriageways, 3 to 15 km, and single carriageway roads, 3 to 7 km. It is permissible to create segments with lengths less or greater than those indicated above, provided that the segments are as homogeneous as possible and their length does not significantly exceed the significantly the limit values.

Measures of safety in the reactive method are:

- the density of traffic accidents in a given period relative to the length of the segment,
- the traffic accidents ratio in a given period in relation to traffic volume.

Using Road Safety indicators, we classify the section into one of the safety classes: safe (green), moderately safe (orange), and dangerous (red).

The method does not explain how to calculate risk levels. It is necessary to use the included calculation forms. Unfortunately, it does not include a detailed description of the criteria for classifying a section into safety classes. The Polish method is based on the guidelines "*Network Wide Road Safety Assessment Methodology and Implementation Handbook*" (EU, 2023).

3.2.7 Network Safety Management Practice in Sweden

The Swedish Transport Administration does not carry out retroactive, accident based NSM due to the relatively low number of accidents with fatality and severe injury. In 2023, the number of fatalities in road accidents was 229 and the number of severely injured was 4300 (Trafikverket, 2024). The Swedish road network consists of 98,500 km state roads and 42,300 km municipal streets and roads. The relatively small number of accidents of interest and the randomness of accident occurrence does not provide a sufficient base for a meaningful statistical analysis to be able to identify high-risk sections. Hence, the Swedish Transport Administration only practices proactive NSM.

3.2.8 IRAP Crash Risk Mapping

iRAP Crash Risk Mapping protocol (CRM) can be applied globally, with 20 European countries which already performed the road safety assessment[2]. Crash Risk Mapping is an inexpensive method, which does not rely on complex or extensive input data. Crash Risk Mapping can be performed on any kind of road, for which a number of fatal or seriously injured is known. For a best performing result, it is advisable to perform the survey on a network wide level, as smaller road samples can provide inconclusive results if Risk Mapping is performed as a targeting process for the Star Rating.

Crash Risk Mapping is an inexpensive and easy to present method for network wide road assessment. Risk Mapping provides a colour coded representation of the crash occurrence on roads of the assessed network. Road safety engineer performing the Risk Mapping should have some experience in network wide safety assessment for an easier understanding of the process and output results.

Crash Risk Mapping protocol can be used to assess the safety level of a country road network and determine the risk of fatal and serious road traffic accidents occurrence, either on selected individual roads on the observed road network or on the network-wide scale. The outputs obtained based on the CRM procedure offer an insight on the car crash occurrence rate on a country's network, easily understandable by broader public.

Data necessary for Risk Mapping can usually be obtained from official state sources such as the Ministry of Interior, road infrastructure management agencies or ministries.

The cost of implementation consists in staff pays and technical equipment expenditures.

As the Risk Mapping protocol does not require extensive input data, it has a high transferability and generalisability rate. Input data required constitutes basic road safety parameters of which almost every country keeps track.

Main strengths of the method are its reliability and fast implementation, accompanied by low implementation costs. High comparability and transferability of the method enable a comparison of the road network safety state between countries.

If, on one hand, the CRM method is fast and easy to perform, without the need for extensive input data, on the other hand, the same basic data needed for the method represents its limitations. Risk Mapping does not provide any feedback on possible countermeasures, nor does it identify black spots, but rather it identifies black road sections. The process for conducting CRM is shown within the Figure 3.31.

[2] https://irap.org/safety-insights-explorer/

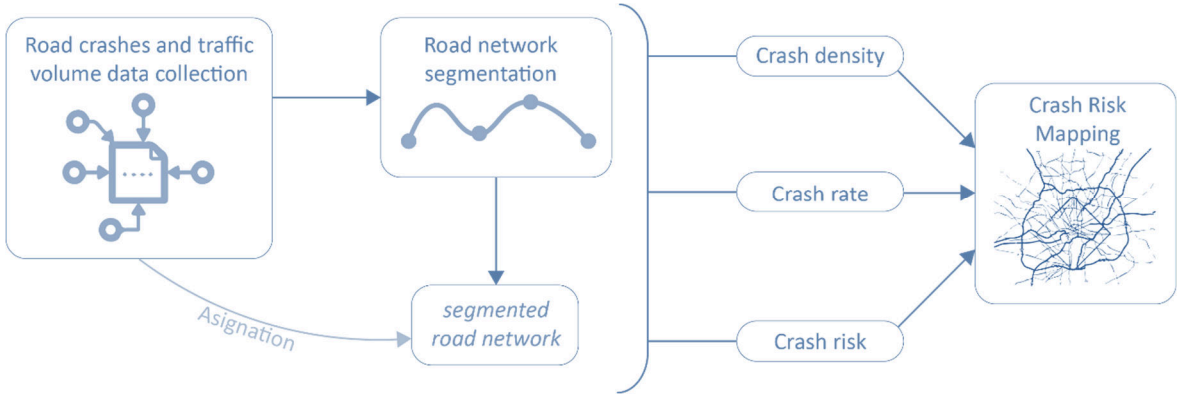


Figure 3.31. iRAP Crash Risk Mapping process. Source: Extrapolated from https://irap.org/2024/04/updated-irap-crash-risk-mapping-manual-now-available/

3.2.8.1 Input Data

To obtain CRM results, a set of input data is required. It is necessary to define an assessment period, for which the input data will be procured. Usually, this period is between 3 to 5 years. Gathering data for a period which is less than 3 years can produce inconclusive results while, on the other hand, procuring data for a period longer than 5 years can add unnecessary complexity to the data gathering process, with no added benefits in form of output accuracy. When an assessment period is selected, data regarding fatal and serious injuries for the selected period is gathered. It is necessary to obtain geospatial data of the roads included in the assessment to allocate crash data to corresponding locations. Besides geospatial and crash data, it is necessary to provide data regarding speed limits, AADT and road length.

3.2.8.2 Algorithms

To implement the Crash Risk Mapping method, it is necessary to calculate few key values, one of which is the scaling factor. Scaling factor value simply gives a better estimate of relative long-term crash rate for each section and means that maps are plotted to a scale for each country with different thresholds (although still described as low, low-medium, medium, medium-high and high risk) for each band depending on how their crash data and RAP network are defined.

To obtain the road network scaling factor, the number of fatal and serious crashes is divided with the number of fatal crashes (FS/F). If, for example, 400 fatal and serious injuries occurred on a road network, 100 of which being fatal injuries, scaling factor equals to:

$$\frac{FS}{F} = \frac{400}{100} = 4 \qquad (42)$$

Traffic flow expressed in billion vehicle-kilometres travelled for a given road section will be calculated by multiplying the Annual Average Daily Traffic (AADT) by the route length and by the relevant number of days as shown in the following formula:

$$BVKM = \frac{L\,[km] \cdot AADT[veh/day] \cdot T[days]}{1{,}000{,}000{,}000} \qquad (43)$$

where:
BVKM – traffic flow, expressed in billion-vehicle kilometres travelled.
L – length of road section.
T – time period in days.

