Network Wide Road Safety Assessment

Methodology and Implementation Handbook

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Directorate-General for Mobility and Transport
Study on a Methodology for Network-wide Road Safety Assessment

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ABSTRACT:

The aim of the present Handbook is to provide required guidance to road safety practitioners and road authorities regarding the effective implementation of the Network-Wide Road Safety Assessment (NWA) methodology, as endorsed by the Member States in the 13th meeting of the Expert Group on Road Infrastructure Safety (EGRIS) Plenary Session of November 21, 2022. The handbook is provided as methodological guidance to Member States according to Article 5 - point 5 of Directive 2008/96/EC, as amended by Directive (EU) 2019/1936.

The objective of the NWA methodology is to provide a cost-effective safety assessment of the road network within the scope of the Directive and ranking in at least three classes. The safety assessment is to be based on the evaluation of both the design characteristics of the road (in-built safety) and historic crash data (if available), and serves a screening purpose in order to prioritize in an efficient way either targeted road safety inspections or direct remedial actions. Particular emphasis is placed on the needs of vulnerable road users, as required in Article 6b of the revised Directive.

The methodology comprises two approaches: one for the assessment of roads on the basis of crash occurrence analysis (reactive methodology, NWA-reactive) and one for the assessment of the in-built safety of roads (proactive methodology, NWA-proactive). The two methodologies are both applied over the same network and the resulting assessment outcomes are combined via an integration methodology to provide the final road network rating and ranking.

The handbook provides step-by-step guidance on the two approaches as well as on the procedure to integrate reactive and proactive assessment results and estimate the final safety ranking of each road section. Furthermore, the theoretical background, assumptions and development considerations for each approach is presented (in Annexes), along with concise user guides for the excel based calculator tools that have been developed for use by road safety practitioners.

Keywords: network wide road safety assessment, crash occurrence, in-built safety, integrated methodology, motorways, primary roads.

Résumé:

L'objectif du présent manuel est de fournir les orientations nécessaires aux praticiens de la sécurité routière et aux autorités routières concernant la mise en œuvre efficace de la méthodologie d'évaluation de la sécurité routière à l'échelle du réseau (NWA), telle qu'approuvée par les États membres lors de la 13e réunion du groupe d'experts sur la sécurité des infrastructures routières (EGRIS) du 21 novembre 2022. Le manuel est fourni à titre d'orientation méthodologique aux États membres conformément à l'article 5 - point 5 de la directive 2008/96/CE, telle qu'amendée par la directive (UE) 2019/1936.

L'objectif de la méthodologie NWA est de fournir une évaluation de la sécurité rentable du réseau routier dans le champ d'application de la Directive et un classement dans au moins trois classes. L'évaluation de la sécurité doit être basée sur l'évaluation à la fois des caractéristiques de conception de la route (sécurité intégrée) et des données d'accidents historiques (le cas échéant), et sert un objectif de sélection préliminaire afin de hiérarchiser de manière efficace soit inspections ciblées de sécurité routière ou actions correctives directes. Un accent particulier est mis sur les besoins des usagers vulnérables de la route, comme l'exige l'article 6b de la Directive révisée.

La méthodologie comprend deux approches : une pour l'évaluation des routes sur la base de l'analyse des occurrences d'accidents (méthodologie réactive, NWA-réactive) et une pour l'évaluation de la sécurité intégrée des routes (méthodologie proactive, NWA-proactive). Les deux méthodologies sont toutes deux appliquées sur le même réseau et les résultats de l'évaluation qui en résultent sont combinés via une méthodologie d'intégration pour fournir l'évaluation et le classement finaux du réseau routier.

Le manuel fournit des conseils étape par étape sur les deux approches ainsi que sur la procédure d'intégration des résultats d'évaluation réactive et proactive et d'estimation du classement de sécurité final de chaque section de route. En outre, le contexte théorique, les hypothèses et les considérations de développement pour chaque approche sont présentés (en annexes), ainsi que des guides d'utilisation concis pour les outils de calcul basés sur Excel qui ont été développés pour être utilisés par les praticiens de la sécurité routière.

Mots-clés : lignes directrices, occurrence d'accident, sécurité intégrée, méthodologie intégrée, autoroutes, routes principales.

Management Summary:

The aim of the present Handbook is to provide required guidance to road safety practitioners and road authorities regarding the effective implementation of the Network-Wide Road Safety Assessment (NWA) methodology, as endorsed by the Member States in the 13th meeting of the Expert Group on Road Infrastructure Safety (EGRIS) Plenary Session of November 21, 2022. The handbook is provided as methodological guidance to Member States according to Article 5 - point 5 of Directive 2008/96/EC, as amended by Directive (EU) 2019/1936.

The scope of the revised Directive (and of the NWA methodology) includes:

- roads which are part of the trans-European road network,
- motorways (rural and urban),
- other primary roads (i.e. roads outside urban areas that are right below motorways in Member States' road functional classification system), and
- other roads situated outside urban areas, which do not serve properties bordering on them and which are completed using Union funding.

The objective of the NWA methodology is to provide a cost-effective safety assessment of the road network within the scope of the Directive and ranking in at least three classes. The safety assessment is to be based on the evaluation of both the design characteristics of the road (in-built safety) and historic crash data (if available), and serves a screening purpose in order to prioritize in an efficient way either targeted road safety inspections or direct remedial actions. Particular emphasis is placed on the needs of vulnerable road users, as required in Article 6b of the revised Directive.

The methodology comprises two approaches: one for the assessment of roads on the basis of crash occurrence analysis (reactive methodology, NWA-reactive) and one for the assessment of the in-built safety of roads (proactive methodology, NWA-proactive). The two methodologies are both applied over the same network and the resulting assessment outcomes are combined via an integration methodology to provide the final road network rating and ranking.

The NWA-reactive methodology is based on the assessment of crash data on fatal and injury crashes for the last three years (at least). If such data are unavailable the reactive methodology cannot be implemented, and the assessment will be based on the outcome of the NWA-proactive. Crash data includes crashes with all road users, namely motor vehicles, bicyclists and pedestrians. Three segmentation approaches are considered. In the first one, sections include both segments and junctions. In the second and third approaches, junctions are assessed separately from road segments and the difference between the approaches lies in the junction length; this can either be predefined based on the junction type or measured. Sections are defined with the objective to be roughly homogeneous based on number of lanes, junctions' presence and horizontal curvature. Recommended maximum section lengths are provided for each road type, with the objective to ensure large enough sections and so, adequate number of crashes per section. Then, available crash data is located to sections (and junctions). The next step is the definition of reference population per road type. Two safety performance metrics can be used for the assessment, namely crash density and crash rate and for each metric an upper and lower threshold are defined for the assessment. Based on the threshold, sections are classified as "High risk: or "Low risk". If the analysis does not yield to statistically significant results, sections are classified as "Unsure". An excel-based tool has been developed for the implementation of the reactive methodology.

The NWA-proactive methodology is initiated with the correct identification of the road type. The geographical limits of the assessment are clearly defined. The proactive methodology requires a first stage of data collection that is essential for the network segmentation. Two approaches are considered for the segmentation. Either a fixed

length segmentation of short segments (e.g., of 600m) or a varying length segmentation, focusing on the formation of roughly homogeneous sections. Roughly homogeneous sections that consist of segments and junctions are defined based on traffic volume, horizontal curve, speed limit and terrain type data. A second stage of data collection follows to gather all necessary road and operational data for the assessment of the parameters; six parameters are used for the assessment of urban and rural motorways and nine parameters are used for the assessment of primary (or other EU-funded rural) roads. A Reduction Factor (RF) is estimated for each parameter and based on the value of all RFs the final score of the section is estimated. Based on this scoring, each section is ranked as "High risk", "Intermediate risk" or "Low risk". An additional scoring criterion, related to the sections traffic volume, is applied: if the section has very low traffic volume compared to rest of the network (i.e., belongs to the lowest 15% of traffic ranking) and if the section has been classified as "High risk", it is assigned to "Intermediate risk" class. An excel-based tool has been developed to assist in coding the information for each parameter and the respective reduction factor and then, estimate the final score of each section.

The integrated methodology combines the results of the proactive and the reactive methodologies. The integrated methodology assumes a five-class ranking system, namely "Very high priority", "High priority", "Intermediate priority", "Low priority", "Very low priority". As the proactive and the reactive methodologies use a different segmentation approach, it is described how to combine these two different segmentation approaches and produce the final sections of the network. This is the end of the NWA methodology. Follow-up actions (e.g., road safety inspection) are recommended based on the final ranking however, they are not part of this process.