Aggregated AADT for road sections that consists of a series of links will be calculated according to the following expression:

$$BVKM_{agg} = \frac{\sum_{Links}(AADT_{Link}[veh/day] \cdot L_{Link}[km])}{\sum_{Links} L_{Link}[km]} \quad (44)$$

3.2.8.3 Statistical analysis of crash data

There are four basic analyses which will be conducted for all the roads sections in the network: (i) Crash density, (ii) Crash rate, (iii) Crash costs and potential for investment returns, and (iv) reductions in crash numbers. Risk rates on the individual road sections will be determined based on the available traffic accident data for the period 2019-2023.

Crash density is a measure of collective risk. It refers to the number of crashes per unit length of road on each route. Crash density will be calculated for each road network section, according to the following formula:

$$RC_{Density} = \frac{N_{crashes}}{L\,[km]} \quad (45)$$

where:
$RC_{Density}$ – density of road crashes, expressed in the number of road crashes per kilometre of each observed road section;
$N_{crashes}$ – total number of fatal, serious and slight injury crashes on observed road section;
L - length of observed road section [km].

Crash rate is a measure of individual risk. It is the number of crashes relative to the total number of vehicles using the road. It will be calculated for each road section, based on the following expression:

$$RC_{rate} = \frac{N_{crashes}}{BVKM} \quad (46)$$

where:
RC_{rate} – Crash rate, expressed in the number of road crashes relative to the total number of billion vehicle-kilometres travelled;
$N_{crashes}$ – total number of fatal, serious and slight injury crashes on observed road section;
BVKM – traffic flow, expressed in billion-vehicle kilometres travelled.

Crash risk by road type with risk rate expressed as fatal, serious, and slight injury crashes per billion vehicle km, relative to the average risk rate of roads with a similar traffic flow, will be calculated according to the following equation:

$$\Delta RC = \frac{RC_{rate}}{\overline{RC_{rate}}} = \frac{\frac{N_{crashes_i}}{VKM_i}}{\frac{\sum_{i=1}^{n} N_{crashes_i}}{\sum_{i=1}^{n} BVKM_i}} = \frac{\frac{N_{crashes_i} \cdot 10^9}{L \cdot AADT \cdot 365 \cdot T}}{\frac{\sum_{i=1}^{n} N_{crashes_i} \cdot 10^9}{\sum_{i=1}^{n} L_i \cdot AADT_i \cdot 365 \cdot T}} \quad (47)$$

where:
ΔRC – Ratio of individual i-th road section risk rate RC_{rate} and determined average traffic accident occurrence risk rate within the observed road category $\overline{RC_{rate}}$;
RC_{rate} – Road traffic accident occurrence risk per billion vehicle kilometres;
$\overline{RC_{rate}}$ – Average crash risk per billion vehicle kilometres travelled for each 'road type';
BVKM – traffic flow, expressed in billion-vehicle kilometres travelled;

L – observed road section length [km];
AADT – annual average daily traffic [veh/day];
T – observed time period [years].

Crash risk by road type will be separately determined for the road sections belonging to the following four categories:

(1) Motorways;

(2) Main roads < AADT=10.000 [veh/day];

(3) Main roads AADT=10.000 – 20.000 [veh/day] and

(4) Main roads > AADT=20.000 [veh/day].

The potential crash savings, i.e. the total number of road crashes that can be prevented if all road sections with crash rates above road network average are brought to the average risk level determined for four considered road categories, will be calculated according the following formula:

$$\Delta PN = \frac{RC_{Density} \cdot (\Delta RC - 1)}{\Delta RC} \quad (48)$$

where:
ΔPN – potential crash savings per kilometre;
$RC_{Density}$ – Risk rate expressed as the number of road crashes per km per year;
ΔRC – Ratio of individual i-th road section risk rate RC_{rate} and determined average traffic accident occurrence risk rate within the observed road category $\overline{RC_{rate}}$;

3.2.8.4 Crash risk map types, with calculation examples

Using Crash Risk Mapping method, 4 types of maps can be produced and namely:

1. Risk of traffic accident occurrence based on travelled kilometer
2. Traffic accident density
3. Road category based risk
4. Potential crash savings
5. Crash cost mapping

Map 1: risk of traffic accident occurrence based on travelled kilometre

Individual risks of traffic accident occurrence with severe or fatal injuries per billion vehicle – kilometres driven are calculated for every segment based on data of traffic accidents, the size of average annual daily traffic, segment length and number of years of observed time period

$$\frac{30\ km * 100.000 \frac{veh}{day} * 365\ days * 5\ years}{10^9} = 5,48 \quad (49)$$

For example, if in 5 observed years there are: 30 road accidents with severe and fatal consequences on a road segment 30 kilometres in length on which 100.00 vehicles drive daily, individual risk per billion vehicle – kilometres driven will be calculated from the ratio of number of traffic accidents with severe or fatal injuries (30) and number of billion vehicle – kilometres driven on that segment (30 km x 100.000 veh/day x 365 days x 5 years / 10^9). For this given example, that means that the level of individual risk equals to 5,48 traffic accidents per billion driven kilometres and the segment will be classified in the low risk category

Map 2: traffic accident density

Collective risks off traffic crash occurrence with severe or fatal injuries per kilometre of every analysed segment are calculated based on data of traffic accident number, segment length and number of years in assessment period, following the expression:

$$\frac{30\ traffic\ accidents}{5\ years} = 6 \qquad (50)$$

$$\frac{6}{30\ km} = 0,2 \qquad (51)$$

For example, if in 5 assessment years there are: 30 traffic accidents with severe and fatal injuries on a road segment 30 kilometres in length on which 100.000 vehicles drive daily, collective risk of traffic accident occurrence per kilometre of road segment is calculated from the ratio of number of crashes with severe and fatal injuries per year of assessed period (30/5 years) and segment length expressed in kilometres (30 km). For the given example, that means that collective risk will be equal to 0.2 crashes per kilometre of segment and the assessed segment will be classified in low risk category.

Map 3: road category-based risk

Size of deviation values of the individual risk from the average risk is determined based on ratio between average cumulative individual risk values calculated for every segment which belongs to one of four main road categories: (1) motorways (2) main roads less than 10,000 AADT (3) main roads 10,000-20,000 AADT (4) main roads greater than 20,000 AADT and individual risk defined on determined road segments of the analysed road network, where ratios are defined based on risk values determined from traffic accidents with severe and fatal injuries data on billion vehicle – kilometres driven. With this method, data on tolerance variation of the individual risk on determined road segments compared to the average cumulative risk value for that same segment of the road network is obtained, using the following expression:

$$\frac{30\ km * 100.000 \frac{veh}{day} * 365\ days * 5\ years}{10^9} = 5,48 \qquad (52)$$

$$\frac{5,48}{127,53} = 0,042 \qquad (53)$$

For example, if in 5 years of assessment there are: 30 crashes with severe and fatal injuries on a road segment 30 kilometres in length, on which 100.000 vehicles drive daily, size of individual risk deviation for the assessed segment (5,48 traffic accidents per billion vehicle – kilometres travelled) from the average cumulative risk size determined for that road category (127,53 traffic accidents per billion vehicle – kilometres travelled) would equal to 0,042 which would classify the assessed segment in low deviation category.

Map 4: potential crash savings

Potential level for decrease of traffic accident with severe and fatal injury on individual segments of assessed road network, is established based on ratio between individual risk determined on defined road segments and average cumulative individual risk determined for every assessed road category and social risk data determined on those segments based on

calculated number of traffic accident density (number of traffic accidents with severe and fatal injuries per kilometre).

Map 5: crash cost mapping

Cost scale of a traffic accident with severe and fatal injuries on individual segments of assessed traffic network are determined based on data of traffic accidents with severe and fatal injury, social cost scale of a single crash with severe or fatal injuries and segment length of the assessed road network. Social cost of a single crash with fatal consequences is calculated based on recommendation of the EuroRAP method from the value of Gross Domestic Product per capita (GDP x 70). For traffic accidents with severe injuries, social cost is estimated based on EuroRAP recommendation where the value of a single traffic accident with severe injuries equals to 1/4 value of a human life. Following table represents statistical categories of economic costs of crash.

Table 3.8. Statistical categories of economic costs of crash. Source: iRAP Crash Risk Mapping Manual.

Low cost	20% of routes with minimal economic costs
Medium – low cost	Next 20% of routes
Medium cost	Next 20% of routes
Medium – High cost	Next 20% of routes
High cost	20% of routes with the highest economic cost

3.2.9 EC NWA reactive method

The EC NWA reactive approach[3] is based on data and analysis of existing traffic accidents. The method for implementing the EC NWA reactive approach is detailed in the guidelines provided by the European Commission and is designed to be comprehensive yet applicable, aiming to adapt to different types of roads and conditions on the road networks of member states.

The first step of the EC NWA reactive approach is the segmentation of the road network. Segments are defined based on specific parameters such as the number of traffic lanes, geometric elements of the road, and average annual daily traffic (AADT).

After network segmentation, the next step involves collecting data on traffic accidents. These data are usually obtained from national or regional databases and should cover at least three years. Traffic accident data should include parameters such as the type, circumstances, and consequences of the accident, participants, etc.

In the next step, a statistical analysis of the collected traffic accident data is conducted, based on which a risk class is determined for each road segment. These segment evaluations form the basis for the final step, which involves ranking road segments by categorizing them into three risk classes (Figure 3.32):

[3] Source from which this chapter is summarised from: https://road-safety.transport.ec.europa.eu/eu-road-safety-policy/priorities/infrastructure/road-infrastructure-guidelines_en

- If the parameter of accident density or rate for the reference population is lower than the lower limit, the corresponding segment/node/intersection is classified as "High Risk" (Class r3).
- If the parameter of accident density or rate for the reference population is higher than the upper limit, the corresponding segment/node/intersection is classified as "Low Risk" (Class r1).
- If the parameter of accident density or rate for the reference population is between the lower and upper limits, or equal to one of the limits, the corresponding segment/node/intersection is classified as "Uncertain" (Class r2).

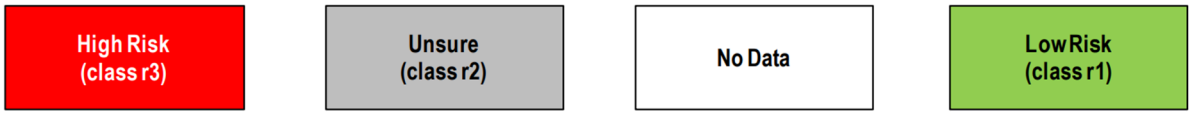


Figure 3.32. Risk Classification Categories According to the EC NWA Reactive Approach. Source: https://road-safety.transport.ec.europa.eu/document/download/93e39cd2-9e71-4ee0-8a8e-4de4fddaf068_en?filename=NWA-Handbook8.pdf

The reactive approach is supported by a tool within the Microsoft Excel software interface, which requires input only in specific cells while the rest of the process is automated.

Figure 3.33 illustrates the flowchart of the EC NWA reactive approach, serving as a comprehensive visual guide for conducting the procedure.

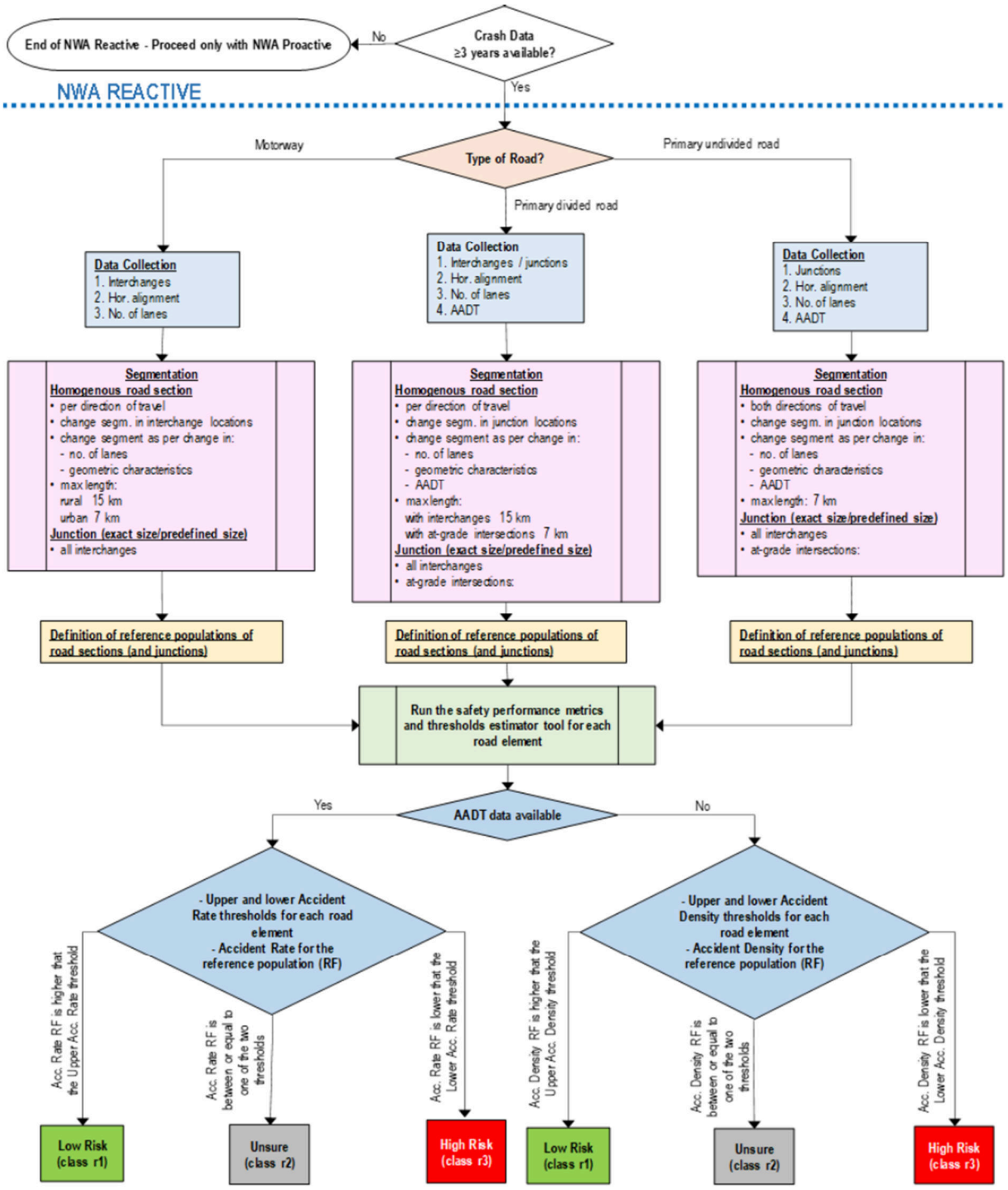


Figure 3.33. NWA-reactive flowchart. Source: https://road-safety.transport.ec.europa.eu/document/download/93e39cd2-9e71-4ee0-8a8e-4de4fddaf068_en?filename=NWA-Handbook8.pdf