Further to the above, Annexes A and B of the Handbook present the development considerations of the reactive and the proactive methodology, along with related background information and the scientific/ research justification and considered alternatives for finally adopted options. Annexes C and D serve as concise user's guides for the excel calculation tools that support the application of the reactive and the proactive methodology respectively.

Résumé analytique:

L'objectif du présent manuel est de fournir les orientations nécessaires aux praticiens de la sécurité routière et aux autorités routières concernant la mise en œuvre efficace de la méthodologie d'évaluation de la sécurité routière à l'échelle du réseau (NWA), telle qu'approuvée par les États membres lors de la 13e réunion du groupe d'experts sur la sécurité des infrastructures routières (EGRIS) du 21 novembre 2022. Le manuel est fourni à titre d'orientation méthodologique aux États membres conformément à l'article 5 - point 5 de la directive 2008/96/CE, telle qu'amendée par la directive (UE) 2019/1936.

La méthodologie NWA se compose de trois éléments : (a) la méthodologie d'analyse des occurrences d'accidents (NWA-réactive), (b) la méthodologie d'évaluation de la sécurité intégrée (NWA-proactive) et (c) la méthodologie intégrée (NWA-intégrée). Cette dernière combine les résultats des deux premières méthodologies en un seul système de classement. Une vue d'ensemble de ces composants est fournie tandis qu'il est également décrit de la manière dont les méthodologies développées au niveau national (ou autre) par l'UE peuvent s'adapter au concept de NWA.

La méthodologie réactive NWA couvre les autoroutes et les routes principales. Avant la mise en œuvre de la méthodologie, il est nécessaire de s'assurer que les données sur les accidents comprenant des accidents mortels et corporels pour les trois dernières années (au moins) sont disponibles et de bonne qualité ; sinon, la méthodologie ne peut pas être mise en œuvre et l'évaluation sera basée sur les résultats de la RNF proactive. Les données sur les accidents comprennent les accidents avec tous les usagers de la route, à savoir les véhicules à moteur, les cyclistes et les piétons. Trois approches de segmentation sont efficaces. Dans le premier, les sections comprennent à la fois des segments et des jonctions. Dans la deuxième et troisième approche, les carrefours sont évalués séparément des segments de route et la différence entre les approches réside dans la longueur des carrefours ; celle-ci peut être prédéfinie en fonction du type de jonction, soit mesurée. Les sections sont créées avec l'objectif d'être à peu près homogènes en fonction du nombre de voies, de la présence de carrefours et de la courbure horizontale. Les longueurs de section maximales recommandées sont fournies pour chaque type de route, dans le but d'assurer des sections suffisamment grandes et donc un nombre adéquat d'accidents par section. Les données sur les accidents sont spécifiques et localisées sur les sections (et les jonctions) et l'étape suivante est la définition de la population de référence par type de route. Deux paramètres de performance de sécurité sont proposés pour l'évaluation, à savoir la densité et le taux d'accidents et pour chaque paramètre, un seuil supérieur et inférieur sont définis pour l'évaluation. Sur la base du seuil, les sections sont classées comme « à haut risque » ou « à faible risque ». Si l'analyse ne donne pas de résultats statistiques significatifs, les sections sont classées comme « incertaines ». Un outil basé sur Excel a été développé pour la mise en œuvre de la méthodologie réactive.

La méthodologie proactive NWA est initiée avec l'identification correcte du type de route. Les limites géographiques de l'évaluation sont clairement définies. La méthodologie proactive nécessite une première étape de collecte de données indispensable à la segmentation du réseau. Deux approches sont proposées pour la segmentation. Soit une segmentation de longueur fixe de segments courts (par exemple, de 600 m) ou une segmentation de longueur variable, se concentrant sur la formation de sections à peu près homogènes. Des sections à peu près homogènes composées de segments et de jonctions sont définies en fonction du volume de trafic, de la courbe horizontale, de la limite de vitesse et des données de type de terrain. Une deuxième étape de collecte de données convient pour rassembler toutes les données routières et opérationnelles nécessaires pour l'évaluation des paramètres ; six paramètres sont utilisés pour l'évaluation des autoroutes urbaines et rurales et neuf paramètres sont utilisés pour l'évaluation des routes principales (ou d'autres routes rurales financées par l'UE). Un facteur de réduction (FR) est estimé pour chaque paramètre et sur la base de la valeur

de tous les FR, le score final de la section est estimé . Sur la base de cette notation, chaque section est classée comme "Risque élevé", "Risque intermédiaire" ou "Risque faible". Un critère de notation supplémentaire, lié au volume de trafic des sections, est appliqué : si la section a un volume de trafic très faible par rapport au reste du réseau (c'est-à-dire qu'elle appartient aux 15 % les plus bas du classement du trafic) et si la section a été classée comme "Risque élevé", il est classé dans la classe "Risque intermédiaire". Un outil basé sur Excel a été développé pour aider à coder les informations pour chaque paramètre et le facteur de réduction respectif, puis à estimer le score final de chaque section.

La méthodologie intégrée combine les résultats des méthodologies proactives et réactives. La méthodologie intégrée suppose un système de classement à cinq classes, à savoir "Très haute priorité", "Haute priorité", "Priorité intermédiaire", "Faible priorité", "Très faible priorité". Comme les méthodologies proactives et réactives utilisent une approche de segmentation différente, il est décrit comment combiner ces deux approches de segmentation différentes et produire les sections finales du réseau. C'est la fin de la méthodologie NWA. Des actions de suivi (par exemple, une inspection de sécurité routière) sont recommandées en fonction du classement final, mais elles ne font pas partie de ce processus.

En plus de ce qui précède, les annexes A et B du manuel présentent les considérations de développement de la méthodologie réactive et proactive, ainsi que les informations de base relatives et la justification scientifique et les alternatives envisagées pour les options finalement adoptées. Les annexes C et D servent de guides d'utilisation concis pour les outils de calcul Excel qui prennent en charge l'application de la méthodologie réactive et proactive respectivement.

Contents

1. INTRODUCTION

1.1 Concept and scope

So far, Member States usually assess road safety based on crash occurrence and aim to identify sections with high crash concentrations. Proactive approaches, such as targeted Road Safety Inspections, are primarily used as targeted measures towards selected road sections of generally small length, or towards specific road elements (e.g., intersections, interchanges, etc.), and not at a large scale. The Road Infrastructure Safety Management Directive 2008/96/EC, as amended by (EU) 2019/1936, complements this approach by formally introducing a new proactive approach assessing the in-built safety of roads based on their design characteristics - hence ex-ante, before crashes even happen - that can be applied at network level and not only as a targeted measure.

The Network Wide Road Safety Assessment Methodology, as presented in the present handbook, has been endorsed by the Member States in the 13th meeting of the Expert Group on Road Infrastructure Safety (EGRIS) Plenary Session of November 21, 2022. The methodology is provided as methodological guidance to Member States according to Article 5 - point 5 of Directive 2008/96/EC.

The Network Wide Road Safety Assessment Methodology is applicable for existing EU roads within scope of Directive 2008/96/EC, as amended by Directive (EU) 2019/1936, and specifically:

- roads which are part of the trans-European road network,
- motorways (rural and urban),
- other primary roads (i.e. roads outside urban areas that are right below motorways in Member States' road functional classification system), and
- other roads situated outside urban areas, which do not serve properties bordering on them and which are completed using Union funding.

The methodology may also be used by Member States to assess roads outside urban areas that are outside the scope of the Directive, on a voluntary basis.

1.2 Existing practices

Road safety assessment is carried out using different methodologies that can be broadly separated into two categories: methodologies that rely on crash occurrence (also known as reactive or ex-post) and those that evaluate the in-built safety of roads (known as proactive or ex-ante).

With regard to **reactive, crash-based assessment** methodologies, the review of existing practices in Europe and internationally identified several different methods, with variations on the safety performance metrics considered, the crash severity types considered, the criteria to classify locations as hazardous, the use of statistical tests, etc.. Overall, twenty two different methodologies currently applied in Europe, US and Australia were studied, including the AASHTO Highway Safety Manual method for hazardous location identification, the respective methods applied by AustRoads, the iRAP Crash Risk Mapping, as well as simple or complex methods developed and used at a national level by Member States. One important difference is related to the scope of the application with some methodologies focusing on the identification of hazardous locations across a network while others aiming at supporting authorities in network safety management process hence, their outcome is a network-wide ranking system illustrating the safety level of all sections. Both for European and international methodologies there are differences with respect to the used safety performance metrics, network screening technique and network segmentation, the classification of sections as hazardous or the ranking of the sections. Commonly identified trends in the examined methodologies are:

- the use of crash rates or crash cost as safety performance metrics,
- the consideration of crashes with fatalities and injuries and rarely Property-Damage-Only (PDO) crashes, and
- the consideration in the analysis of crash data of at least 3 years.

Proactive, in-built safety assessment methodologies can be separated in two broad categories: those that are applied at a site-specific or segment-specific level and are detailed, and those that are applied at the network-level. The first category is represented by Road Safety Inspections, which generally are not appropriate for assessments at a broad network level as they are demanding in terms of time and cost. In the latter category, the following subcategories may be defined: (a) crash prediction models (HSM, PRACT), (b) the iRAP Star Rating protocol, (c) the ANRAM model which is a combination of (a) and (b), and (d) various methods for the classification on networks based on geometric design and operational characteristics. Overall, nine existing in-built safety assessment methodologies were identified and analyzed, with the objective to identify their strengths and shortcomings and consider this information for the development of the network-wide, in-built safety assessment methodology. Particular emphasis was placed on the identification of parameters commonly used for the in-built safety assessment of roads and the assumed relationships between each parameter and crash risk. Commonly identified parameters concern cross-sectional and roadside characteristics of the road, the presence of horizontal and vertical curves, speed -related characteristics, maintenance-related characteristics, and design features related to pedestrians and bicyclists. Crash-related parameters are also sometimes used, mostly for the calibration of the predictive models. Although there are some basic parameters considered by most methods, there are considerable differences between methodologies on the way parameters are measured (e.g., a parameter can be treated as a binary variable vs a variable with multiple levels). Only methods that predict crashes (i.e., AASHTO Highway Safety Manual and PRACT models) provide a direct estimation of a parameter's relationship with crash risk, while other methodologies do not fully (or at all) justify the weights or importance of each parameter, and it is overall hard to compare the effectiveness of the safety rating system.

1.3 Methodology development synopsis

The development of the NWA methodology (reactive, proactive, integration) was based on the common consideration of:

- identified strengths and shortcomings of all aforementioned in-built safety assessment methodologies, reactive and proactive,
- data availability across Member States, as identified through a relevant questionnaire survey, as well as the feasibility of collecting critical missing data,
- parameters commonly used in existing practices or identified in relevant scientific literature as having a considerable impact to crash risk and/ or crash severity, and
- extensive feedback received from the Expert Group on Road Infrastructure Safety (EGRIS).

The following paragraphs summarise the main steps in the development of each part of the NWA methodology (reactive, proactive, integration).

1.3.1 Reactive methodology

The first conceptual framework for the methodology for reactive safety assessment of motorways and primary roads was conceptualized in **March 2021**. In this draft version of the methodology, the overall concept was outlined, consisting of four steps: (a) network segmentation, (b) safety performance metrics calculation, (c) thresholds estimation, and (d) safety ranking.

The first fully developed version of the reactive methodology was prepared in **September 2021**. This first version of the methodology was validated through a preliminary pilot implementation over several kilometres of roads in Italy and Greece.

A second, revised version of the reactive methodology was delivered in **April 2022**, incorporating feedback received from EGRIS meetings. Revisions included the consideration of individual and collective risk by estimation of both crash rate and crash density for every section/ junction, as well as terminology revisions. This version of the reactive methodology was used for the pilot studies.

During the pilot study phase across the EU, starting in June 2022, feedback was obtained to further improve both technical and practical aspects of the reactive methodology. A third revised version was therefore developed in **November 2022 - current version** endorsed by the Member States, with revisions including:

- the improvement of the segmentation criteria and the provided upper and lower thresholds for section lengths,
- the update of the estimation formula for the crash density metric, now also incorporating the number of years of crash data used for the analysis,
- the revision of the applied method for the threshold estimation; the Poisson method is now used for estimating the confidence intervals of the observed number of crashes per section instead of estimating the expected crash density for the section, and
- the prioritization of crash rate (if traffic data are available) for the final ranking of a section, instead of the most conservative outcome between the crash rate and crash density.

1.3.2 Proactive methodology

The first conceptual framework for the proactive network-wide safety assessment methodology was delivered in **March 2021** and incorporated a modular approach, with a low-cost, low-data needs methodology, namely Network-Wide Assessment-basic (NWA-b), and a higher cost, higher data needs methodology, namely Network-Wide Assessment-advanced (NWA-a). The parameters envisioned to be considered for each methodology were thirteen (13) for the basic methodology NWA-b and twenty seven (27) for the advanced methodology NWA-a.

Through the discussions on this draft concept held in EGRIS meetings, it became evident that more simple methodologies were desired by experts and Member States, considering a smaller number of assessment parameters. Taking this feedback into consideration, a new fully working version of the "in-built" network-wide safety assessment methodology was delivered in **November 2021**, still retaining the modular concept of NWA-b and NWA-a, and separating the safety modelling approach for motorways and for primary roads. Parameters utilized in the assessment were considerably reduced in number; five (5) parameters for motorways and seven (7) for primary roads in the basic methodology NWA-b, and eight (8) parameters for motorways and eleven (11) for primary roads in the advanced methodology NWA-a. The safety impact of each parameter was estimated based on findings from relevant international research, a mathematical formula for the estimation of a combined safety score was established, criteria for the segmentation process were defined and a comprehensive excel calculation tool was developed to assist in the assessment process. The methodology was pilot tested on a 50,6km long section of a rural motorway in southern Greece, and on a 19km long section of an undivided rural road in central Greece, part of the national road network.

Several EGRIS meetings as well as bilateral communications between experts and Member States took place over a period of several months that provided valuable comments and feedback and resulted in a new revised version of the proactive methodology in **April 2022**, with the following modifications and improvements:

1. NWA-basic and NWA-advanced have been merged into a single methodology (hence NWA-proactive, NWA-p). It was realized that the additional parameters considered in NWA-a were limited in number and required already available or easily collectable data; as a result there was no purpose in having two methodologies.
2. Primary divided and undivided roads are now assessed separately, in order to be consistent with the crash analysis ("reactive") methodology.
3. Separate scoring for some assessment parameters for urban motorways has been developed (namely for lane width, interchanges and curvature), inline with differences in consideration of rural versus urban motorways in national design guidelines and reflecting the lower speeds generally observed in urban environment.
4. A filter based on traffic volumes (AADT) has been included as a prerequisite for the classification of a road segment in the highest risk class (worst assessment category), in order to ensure that the (limited) funds available for road safety are not commonly spent on low volume roads, in which the result in terms of benefit for society will be less.
5. The parameter "Quality of signs and markings" for motorways has been removed, since motorways are usually well maintained and have high quality signage, and also the parameter's impact on the overall scoring is anyhow very limited (2% as a maximum).
6. Minor modifications in the estimation of reduction factors for various parameters have been considered.

The version of April 2022 of the proactive methodology was implemented at a pilot stage to over 700km of road segments across 8 Member States, and feedback from its implementation was collected, analyzed and discussed in EGRIS. Taking into consideration the feedback and the pilot experience, a further revised version was developed in **November 2022 - current version** endorsed by the Member States, with the following modifications and improvements:

1. The considered gore points for the parameter "Interchanges" for motorways have been revised, to address the case of segments located very close to the gore points, yet not including them.
2. The option of sidewalks has been examined for the parameter "Roadside", both for motorways and for primary roads.
3. The possibility to consider in the assessment actual operation speed (V85) data for primary roads, if available, has been added where applicable.
4. The parameter "Lighting" has been removed, both for motorways and for primary roads.

1.3.3 Integration

The methodology for the integration of assessment results was first conceptualized in September 2021. Adjustments were subsequently made based on feedback received from EGRIS and the experience gained through the pilot implementation, resulting in the **current version of November 2022** as endorsed by the Member States.

1.4 Objective

According to the relevant requirements for network wide road safety assessment defined in Directive 2008/96/EC (as amended by Directive (EU) 2019/1936), the objective of the network wide road safety assessment methodology is to provide a cost-effective safety assessment of the road network within the scope of the Directive and ranking in at least three classes. The safety assessment is to be based on the evaluation of both the design characteristics of the road (in-built safety) and historic crash data (if available), and serves a screening purpose in order to prioritise in an efficient way either targeted road safety inspections or direct remedial actions. Particular emphasis is placed on the needs of vulnerable road users, as required in Article 6b of the revised Directive.

1.5 Overview of methodology

The Network-Wide Assessment (NWA) methodology comprises two assessment approaches: one for the assessment of the in-built safety of roads (proactive methodology, **NWA-proactive**) and one for the assessment of roads on the basis of crash occurrence analysis (reactive methodology, **NWA-reactive**). The two methodologies are both applied over the same network and the resulting assessment outcomes are combined via an integration methodology to provide the final road network rating and ranking. The overall concept and components of the NWA are presented in Figure 1.1.