3.2.9.1 EC NWA Reactive Approach - Road Network Segmentation

In the EC NWA reactive approach, the road network is divided into smaller sections that can be road segments or nodes (intersections at one or multiple levels). A road segment is defined as the portion of the road between two nodes. The criteria for defining a homogeneous segment are listed below, and each homogeneous segment (or node) represents the unit of analysis for the EC NWA reactive approach. The road is segmented based on one of the following three approaches:

- **Approach 1**: Segments that include both road segments and nodes. If a segment is not homogeneous, it can be further divided into homogeneous segments based on the criteria of horizontal road alignment and the number of traffic lanes.
- **Approach 2**: Segments that include only road segments and nodes that have predefined spatial dimensions depending on the type of node. The start and end points of a node are defined based on their fixed dimensions and center; at-grade intersections for primary roads are defined with a fixed length of 100 meters.
- **Approach 3**: Segments that include only road segments and nodes for which spatial dimensions have been measured. In this approach, nodes are measured from the starting point of the deceleration lane to the ending point of the acceleration lane.

Road tunnels are not included in the analysis, so the defined road segments should end before the tunnel entrance and start after the tunnel exit.

Toll station areas are not included in the analysis, so the defined road segments should end before the beginning of the widened toll station zones and start after the road resumes a uniform cross-section beyond the toll station zone.

Depending on the type of road, upper limits for the length of a homogeneous segment are defined—these upper values are not mandatory and mainly aim to express the typical segment length:

- Rural motorways: 10 km (±5 km) (maximum length = 15 km)
- Urban motorways: 10 km (±5 km) (maximum length = 7 km)
- Primary roads with a physical median that have nodes: 10 km (±5 km)
- Primary roads with a physical median that have at-grade intersections: 10 km (±5 km)
- Primary roads without a physical median that have at-grade intersections: 10 km (±5 km)

For motorways (urban or rural) and primary roads with a physical median, each traffic direction is analyzed separately per carriageway. Therefore, each direction has its own segmentation. An exception is allowed if the accident database lacks most information about the traffic direction.

In the case of segmentation approaches 2 and 3, the road segment between two nodes can be divided into multiple parts to achieve homogeneous segments. Three types of data (four for primary roads) are considered for the segmentation process:

1. Location of nodes
2. Elements of horizontal alignment
3. Number of traffic lanes (per direction of travel)
4. Average Annual Daily Traffic (AADT) – primary roads

3.2.9.2 EC NWA Reactive Approach - Requirements and Recommendations

The data that need to be collected in the EC NWA reactive approach are:

A. Accident Data

B. Traffic Volume Data

3.2.9.2.1 A. Accident Data

Accident data should have the following characteristics, regardless of the type of road:

- Include at least **3 years** of accident data on the roads (for the analyzed road segment). If these data are not available, the EC NWA Reactive Approach cannot be applied.
- Include accidents with at least one **fatality**, **serious injury**, or **minor injury**. Accidents with only material damage are not taken into account.
- Include accidents involving fatalities, minor and serious injuries, related to all types of road users (drivers and passengers in vehicles, motorcyclists, cyclists, and pedestrians).

For motorways (urban and rural) and primary roads with a physical median, accident data should be available per direction of travel. If these data are not available, it is recommended to assign accidents to the corresponding side of the road. If that is not feasible, the analysis can still be conducted but without distinguishing the direction of travel. For primary roads without a physical median, accident data for both directions of travel are used.

- When analyzing a motorway segment and there is a node connecting the motorway with another motorway or primary road, accidents that occurred on the ramps of the node should be added to the accidents of the nearest road (motorway or primary road), depending on the specific location of the accident on the ramp.
- When analyzing a motorway segment and there is a node connecting the motorway with a road outside the scope of Directive 2019/1936, accidents that occur on the ramps of the node should be added to the accidents of the motorway.
- When analyzing a segment of a primary rural road and there is a node connecting the road with another primary rural road covered by Directive 2019/1936, accidents that occur on the ramps of the node are counted as accidents of the nearest road.
- When analyzing a segment of a primary rural road (with or without a physical median) and there is an at-grade intersection with another primary rural road covered by Directive 2019/1936, accidents that occur at the at-grade intersection should be assigned to:
  - The intersection if segmentation approaches 2 or 3 are used, or
  - Equally to both roads if segmentation approach 1 is used.
- When analyzing a segment of a primary rural road (with or without a physical median) and there is an at-grade intersection with another road not covered by Directive 2019/1936, accidents involving vulnerable road users that occurred at the at-grade intersection or on the lower-category road are counted as accidents of the primary road.

3.2.9.2.2 B. Traffic Volume Data

Traffic volume data refer to the **Average Annual Daily Traffic (AADT)** and are expressed in vehicles per day [veh/day].

For motorways and primary rural roads with a physical median, traffic volume data are used per direction of travel. If traffic volume data are not known per direction of travel but the total traffic volume for both directions is known, the total traffic volume can be divided equally.

3.2.9.3 Reference Population

The reference population is a set of roads with similar operational and infrastructural characteristics. In the EC NWA reactive approach, it is used as a reference group for assessing the safety status of individual road segments. Depending on the type of road and the segmentation method, Table 3.9 shows possible reference populations.

Table 3.9. Reference Population Groups Depending on the Type of Road and Segmentation Approach. Source: https://road-safety.transport.ec.europa.eu/document/download/93e39cd2-9e71-4ee0-8a8e-4de4fddaf068_en?filename=NWA-Handbook8.pdf

Type of Road	Segmentation Approach	Reference Population
Rural motorway	1	Road segments on rural motorways
Rural motorway	2 or 3	Node segments on rural motorways
Urban motorway	1	Road segments on urban motorways
Urban motorway	2 or 3	Node segments on urban motorways
Primary road with physical median	1	Road segments on primary roads with physical median
Primary road with physical median	2 or 3	Segments of grade-separated nodes or at-grade intersections on primary roads with physical median
Primary road without physical median	1	Road segments on primary roads without physical median
Primary road without physical median	2 or 3	Segments of at-grade intersections on primary roads without physical median

If roads of lower category than primary roads are considered, additional reference groups need to be defined.

For each reference population group, the following data are required:

1. **Accident Data** on all roads (or intersections) within the group:
    - Total number of accidents for the same time period
    - Distribution of accidents by type of road user and consequence, including accidents with fatalities, serious injuries, and minor injuries by type of road user
2. **Data on the Length** of all segments within the group
3. **Average Traffic Volume Data** on all segments within the group

- If traffic volume data are available only for a subset of roads (or intersections) within the same reference population group, then a new reference population needs to be defined.