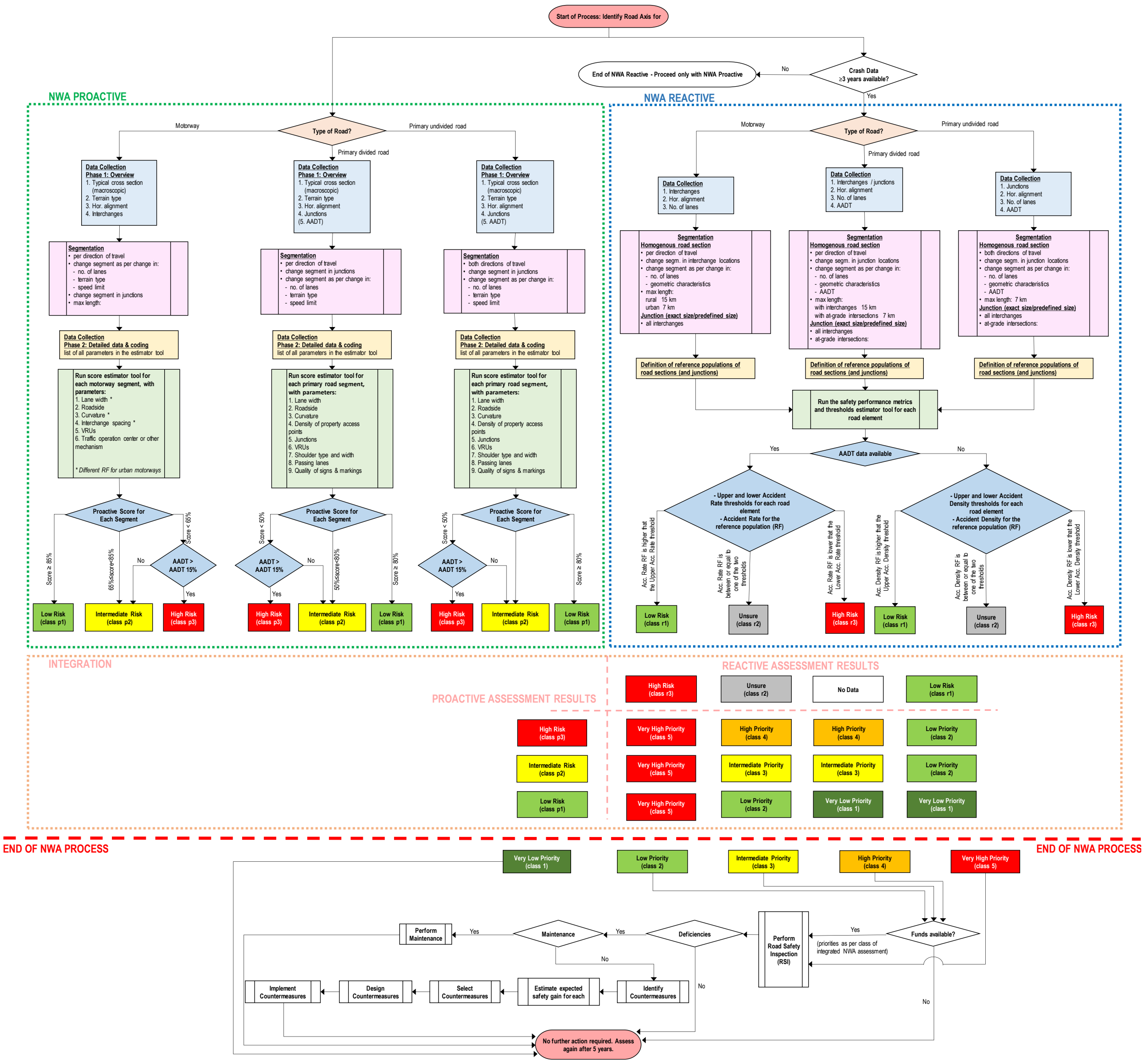


Figure 1.1: *NWA flowchart.*

The NWA process starts with the identification of the road axis to be assessed and the investigation of whether crash data of adequate timespan, i.e., for at least three years[1], and quality (especially with regards to crash geographic location and data reliability) are available. If such data are available, both methodologies, NWA-proactive and NWA-reactive are applied for the safety assessment of the road axis; if not, the NWA-reactive methodology cannot be applied, and only the NWA-proactive methodology is implemented.

The step after the implementation of the two methodologies (or only the NWA-proactive if reliable crash data are not available), is to integrate the outcome of the two methodologies and determine the final rating and ranking on the road. A set of **follow-up actions after** the implementation of the NWA are also illustrated in Figure 1.1, however these actions are out of the scope of the methodology and are not discussed in this document.

1.5.1 Network Wide Assessment - reactive

The NWA-reactive methodology (or simply the reactive methodology) aims to assign a section or junction to one safety class **on the basis of statistical analyses of crash data**. The methodology differentiates between the road type, i.e., rural or urban motorway, divided rural road or undivided rural road The crashes to be considered are those that involve at least one casualty (i.e., fatality or injury) and must refer to a period of at least three years.

The implementation of the reactive methodology involves the segmentation of the network which can be performed using three alternative segmentation approaches; the network is divided in a set of sections or a set of sections and a set of junctions. Using the Poisson method, upper and lower thresholds are defined for the observed number of crashes of each section (and junction). Then, these thresholds are converted to crash density and crash rate thresholds for each section. For the final ranking of the section it is recommended to rely on the crash rate comparison, if they are available. Otherwise, the ranking relies on the crash density comparison. Each section is classified as "low risk", "unsure" or "high risk".

If reliable crash data for at least three years are not available, the reactive methodology cannot be implemented.

Details and guidance for the implementation of the reactive methodology are provided in Chapter 2.

[1] A longer period of time (>3 years) could be used when few crashes by year are recorded