3.3 Integration of Results from Crash Data Analysis and Assessment Based on Road Characteristics

3.3.1 EC NWA integration approach

The integrated approach in EC NWA combines the results of the EC NWA reactive and proactive approaches, prioritizing segments into five classes. These classes range from Class 5, indicating very high priority, to Class 1, indicating very low priority.

The EC NWA method states that "any change in a segment in either of the two approaches (EC NWA Reactive and EC NWA Proactive) mandates a change in the segment in the EC NWA Integrated approach," thus enabling the final ranking of road segments. The integration matrix of results is shown in Figure 3.

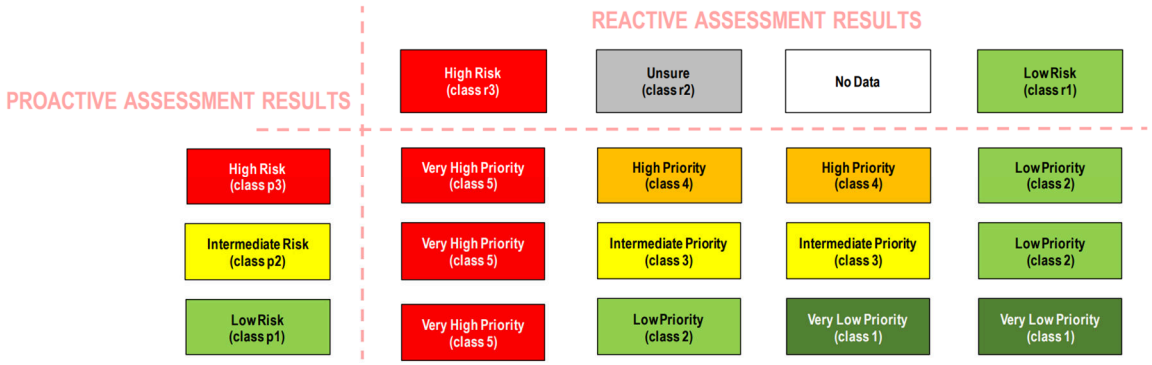


Figure 3.34. Integration of EC NWA Proactive and Reactive Approach Results. Source: https://road-safety.transport.ec.europa.eu/document/download/93e39cd2-9e71-4ee0-8a8e-4de4fddaf068_en?filename=NWA-Handbook8.pdf

Within each priority class, a more detailed prioritization can be performed using specific criteria and indicators, at the discretion of each member state. Essentially, for the final ranking it is needed to have the outcomes of the proactive and reactive methods well-organized in a way that allows to visualize and compare the two outcomes for the same part of the road. This can be done for example in Excel by colouring the cells that present the final ranking of proactive and reactive methods. In the indicative example of Figure 3.35, with black vertical lines representing the change of segments and colour-coding the obtained assessment results, it can be observed that, starting with seven (7) segments in the reactive method and ten (10) different segments in the proactive method, a finally integrated result divided into thirteen (13) segments is obtained.

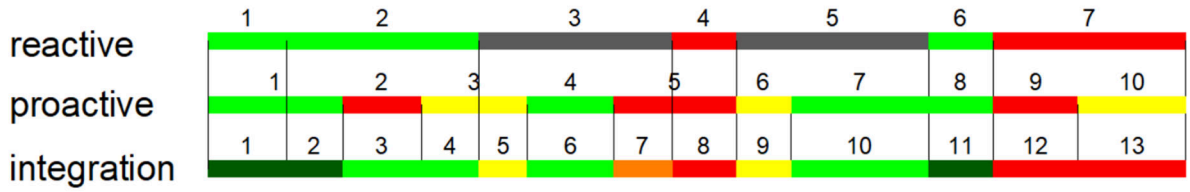


Figure 3.35. Example of combining results with different segmentation in each method. Source: https://road-safety.transport.ec.europa.eu/document/download/93e39cd2-9e71-4ee0-8a8e-4de4fddaf068_en?filename=NWA-Handbook8.pdf

Although the EC NWA Integrated approach provides a detailed classification system for road safety, Directive EC 2019/1936 does not prescribe which classification system should be used. Instead, it requires member states to classify all parts of the road network into at least three categories according to their safety level, leaving the specifics to the member state.

3.3.2 iRAP integration recommendations

iRAP CRM reactively analyses existing traffic accidents that result from a combination of road infrastructure factors, driver behaviour, and vehicle safety. On the other hand, the iRAP Star Rating proactively measures the level of road safety provided by the infrastructure. Both approaches can be implemented simultaneously for prioritizing and investing in improvements to road safety levels, aiming to reduce the risk of serious traffic accidents. Figure 3.36 contains iRAP's recommendation for integrating the iRAP CRM and iRAP Star Rating methods, which includes three levels of prioritization.



Figure 3.36. iRAP's Recommendation for integrating the iRAP reactive and proactive methods. Source: https://irap.org/2024/04/updated-irap-crash-risk-mapping-manual-now-available/

4 APPROPRIATE LEARNING FORMATS FOR THE VARIOUS NWRSA TOOLS

4.1 Learning formats for Proactive Methods

The proactive road safety assessment methods presented in this report are based on structured and data-oriented analyses of road infrastructure. Their application in education requires thoughtfully developed materials that clearly communicate key principles to students, professionals, and road safety stakeholders. In accordance with the aims of Task 2.2, these methods should be made accessible through different educational environments, such as online learning, blended formats, and traditional classroom-based teaching. In doing so, they must incorporate suitable communication tools to maintain learner engagement and ensure clarity in the presentation of technical content.

Proactive methods are particularly well suited to learning formats that integrate analytical tasks and applied practice. For example, the iRAP Star Rating system includes the evaluation of road infrastructure using video footage or visual inspection, followed by the processing of data through digital platforms such as ViDA. These steps can be transformed into digital learning exercises that are ideal for remote instruction. Participants can view coding videos, complete evaluations using sample datasets, and interpret safety classifications independently, allowing for flexible, self-paced learning.

In blended learning formats, these digital exercises can be supplemented with classroom discussions or guided activities. Learners may begin with independent analysis and continue with collaborative reviews or applied case studies in a group setting. For classroom-based learning, such as the pilot sessions in WP4, the use of live demonstrations, field-based evaluations, and facilitated workshops enhances understanding through direct interaction with real infrastructure scenarios.

Selecting appropriate communication formats is essential for helping learners absorb complex material. Visual representations such as risk maps, road classification charts, and safety rating diagrams are useful across all learning environments. Videos that demonstrate field inspections, coding techniques, and methodology workflows are especially beneficial in remote and hybrid settings. Interactive coding exercises using tools such as WebGIS provides opportunities to simulate hands-on work. To further support comprehension, clear infographics, visual guides, and simplified flowcharts can be used to explain procedures step by step and encourage learner involvement.

To ensure that the content of this report contributes directly to later stages of the project, the tools and examples presented here should be integrated into the teaching modules developed in WP3 and also into the structure of WP4 training activities. Materials such as sampling road segments, video-inspection datasets, and segment classification tasks are highly suitable for use in assignments, workshops, or applied project work.

By aligning methodological content with appropriate educational formats, it is ensured that proactive road safety assessment techniques are both technically robust and pedagogically effective. The integration of the guidance from T2.2 with the practical detail of T2.3 provides a solid basis for teaching, learning, and capacity-building in the field of infrastructure safety.