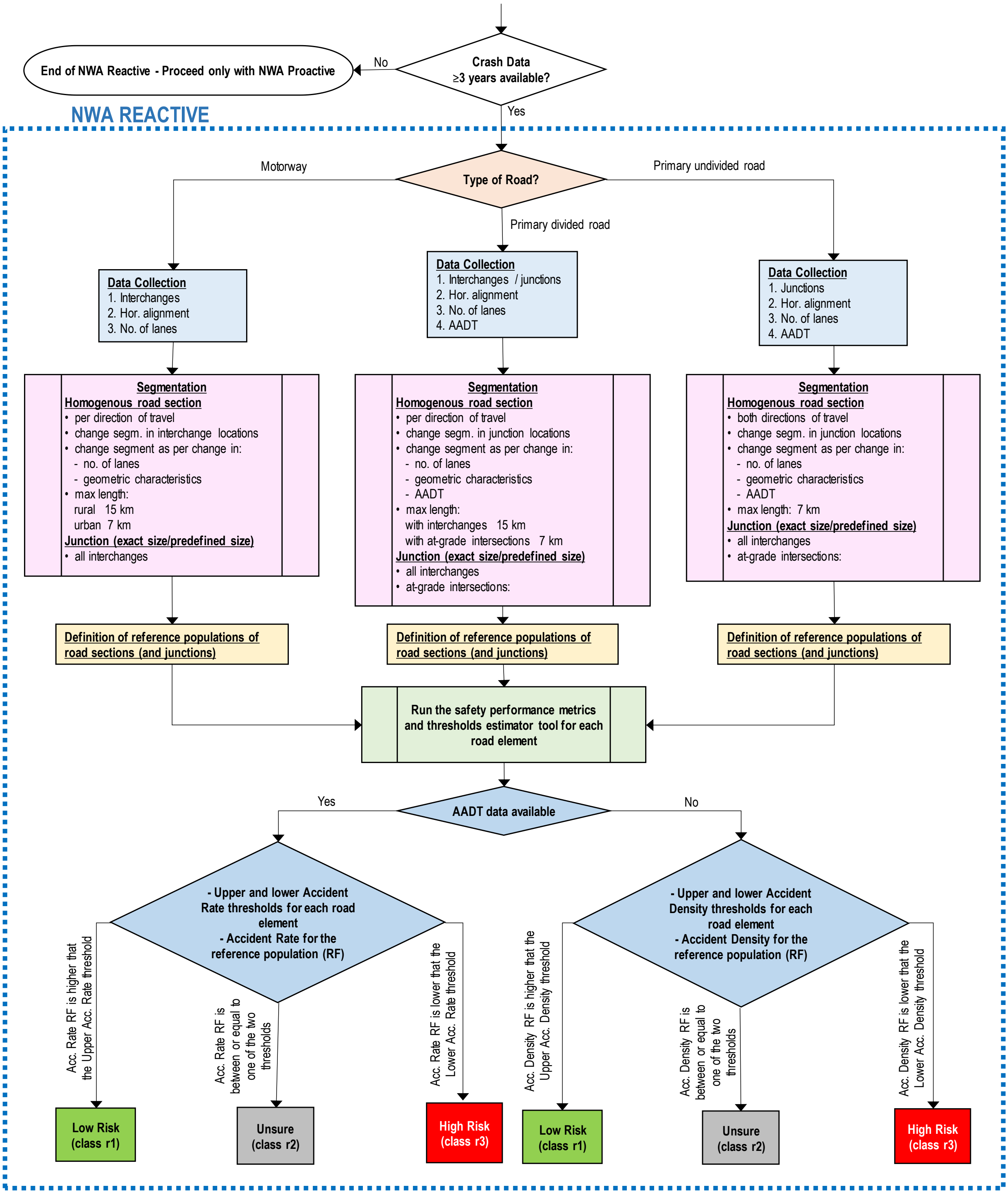


Figure 1.2: *NWA-reactive flowchart.*

1.5.2 Network Wide Assessment - proactive

The implementation of the proactive methodology consists of the parts shown in the following flowchart (Figure 1.3). The methodology differentiates between the road type, i.e., rural or urban motorway, divided rural road or undivided rural road. The network also needs to be segmented for the implementation of the proactive methodology. Sections are formed by segments and junctions, and are not necessarily identical to the segments of the reactive methodology, as segmentation criteria are different.

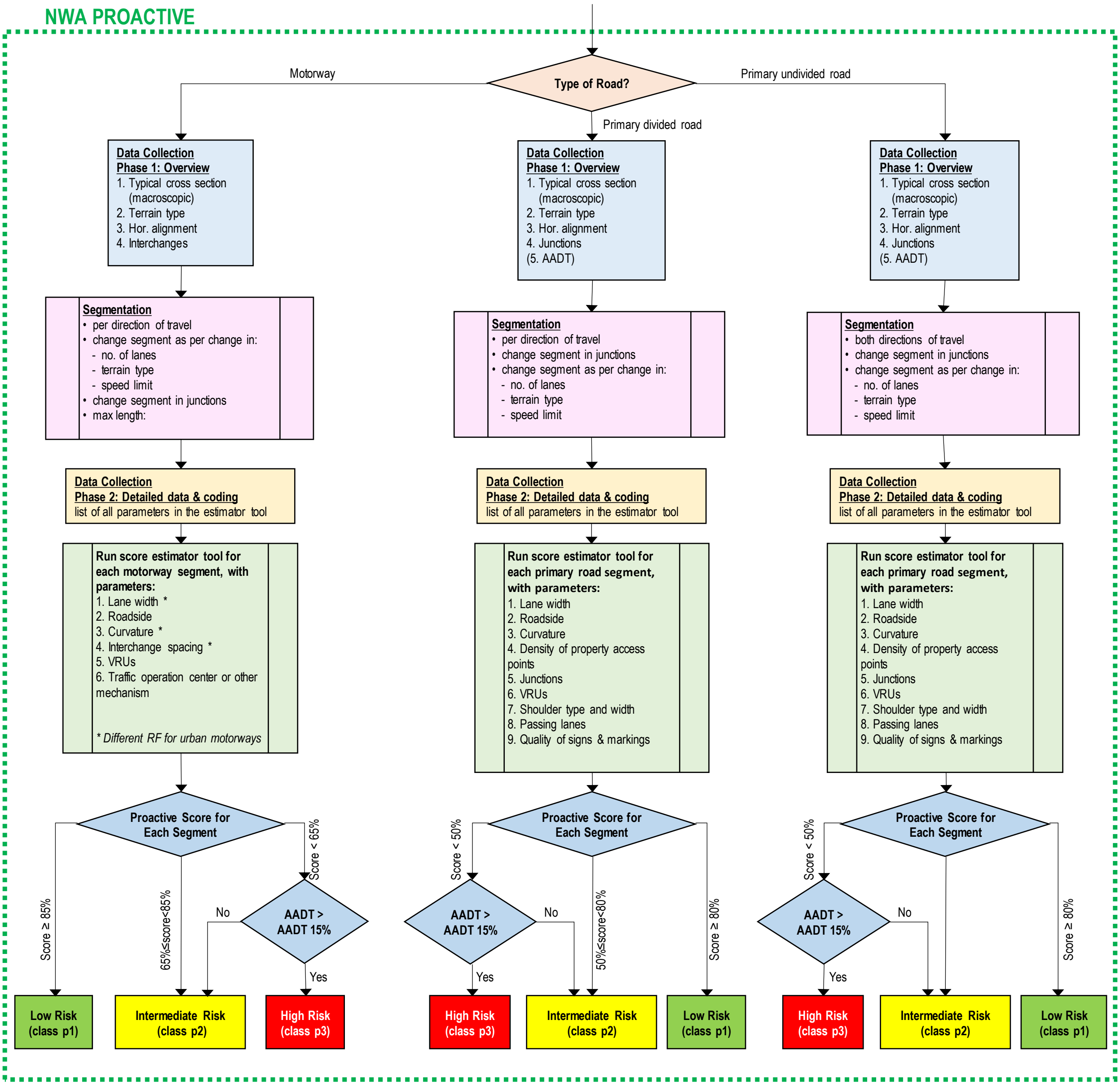


Figure 1.3: *NWA-proactive flowchart.*

Each road section is assessed based on a set of design or operational characteristics. Different characteristics are considered for motorways and primary (or other[2]) rural roads, but the overall logic of the assessment is the same. An ideally safe road section receives a safety score equal to 100 points. Less safe sections get a lower score, and reduction is determined with the use of Reduction Factors (RF). Each RF corresponds to a parameter used for the assessment of roads and expresses the safety level of the specific parameter. RFs range from zero (without being equal to zero) to one and one corresponds to the safest condition.

$$Score_i = 100 \times RF_{1i} \times RF_{2i} \times \ldots \times RF_{ni}$$

[2] Roads that are below primary rural roads in a Member State's road functional classification system, are outside of urban areas and have received EU funds.

Based on the score, a road section is classified as “low-risk”, “intermediate-risk” or “high-risk. Both motorway and primary (or other rural) road sections are assessed based on a procedure that relies on Reduction Factors and three safety classes; however, different parameters and different scores are used for the assessment of each road type as they have significant differences in design and operational characteristics. Specifically, the distinguished road types are: rural motorways, urban motorways, primary divided roads, primary undivided roads. Scores between different road types are not comparable.

Parameters considered for the in-built safety assessment of roads differ for motorways and for primary (or other) rural roads and are as follows (Table 1.1):

Table 1.1: *Considered in-built safety parameters for NWA-proactive*

Number	Parameter
	MOTORWAYS
1	Lane width *
2	Roadside (clear zone width, obstacles, presence of barriers)
3	Curvature *
4	Interchanges *
5	Conflicts between pedestrians/ bicyclists and motorized traffic
6	Traffic operation centers and / or mechanisms to inform users for incidents
	PRIMARY ROADS
1	Lane width **
2	Roadside (clear zone width, obstacles, presence of barriers) **
3	Curvature
4	Density of property access points **
5	Junctions
6	Conflicts between pedestrians/ bicyclists and motorized traffic
7	Shoulder type and width **
8	Passing lanes **
9	Signs and markings

Notes:
1. *Parameters noted with one asterisk are treated differently for urban and rural motorways.*
2. *Parameters noted with two asterisks are treated differently for divided and undivided primary roads.*

In addition to the above assessment parameters, operational characteristics such as traffic volume - AADT (if data is available), speed limit and presence of automated speed enforcement (or operation speed V_{85}, if data is available), affecting either the safety scoring (Reduction Factors) of selected parameters or the final ranking. At the end of the proactive methodology implementation, every road section is classified as "high risk", intermediate risk" or "low risk".

Details and guidance for the implementation of the proactive methodology are provided in Chapter 3.

1.5.3 Network Wide Assessment - integration

As briefly presented above, each road network is typically assessed using both the NWA-proactive and the NWA-reactive methodologies. The NWA-proactive methodology classifies each road section in three classes, namely "high risk", intermediate risk" or "low risk", whereas the NWA-reactive methodology classifies a road section as "low risk" or "high risk", if statistically significant results are obtained; otherwise, a section is classified as “unsure”. The case of not having adequate crash data to implement the NWA-reactive methodology (e.g., on recently constructed roads) is considered to yield a result of "no data".

The NWA-integrated methodology assumes a rule-based, straightforward system to classify each road section in one out of five classes, considering the results of the NWA-proactive and NWA-reactive methodologies. The **five classes** of the integrated methodology correspond to a colour and have been named according to the relevant level of priority for safety related actions after the end of the NWA procedure, e.g. targeted Road Safety Inspection, identification of appropriate countermeasures, selection, design and implementation of safety treatments.