4.2 Learning formats for Reactive Methods

Effective learning of the accident based reactive method can be carried out using example set of georeferenced accident data for the road network (individual accidents should be positioned in the road network on a map) of a certain area/region during a 3–5-year period. The backbone of the training activities is going through the steps of the accident-based method in practical activities, using excel spread sheets for data analyses. supported by introductory lecturers for each step of the method. After each main cluster of topics, a workshop is proposed for discussing methodological issues among the course participants.

4.3 Learning formats for Integration of Results from Proactive and Reactive Methods

The integration of proactive and reactive safety assessment methods, as described in the third chapter of this report, presents a unique opportunity for developing educational content in a relatively uncharted territory that reflects the complexity and realism of modern road safety management. While proactive methods rely on infrastructure characteristics and predictive risk factors, reactive approaches focus on empirical crash data and injury outcomes. The combination of these two dimensions introduces a strategic, system-wide perspective that is both analytically rich and practically oriented. Teaching this integrated approach effectively requires careful alignment with appropriate learning formats and communication tools, especially in the context of Task 2.2 and work packages WP3, and WP4.

The integration of proactive and reactive results aligns particularly well with case-based learning, where students or professionals are exposed to multi-dimensional problems requiring critical thinking, data interpretation, and structured decision-making. This integrated content is well suited for use in remote learning environments through the use of scenario simulations, interactive dashboards, and comparative data visualizations. Learners can work with fictional or real datasets that combine infrastructure attributes with crash data and are tasked with identifying priority segments, proposing measures, and justifying their decisions using evidence from both assessment approaches.

For hybrid or blended learning settings, the integration of both methodologies allows for a clear division between asynchronous content preparation and in-person application. Students may begin by individually analyzing road segments using proactive tools such as the iRAP Star Rating or EC NWA methodology, followed by an in-class session where they receive crash statistics for the same road network and are asked to revise or justify their safety priorities. This approach reinforces the importance of understanding both infrastructure risk and real-world safety outcomes while encouraging data-driven reasoning.

In classroom-based trainings such as the WP4 project level pilot sessions, integrated methods can be taught through structured workshops where participants move from raw data to final safety recommendations. Working in groups, learners can use predefined templates to process proactive and reactive inputs, perform ranking exercises, and present their conclusions. The process helps to simulate actual planning conditions in road authorities or consulting teams, preparing participants for professional applications of the methodology.

Presenting integrated results requires the use of clear, comparative communication formats. Tables that align infrastructure-based safety classes with crash density and severity rates are particularly useful. Time series graphs can also be introduced to demonstrate how reactive data trends evolve after proactive measures are implemented and it can be observed how they

fare with integration. Such tools help learners to identify relationships, trade-offs, and areas of uncertainty, all of which are essential skills in road safety assessment.

To support the development of WP3 educational materials and WP4 training pilots, examples of integrated case studies should be included in WP3. These can be based on the pilot applications described in the main body of this report and adapted to classroom settings. Learners should be encouraged to engage with the full cycle of assessment and not only results integration (from data collection and segmentation to rating, comparison, and intervention planning). In this way, they develop both the technical skills required for infrastructure evaluation and the interpretive judgement needed to prioritize safety interventions.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Accident based reactive Network Safety Management

5.1.1 Best practice in accident based reactive Network Safety Management

The best currently known method for Network Safety Management, from a theoretical point of view, is the State-of-the-art approach, which presumes that all relevant data about accidents, traffic volume, road design, traffic control and surrounding environment are available, have sufficient quality, unambiguously located on the road network and interoperable with each other. However, since this is rarely the case, the second-best method is the best practice approach, which is constrained to limited data regarding quantity and quality. The best practice approach should control for **random fluctuations** and **systematic variation** in the number of accidents. It should identify **local risk factors,** and it should consider **injury severity** in a systematic way.

According to the best practice method, the road network to be divided into homogenous sections regarding type of road, cross section, presence of middle separation, road alignment, roadside buildings, speed limit and traffic volume. To make sure that the sections are homogenous, the sections may have different lengths. It is recommended that the lengths of these homogenous road sections are between 2 and 10 kilometres.

Hazardous road sections should be identified using a model-based approach. Such an approach is the Empirical Bayes method, which takes systematic variation and partially random fluctuations into consideration. According to the Empirical Bayes method, the expected number of accidents on a specific site is estimated by weighing the registered number of accidents at the site and the predicted number of accidents for all similar sites estimated by accident prediction models. For each type of section the ‘normal’, predicted number of accidents per km (of each severity type) should be estimated with help of an accident prediction model for the road type in question and it should be combined with the number of recorded accidents for the section in question, yielding an estimate of the site-specific expected number of accidents. A road section is be considered hazardous if the expected number of accidents per km is (substantially) higher than the ‘normal’, predicted number of accidents for similar sections. If there are no exiting accident prediction models developed for the road types in question, as the second-best solution, the average number of accidents per km for all road sections of the same type can be used.

Accident severity should be integrated into the analysis by weighing accidents according to their severity. The objective of weighting the accidents is to identify those accidents that make the most significant contribution to Injury Severity Density (ISD). ISD is a construct of the number of accidents at a road section, weighted by the societal costs of the injury accidents by severity degree. Accidents with fatalities and severe injuries are weighted more than

accidents with slight injuries. The weight should be based on the socioeconomic cost per accident by severity type. If these costs are not yet established in the country in question, efforts should be made to estimate them for future use!

A site visit to be carried out at the identified hazardous sections to verify their hazardousness. The site visit should concern not only the possible contributory factors to the registered accidents but also general problems that, by chance, have not been a contributory factor to the recorded accidents. After the site inspection, a final diagnosis should be made for the specific section, identifying safety issues related to road design and traffic engineering.

Conclusion on best practice in accident based retroactive Network Safety Management

The preconditions for the best practice approach are:

- The availability of geo-located data of accidents with fatality, severe injury and slight injury during a three to five year´s period.
- Information available for each individual road section regarding cross section, presence of middle separation, road alignment, speed limit and traffic volume.
- The existence of accident prediction models for ach severity type and for each road type in the road network.
- The existence of monetary values of societal costs of accidents with fatality, severe injury and slight injury.

5.1.2 Network Safety Management Practice in some European countries

In Denmark, the best practice approach is followed to some extent. The road network is divided into homogenous sections regarding annual average daily traffic, type of road, number of lanes, roadside buildings, speed limit and presence of bicycle lanes and side strips. The identification of hazardous road sections is based on the so-called reduction potential index (RPI), which is estimated as the absolute difference between the recorded accident cost weighted density of accidents for the given road section, and the average accident cost weighted density of accidents for the category to which the road section belongs. Hazardous road sections are identified as sections with RPI larger than 4. The identified road sections are analysed to ascertain whether they are true hazardous road sections, and, if so, why they are hazardous.