The five integrated NWA classes are named and colour coded as follows (Figure 1.4).

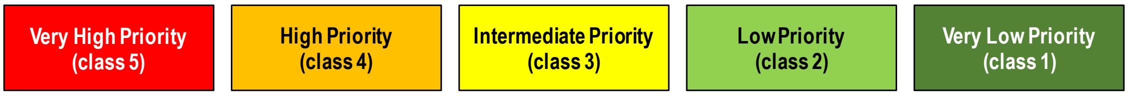


Figure 1.4: *Classes of integrated Network Wide Assessment.*

- Class 5 (worst performing): Very High Priority - colour: red
- Class 4: High Priority - colour: orange
- Class 3: Intermediate Priority - colour: yellow
- Class 2: Low Priority - colour: light green
- Class 1 (best performing): Very Low Priority - colour: dark green

Details and guidance for the implementation of the methodology for the integration of NWA results are provided in Chapter 4.

1.6 Document map

The present handbook is structured as follows:

Chapter 1 - Introduction (this chapter) provides initial information, context and the overall framework for the network-wide assessment (NWA) methodology.

Chapter 2 - The Reactive Methodology is focused on the methodology based on the analysis of existing crash data (hence referred to as NWA-reactive). Staring from the scope of the application and limits of the assessment, the Chapter then provides guidance on network segmentation and data collection. The estimation of crash metrics to assess safety levels is defined and finally, it is explained how to rate and rank a section based on these metrics.

Chapter 3 - The Proactive Methodology focuses on the part of the methodology assessing the in-built safety of roads based on their design characteristics (hence referred to as NWA-proactive). The scope of application is presented and the limits of the assessment are defined, along with the segmentation requirements process for the implementation of the methodology. Data requirements are described and detailed guidance on data collection and coding is provided. Parameters considered in the assessment are described, along with the scoring of the parameters, the assessment rating and ranking of each section.

Chapter 4 - The Integrated Approach describes the integrated methodology that allows assessment results of the proactive and reactive methodologies to be combined in order to produce the final rating and ranking of the examined road network.

Annexes: The development of the reactive and the proactive methodology are presented in Annexes A and B of the present handbook, along with related background information and the scientific/ research justification and considered alternatives for finally adopted options. Annexes C and D serve as concise user's guides for the excel calculation tools that support the application of the reactive and the proactive methodology respectively.

2. THE REACTIVE APPROACH

This chapter presents a **step-by-step guide** on the application of the crash occurrence analysis methodology of the network-wide road safety assessment, also noted as **NWA-reactive**. The following flowchart (Figure 2.1) illustrates the steps to be followed for the implementation of the NWA-reactive.

Annex C presents steps on how to use the excel-based tool that was developed to support the implementation of the reactive methodology.

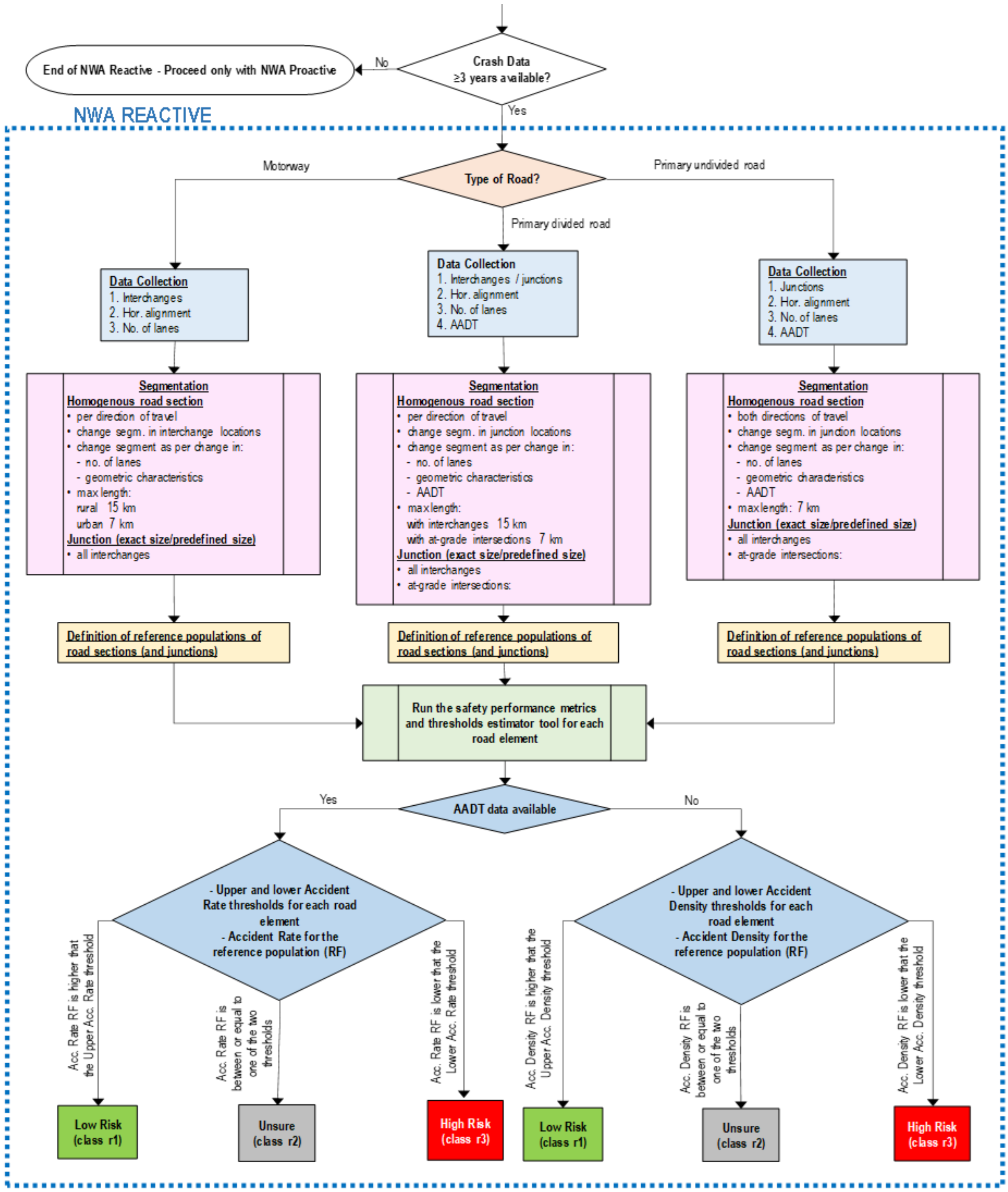


Figure 2.1: *NWA-reactive flowchart.*

2.1 Scope of application

The crash occurrence analysis methodology also mentioned as "NWA-reactive" is applicable for urban and rural **motorways** and **primary or other rural roads covered by the 2008/96/EC Directive**. In the case of non-primary rural roads, low-volume and/or low-functionality roads, they can potentially be assessed using the methodology for primary undivided roads.

The crash occurrence analysis methodology assesses roads taking into consideration **all road users** that may be present on the road. In that sense, it is not limited to motorized vehicles only, but instead it also considers the safety of bicyclists and pedestrians, noted as **VRUs** (Vulnerable Road Users). Therefore, crashes that involve these road users are also to be considered in the analysis.

With regard to **road tunnels**, the crash occurrence analysis methodology is not applicable. It is also noted that tunnels with a length over 500m are also outside the scope of the Road Infrastructure Safety Management Directive 2008/96/EC. Therefore, road tunnels are expected to be excluded from the assessment which in practice means that tunnels sections and crashes that have occurred there will not be considered for the assessment.

With regards to **bridge** sections on motorways and primary roads, the crash occurrence analysis methodology is applicable, as with other road sections.

With regards to **toll station areas**, the crash occurrence analysis methodology is not applicable, as these areas are particularly complex. Toll station areas as well as crashes occurring in toll stations areas are to be excluded from the assessment.

2.2 Geographical limits of the assessment

This section presents the limits of the assessment of the NWA-reactive methodology, and in turn of the integrated one. The focus is on roads covered by the Directive 2008/96, while some extensions are foreseen in the area of junctions as explained below.

In **motorways**, either urban or rural, the following parts are considered:

- **Motorway segments**
  All motorway segments are assessed by the reactive methodology. Therefore, crashes occurring on motorway segments are considered for the analysis in addition to the respective traffic volume (if these data are available).
- **Interchanges**
  For interchanges, the assessment considers the location of exit and entry ramps to derive the spacing between consecutive ramps (within the same interchange or between successive interchanges). Crashes occurring on the aforementioned parts a motorway are considered for the analysis. If an interchange connects a motorway or a primary divided rural road with a road not covered by the Directive, then, no part of the secondary road and in turn, no crashes occurring at the secondary road are considered.
- **Ramp segments**
  Ramp segments are considered in the methodology but as part of the interchange. Therefore, crashes occurring on ramp segments count as interchange crashes.
- **Over- or underpasses** of local roads above or below a motorway are not considered by the methodology.