In Germany, the road network is divided into road sections that more or less have the same traffic volume, the same cross section and the same type of environment. The road sections are around 10 kilometres and at least 3 kilometres long. A distinction is made between three levels of accident severity, i.e., serious injury accidents (including fatal accidents), slight injury accidents and property-damage-only accidents. To identify hazardous road sections, four indicators of safety performance are used:

1. Accident density: Number of accidents per kilometre per year
2. Accident cost density: Societal cost of accidents per kilometre per year
3. Accident rate: Number of accidents per million vehicle kilometres
4. Accident cost rate: Societal cost of accidents per million vehicle kilometres

All these indicators are stated in terms of the recorded number of accidents during a period of 3-5 years. No attempt is made to adjust for possible random fluctuations. To identify road sections with poor safety performance, accident cost density is used. The safety potential (SAPO) is defined as the amount of accident costs per kilometre that could be reduced if a road section had a best practice design. The higher the safety potential the more societal benefits can be expected from improvements of the road. SAPO is calculated as the difference between the current accident cost density (ACD) and the basic accident cost density (bACD), which represents the anticipated average annual number and severity of accidents, which can be achieved by a best practice design. The sections are ranked according to the magnitude of the safety potential. Sections with a high rank are selected for more detailed engineering study designed to propose safety measures.

In Norway, the approach follows the best practice method. The national road network is divided into one-kilometre road sections. The identification method is based on the concept of injury severity density (ISD), considering accidents with fatality, critical injury, severe injury and slight injury. To develop unbiased estimates of injury severity density for any road section, the empirical Bayes method is applied. Multivariate accident models are fitted to explain the

number of injured road users of a given injury severity per kilometre during a period of eight years. Separate models are fitted for each level of injury severity. Annual average daily traffic, speed limit, the type and status of road, number of lanes and number of junctions per kilometre are used as explanatory variables in the models. Hazardous road sections are identified as those 10% of all national roads that have the highest values for expected injury severity density, and where accidents resulting in fatalities or serious injuries have been recorded during the last eight years. Once hazardous road sections are identified, an analysis of accidents is performed, using routinely available data only and not visiting each section. The objective of the accident analysis is to identify those accidents that make the greatest contribution to injury severity density.

The Polish experience suggests that the reactive method needs to be updated. At its introduction stage, no pilot studies were carried out to adapt it to Polish conditions. There are no clear and unambiguous guidelines on how to carry it out, which results in the possibility of different results depending on the person who performs the analysis or on the class of road, the division into sections used, and the definitions used (e.g. termination of an intersection). It is also not specified which roads the analyses are obligatory for and for which they are not.

In Sweden, retroactive, accident based NSM is not carried out, due to the relatively low number of accidents with fatality and severe injury. The relatively small number of accidents of interest and the randomness of accident occurrence do not provide a sufficient base for a meaningful statistical analysis to be able to identify high-risk sections. Hence, the Swedish Transport Administration only practices proactive NSM.

5.2 Proactive Network Safety Management methods

Proactive network-wide road safety protocols in the European Union (EU) involve identifying and mitigating potential hazards across road systems before accidents occur. These methods use predictive assessments, advanced data analytics, and proactive infrastructure changes to reduce risk and improve overall road safety. One key aspect of these protocols is the adoption of comprehensive safety ratings for road networks, which evaluate the risk of accidents based on the road's design, layout, and features.

Key Aspects of Proactive Network-Wide Road Safety Protocols:

1. **Predictive risk mapping:** Proactive protocols use predictive models that analyse historical crash data, traffic patterns, road features, and environmental conditions to identify potential risks across the network. This approach allows for anticipating where accidents are likely to occur and implementing preventive measures before crashes take place, even in areas with little to no past accident history.
2. **Comprehensive safety assessments at network level:** A proactive, network-wide road safety assessment protocols evaluates the entire road infrastructure for safety risks. These assessments occur during the planning and design phases of road projects, ensuring that potential hazards are identified and addressed before construction begins. By considering factors such as road geometry, intersection design, and pedestrian facilities, authorities can implement changes proactively, rather than reactively.
3. **Safety ratings based on road design and features:** Roads are assessed for their safety performance through a rating system that evaluates risk based on factors such as lane width, shoulder design, road curvature, and the presence of safety barriers or clear signage. This rating allows for a clear understanding of how safe each section of the network is and where improvements are needed. Roads with lower safety ratings can be prioritized for improvements, such as redesigning dangerous intersections, improving visibility, or adding protective barriers.

4. **Targeted safety improvements in high-risk Areas:** High-risk areas, identified through network wide road safety assessment being targeted for early intervention is one of key usages of the NWRSA protocol. Improvements might include installing additional signage, redesigning intersections, or adding pedestrian crossings in areas where they are lacking. Key difference between this and reactive implementation is that these changes are made proactively, based on the anticipated risk from NWRSA assessment rather than waiting for an accident to highlight the issue.
5. **Scenario analysis and stress testing:** Proactive road safety assessment can be utilised for modelling worst-case scenarios to assess how the road network will perform with implemented changes, which allows for the early introduction of targeted contingency measures within the planning phase.

Benefits of Proactive Network-Wide Safety Protocols:

- **Prevention Over-reaction:** Proactive measures address safety issues before accidents occur, significantly reducing the risk of fatalities and injuries.
- **Targeted Resource Allocation:** By identifying high-risk areas through predictive analysis and safety ratings, resources can be allocated more efficiently to address the most dangerous parts of the network.
- **Cost Efficiency:** Investing in proactive safety measures typically results in lower long-term costs compared to the reactive approach of responding to accidents and their aftermath.
- **Improved Safety Outcomes:** Proactive safety measures create safer road environments by identifying and addressing hazards before they lead to accidents, improving the overall safety of the road network.

5.3 Integration of results from reactive and proactive methods

Using both reactive and proactive approaches to road safety assessment is highly beneficial as each method captures unique aspects of road risk. Reactive approaches, grounded in accident history, are adapt at identifying high-risk segments where incidents have already occurred. These approaches highlight real-world hazards linked to specific road segments, providing empirical evidence of areas that need immediate attention. When focusing on historical data, reactive methods can direct resources toward reducing known risks, making them especially effective in addressing current safety concerns and preventing further incidents in identified hotspots.

Proactive approaches focus on potential risks by assessing in-built road infrastructure attributes, such as road design, speed limits, and the presence of road safety barriers and pedestrian crossings, without relying on past accident data. This predictive capability enables road authorities to identify areas with inherent safety weaknesses — even if accidents have not yet happened there. Proactive methods are especially useful in European countries where there is a lack of statistical robustness regarding input data due to a very low occurrence of road accidents. This approach helps in prevent accidents before they occur by addressing design flaws or environmental factors that increase risk,

Integrating both reactive and proactive approaches provides a comprehensive view of road safety by combining actual risk (from accident history) with potential risk (from infrastructure attributes). This integration allows for more precise prioritization, as areas with high historical incidents and structural risks can be addressed first, while areas flagged solely by proactive methods can receive pre-emptive safety measures. By uniting these approaches, road safety analysis can achieve a balanced, forward-looking strategy that not only mitigates existing hazards but also builds inherently safer roads for the future, making this combination a robust recommendation for effective road safety management.

Currently, two road safety methods have a well-defined guidelines (EC NWA) and suggestions (iRAP) for integrating reactive and proactive approaches to enhance road safety through systematic classification and prioritization of road segments.

The EC NWA framework combines reactive and proactive assessments to prioritize road segments in a five-class system, from high-priority Class 5 to low-priority Class 1. A key feature is its dynamic integration matrix, requiring adjustments whenever changes occur in either the proactive or reactive analysis. This adaptability allows for a comprehensive ranking of road segments based on evolving safety data.