In **primary roads** (or other rural roads within scope of Directive 2008/96/EC), the following parts are considered:

- **Road segments**
  All primary road segments are assessed by the reactive methodology. Therefore, crashes occurring on primary road segments are considered for the analysis in addition to the respective traffic volume (if these data are available).
- **Junctions**
  The assessment considers junctions (grade-separated or at-grade intersections). In the case of at-grade intersections, the part of the secondary road to be considered for crashes is the part starting from the middle point of the intersection to the point where the cross-section of the secondary road reinstates to its initial width.
- **Over- or underpasses** that crashes on over/ underpasses of motorways are not counted as motorway crashes.

2.3 Identification of road type

Based on the flowchart (Figure 2.1) for the reactive methodology, the first step is to determine the road type of the road axis to be assessed. There are four road types:

1. Motorway - rural
2. Motorway - urban
3. Primary road - divided
4. Primary road - undivided

The following notes are also provided to assist in the road type identification process.

- For the identification of **motorways** and **primary roads**, the definitions of Directive 2008/96/EC shall apply.
- The **road type might change** along the same road axis. For example, a motorway connecting two major cities might be classified as urban for the first and last sections (inside or near city limits) and rural for the part crossing the countryside.
- The road type should not change inside a section (see also section 2.5 on segmentation). In the above example, a new section should start at the limit of the urban area.
- The identification of the exact point where the type of a motorway changes from urban to rural should rely on criteria such as (indicatively): applied design standards and design speed (if known), speed limit, land use next to the motorway, type and distance between interchanges. No specific values are defined for these criteria; road safety practitioners are expected to judge on a case-by-case basis applying engineering judgement.

2.4 Overview of data collection and assessment

The NWA-reactive methodology can be implemented only if at least three years of **crash records** on crashes with casualties are available for the assessed road. Therefore, the first step is to make this check. If these **data are not available,** the **reactive methodology cannot be implemented**.

When crash data are available for a period of at least three years and are also of good quality, the reactive methodology involves **three stages of data collection**:

1. Data to perform the network segmentation (overview data).

2. Data to estimate the reference population group statistics (detailed data); see section 2.6 for the definition of the reference population. These data consist of:

    a. Crash data with crashes with casualties for at least three years for roads with same characteristics

    b. Total length of those roads

    c. Average traffic volume data for those roads (if these data are available)

3. Data for the road under assessment (detailed data): crash data collection and traffic volume (if these data are available)

Stage 1 (overview data) is different from stages 2 and 3 as they concern different types. However, it is a good practice whenever possible to acquire all relevant data at once, for example, all data stored in road design files (e.g., CAD files (.dwg) or paper format), in road inventory databases (registries), or through targeted geometric data collections using online tools (e.g., Google Maps, Google Earth, OpenStreetMaps) or site surveys.

The following subsections provide further guidance for the 1st stage of overview data collection, prior to the segmentation process. Guidance for the 2nd and 3rd stages is provided in section 2.6.

2.4.1 Motorways

For urban and rural motorways data is more likely to be available (e.g., through the road constructor or road operator) and so, it is more likely to be easily retrieved.

2.4.2 Primary or other rural roads

Relevant road data for rural roads can also be derived from CAD files or other databases. In some cases, it is expected that data for rural roads is less organized and, in this case, it may be required to retrieve road data using online tools (e.g., Google Maps, Google Earth, OpenStreetMaps) or even site surveys.

2.5 Segmentation

This section describes the way a road network is divided in smaller parts, which can be either **sections or junctions**. As section is defined the part of the road between two junctions. This part may be further divided in smaller parts, which are called **homogeneous sections**. The criteria to define a homogeneous section are given below. Each homogeneous section (or junction) is a unit of analysis for the reactive methodology.

Some **general points** regarding the segmentation in the **reactive methodology** are:

- A road can be divided into smaller parts based on one of the following three approaches.
    - Approach 1: Sections that include both road segments and junctions
    - Approach 2: Sections that include only road segments and junctions (of predefined dimensions)
    - Approach 3: Sections that include only road segments and junctions (of measured dimensions)
- Across a specific road category (e.g., rural motorways) more than one approaches can be selected. What matters is not to mix segmentation approaches along the same road.
- Roads are divided in (roughly) **homogeneous sections**.

- Road **tunnels** are excluded from the assessment (see also section 2.1). Defined road sections in the segmentation process should end before the tunnel entrance and start after the tunnel exit.
- **Toll station areas** are excluded from the assessment (see also section 2.1). Defined road sections in the segmentation process should end before the beginning of the toll plaza widening and start after the road assumes a uniform cross section after the toll plaza.
- With regards to **bridge** sections on motorways and primary roads, the reactive methodology is applicable, as with other road sections. In case of long bridges (e.g. more than 200m), it is recommended to apply a separate section for the bridge.
- It is recommended to **align** the start and end points of sections for the proactive assessment to start and end points of sections for the reactive assessment if they are close to each other (e.g., less than 100m apart), as this will reduce the effort of integrating the two methods results and eliminate short length segments in the final (integrated) results. Considering that the reactive methodology requires larger segments for reasons of statistical validity, it can be expected that segments for the crash-based assessment will normally include more than one proactive assessment segments.
- Depending on the road category, **upper thresholds** are recommended for the **section's length**; these upper values are not mandatory and mainly aim to express the magnitude of the section's length.

2.5.1 Motorways

For motorways, urban or rural, **each direction of traffic** is analyzed separately. Therefore, each direction of traffic has its own segmentation. Exemptions are allowed only in the case that all/the majority of crash records lacks the information regarding the direction of traffic.

Generally, sections are formed between successive interchanges. So, an interchange is the start point of a section and the following interchange is the end point of that section. Only in the case of urban motorways, it may happen that the section between two junctions is too short compared to the dimensions suggested below, in which case it may be decided to extend the section to the following junction (thus the section will contain a junction).

A road section between two interchanges can be divided in more parts with the objective to have **homogeneous sections.** Three data types are taken into account for the segmentation process of motorways, namely **(a)** interchange location, **(b)** horizontal alignment and **(c)** number of lanes. Additionally, to those characteristics, recommended maximum section lengths are provided below for rural and urban motorways.

- **Location of interchanges**

The location of the interchanges offers a first rough segmentation of the network.

Depending on data availability on interchange location and dimensions, three alternative approaches for the segmentation can be used. The decision to consider junctions as distinct and separate units from sections is only a matter of data availability.

Approach 1- Homogenous road sections:

a. A first rough section is defined between two successive junctions and the start and end points of the section are the respective midpoints of the junction.

b. This section can be further divided into homogeneous sections, based on the curvature and number of lanes criteria, if it is not already homogeneous.

Approach 2 – Homogenous road sections and junctions of fixed dimensions:

This approach differentiates between road segments and junctions (interchanges).

a. Interchanges, depending on their type, have fixed/predefined dimensions. The start and end points of a junctions are defined based on their fixed dimension and their midpoint. Table 2.1 lists the predefined dimensions for the various types of interchanges.

b. Sections are defined as the parts between two successive junctions.

c. A section can be further divided into homogeneous road sections based on the curvature and number of lanes criteria, if it is not already homogeneous.

Approach 3 – Homogenous road sections and junctions of measured dimensions:

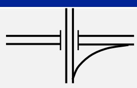
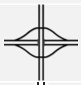
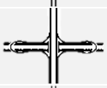
This approach differentiates between road segments and junctions (interchanges).

a. Interchanges, depending on their type, have fixed/predefined dimensions. The start and end points of a junctions are defined based on their fixed dimension and their midpoint.

b. Sections are defined as the parts between two successive junctions.

A section can be further divided into homogeneous road sections based on the curvature and number of lanes criteria, if it is not already homogeneous.

Table 2.1: *Interchanges fixed, predefined dimensions.*

Junction type	Sketch representation	Predefined dimension
Single ramp		200 m
Trumpet		400 m
Diamond		500 m
U-turn*		700 m
Cloverleaf		800 m
Cloverstack		900 m
T-Bone		900 m
Complex geometry	-	1000-1200 m

** this type of junction is not a simple U-turn, but also includes the flow from the intersecting road*

For the approach 3, the dimension of an interchange is the distance between the starting point of the diverging lane and the ending point of the merging lane.