Member states have flexibility in refining these priority classes with additional criteria specific to their unique contexts. Directive EC 2019/1936 mandates that member states classify road networks into at least three safety levels but leaves the exact categorization to each state's discretion.

iRAP utilizes two distinct approaches for assessing road safety: the Crash Risk Mapping (CRM) system, which reactively analyses accident data influenced by infrastructure, driver behaviour, and vehicle safety, and the Star Rating system, which proactively evaluates safety provided by the infrastructure. iRAP's integration matrix recommends three levels of prioritization, facilitating a structured approach to allocate resources and target improvements.

Both EC NWA and iRAP support a dual-method approach, combining predictive and historical data for a more comprehensive view of road safety needs. Through these integrative methods, road safety management can efficiently prioritize high-risk segments for targeted interventions.

5.4 Recommendations

5.4.1 Recommendations for enabling best practice in accident based Network Safety Management

- The accident database should contain geo-located data of accidents with fatality, severe injury and slight injury.
- Establish an electronic road database containing information for each individual road section regarding cross section, presence of middle separation, road alignment, speed limit and traffic volume.
- Establish accident prediction models for ach severity type and for each road type in the road network.
- Establish monetary values of societal costs of accidents with fatality, severe injury and slight injury.

5.4.2 Recommendations for the use of proactive methods

- When developing teaching materials on proactive road safety, it is essential to include key methods such as iRAP, IASP, and the European Commission's Network-Wide Assessment (EC NWA) due to their proven effectiveness in identifying and mitigating risks before accidents occur. These methods offer distinct, but complementary, approaches that not only help in assessing individual road sections but also provide comprehensive, network-wide solutions for improving safety across larger areas. Incorporating them into educational content ensures that stakeholders and students are equipped with a broad range of tools and concepts essential for modern road safety management, which is increasingly focused on prevention rather than reaction.
- iRAP is particularly important as it offers a detailed and structured model for assessing road safety risks at a network level. By evaluating specific infrastructure features such as

lane width, shoulder design, and visibility, it allows for targeted safety improvements. Including iRAP in teaching materials helps stakeholders and students understand how to assess individual road sections and prioritize improvements based on identified risks. This can be especially valuable in creating safer roads for vulnerable road users, such as pedestrians and cyclists.

- The IASP method extends this focus by not just the road design but also road safety inspection elements into network wide assessment. This broader perspective is vital for understanding how safety risks evolve in response to user behaviour, and it helps stakeholders and students learn how to approach safety from a systemic viewpoint. By incorporating IASP with a NWRSA focus, students gain an understanding of how to analyse crash data alongside other critical factors like traffic flow and road maintenance, which can offer deeper insights into road safety than infrastructure evaluation alone.
- Similarly, the EC NWA method is crucial for providing a strategic, network-wide perspective since it is adapted for use on EU level scale. It emphasizes the assessment of entire road networks, identifying areas of high risk based on a combination of traffic data and road features which are commonly available in all EU member states. By learning how to conduct EC network-wide safety assessments, stakeholders will be better prepared to recommend improvements that consider traffic patterns, infrastructure quality, and other network factors.
- The inclusion of these methods ensures that students and stakeholders learn how to assess and improve road safety from multiple angles. iRAP's detailed modelling, IASP's broader evaluations, and EC NWA's network-level analysis all provide students and stakeholders with a comprehensive understanding of how proactive safety measures can be implemented with varying methods based on availability of data and expertise. These methods also emphasize the importance of using data-driven, evidence-based approaches to road safety management, encouraging stakeholders and students to consider both immediate risks and long-term trends. By integrating these methods into EuroS@P NWRSA teaching materials, educators can ensure that future professionals in the field of road safety are well-equipped to develop and implement proactive strategies that will ultimately reduce accidents and fatalities across Europe's road networks.

5.4.3 Recommendations for integration of results of reactive and proactive methods

The integration of proactive and reactive methods in road safety assessment is crucial for a comprehensive approach to reducing risks across road networks. The integration of methods such as EC NWA, iRAP's Crash Risk Mapping (CRM) and Star Rating systems, as well as the EC NWA Proactive and Reactive approaches, ensures that both historical data of accidents and predictive models (e.g., road design features) are considered together. Including these integrated methods in teaching materials allows students to understand how combining different data sources and approaches can result in more effective road safety prioritization and intervention strategies.

The **EC NWA Integrated Approach** is particularly valuable as it enables the synthesis of both proactive and reactive safety assessments into a single, unified framework. By combining the results of the EC NWA Proactive and Reactive approaches, this method allows for the prioritization of road segments based on both past performance (accident history) and predictive risk factors (road design, traffic conditions). The integration ensures that road safety strategies are not solely reactive or proactive but rather take a holistic view of road network safety. Teaching materials should focus on how to perform this integration by comparing and

visualizing the results of both approaches. For instance, using tools like Excel to colour-code and compare the results of the proactive and reactive assessments in a clear, visual manner can help stakeholders and students understand how different segments are prioritized based on a combination of both approaches.

iRAP's methods also offer an excellent example of integrating reactive and proactive safety assessments. The **iRAP Crash Risk Mapping (CRM)** is a reactive method that identifies high-risk areas based on historical accident data, while the **iRAP Star Rating system** is a proactive method that evaluates road infrastructure based on design features and potential hazards. These approaches can be implemented simultaneously to provide a comprehensive safety assessment for a given road network. Teaching materials should include the integration recommendations provided by iRAP, which categorize the results into three levels of prioritization, allowing students to understand how these two methods can complement each other in prioritizing road improvements. By combining CRM's focus on accident data with Star Rating's focus on infrastructure design, students can learn how to create a more complete picture of road safety.

The inclusion of these integration methods into teaching materials will not only provide students and stakeholders with practical tools for assessing road safety, but also foster a deeper understanding of the interconnectedness between reactive and proactive safety approaches. **EC NWA's integration matrix** and **iRAP's integration framework** emphasize the need to combine both sets of data to ensure that road safety improvements are informed by both historical trends and future risk predictions. By emphasizing this integrated approach, students can be taught how to develop more nuanced, data-driven road safety strategies that consider both current hazards and potential future risks.

Moreover, incorporating these methods encourages students to think critically about the balance between short-term fixes and long-term improvements. While reactive methods address existing problems, proactive methods focus on preventing future risks. An integrated approach allows for more accurate, balanced prioritization of safety improvements, which is essential for creating safer road networks. By using integrated methods, students will learn how to prioritize interventions in a way that maximizes safety improvements over time, taking both past accidents and future risks into account.

When integrating proactive and reactive results it is preferable to give the results from the pro-active assessment more weight. A more safety conscious approach is taking the worst result of the two models.

5.4.4 Recommendations for appropriate learning formats for the various NWRSA tools

Learning formats for Proactive Methods…..

Effective learning of the accident based reactive method should be carried out using example set of georeferenced accident data for road network of a certain area/region during a 3–5-year period. The backbone of the training activities is going through the steps of the accident-based method in practical activities, using excel spread sheets for data analyses, supported by introductory lecturers for each step of the method. After each main cluster of topics, a workshop is proposed for discussing methodological issues among the course participants.

Learning formats for Integration of Results from Proactive and Reactive Methods

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