- **Number of lanes**

  Sections should be as homogeneous as possible in terms of the number of lanes. Auxiliary lanes are not considered when defining homogeneous sections (e.g., in the area of an interchange). A new section needs to be defined if the number of lanes changes.

- **Horizontal alignment**

  Sections should be as homogeneous as possible in terms of horizontal alignment. A distinction should therefore be made between tortuous road sections (i.e., with a series of sharp bends) and straight/ gently curving sections. This subdivision criterion can only be met if the length of the resulting sections is consistent with the lengths suggested below.

Recommended ranges for the section lengths are provided for the case of rural and urban motorways.

- Rural motorways: 10 ± 5km (max length = 15km)
- Urban motorways: 5 ± 2 km (max length = 7km)

These lengths are provided to illustrate the **difference in magnitude** between the rural and urban motorways. Shorter or longer sections can also be formed, provided that (a) they are homogeneous and (b) the thresholds are not exceeded by far. For example, it is highly recommended to use sections lengths close to 1km as the analysis will resemble more a hot-spot analysis rather a network-wide. It is highly recommended to avoiding having very large sections, e.g., 20km or more, as it would be difficult to locate the potential unsafe issues.

2.5.2 Primary divided rural roads

For primary divided rural roads (or other divided rural roads covered by the Directive 2008/96/EC), **each direction of traffic** needs to be analyzed separately. Therefore, each direction of traffic will have its own segmentation. However, if crash data is not available per direction of traffic, a section needs to include both directions of traffic.

Four data types are taken into account for the segmentation process of primary divided rural roads, namely **(a)** junction location and dimensions, **(b)** horizontal alignment, **(c)** number of lanes (per direction of traffic) and **(d)** traffic volume:

- **Location of interchanges and at-grade intersections**

  The location of junctions, which can be either grade-separated or at-grade intersections, offers a first rough segmentation of the network.

  Depending on data availability on junction location and dimensions, three alternative approaches for the segmentation can be used. The decision to consider junctions as distinct and separate units from sections is only a matter of data availability.

  Approach 1- Homogenous road sections:

  a. A first rough section is defined between two successive junctions and the start and end points of the section are the respective midpoints of the junction.

  b. This section can be further divided into homogeneous sections, based on the curvature and number of lanes criteria, if it is not already homogeneous.

  Approach 2 – Homogenous road sections and junctions of fixed dimensions:

  This approach differentiates between road segments and junctions.

a. Junctions, depending on their type, have fixed/predefined dimensions. The start and end points of a junctions are defined based on their fixed dimension and their midpoint. Table 2.2 lists the predefined dimensions for the various types of interchanges. An illustrative example for segmentation in the area of a junction is provided in Figure 2.2.

b. Sections are defined as the parts between two successive junctions.

c. A section can be further divided into homogeneous road sections based on the curvature and number of lanes criteria, if it is not already homogeneous.

Approach 3 – Homogenous road sections and junctions of measured dimensions:

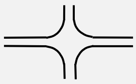
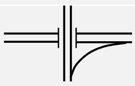
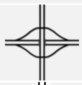
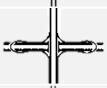
This approach differentiates between road segments and junctions (interchanges).

a. Interchanges, depending on their type, have fixed/predefined dimensions. The start and end points of a junctions are defined based on their fixed dimension and their midpoint.

b. Sections are defined as the parts between two successive junctions.

c. A section can be further divided into homogeneous road sections based on the curvature and number of lanes criteria, if it is not already homogeneous.

Table 2.2: *Junction fixed, predefined dimensions.*

Junction type	Sketch representation	Predefined dimension
At-grade intersection		100 m
Single ramp		200 m
Trumpet		400 m
Diamond		500 m
U-turn*		700 m
Cloverleaf		800 m
Cloverstack		900 m
T-Bone		900 m

** this type of junction is not a simple U-turn, but also includes the flow from the intersecting road*

The dimension of a junction should be measured as the distance between the starting point of the diverging lane and the ending point of the merging lane.

- **Number of lanes**

Sections should be as homogeneous as possible in terms of the number of lanes. Auxiliary lanes are not considered when defining homogeneous sections (e.g., in the area of a junction). A new section needs to be defined if the number of lanes changes.

- **Horizontal alignment**

Sections should be as homogeneous as possible in terms of horizontal alignment. A distinction should therefore be made between tortuous road sections (i.e., with a series of sharp bends) and straight/ gently curving sections. This subdivision criterion can only be met if the length of the resulting sections is consistent with the lengths suggested below.

- **Traffic volume**

A new section should be defined where there are major changes in the traffic volume.

Recommended ranges for the section lengths are provided for primary divided roads. It is important to note that the sections used for the reactive methodology are quite long. For primary divided rural roads the following **section lengths are recommended**:

- If the road has interchanges: 10 ± 5 km
- If the road has at-grade junctions: 5 ± 2 km

These **lengths are indicative**, to understand the magnitude of the section lengths in the case of different road types, and not mandatory to follow. It is highly recommended to form sections as homogeneous as possible. Additionally, it is recommended to avoid having too short (e.g., 1km) or two large sections (around 20km or more).

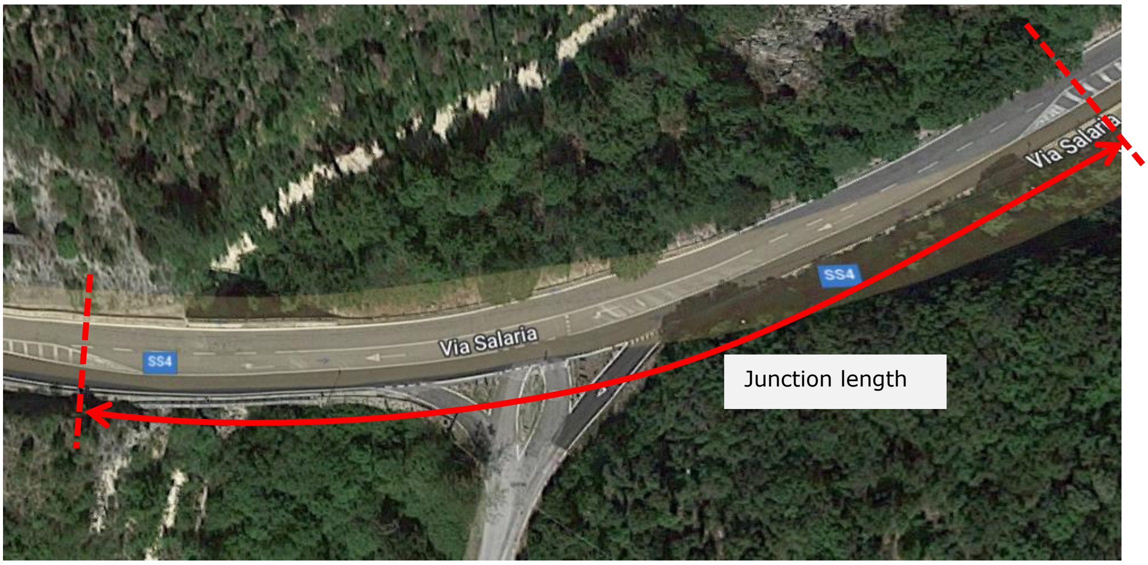
2.5.3 Undivided primary rural roads

The segmentation process is similar to the case of divided rural roads. There are three differences:

1. For undivided primary rural roads (or other undivided roads that have received EU funds), **both directions of traffic** are assessed and so, the segmentation is performed for both directions.

2. There are no grade-separated junctions, and so, in the 2nd segmentation approach the only needed fixed junction length is that of at-grade intersections, which is considered equal to 100m.

3. Recommended ranges for the section lengths are: 5 ± 2 km.



Maps data: Google, © 2023, Imagery Date: 6/2/2022

Figure 2.2: *Example of segmentation at the area of an at-grade intersection.*

At the **end of this step** there should be a list will all sections (or junctions) showing the section's number, its start and end point, and its length.

2.6 Data collection

This section describes the data collection process, noted as detailed data collection. It consists of two parts: 1. Data for the road axis under assessment and 2. Data for the reference population.

2.6.1 Road axis level

2.6.1.1 Crash data

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

- Include at least 3 years of road crashes (for the under-study road axis).
  – if this information is not available, then the reactive methodology cannot be implemented.
- Include crashes that involve at least one casualty (i.e., fatality, severe or slight injury); property damage-only crashes are not considered.
- Include crashes (with fatalities/injuries) that concern all road user types, namely motorized vehicles, motorcyclists, bicyclists and pedestrians.

The number of years of crash data used for the analysis is an additional information to be used. Once crash data with the aforementioned characteristics is obtained for a road axis, these data should be **allocated to the correct part of the road**.

For **motorways (urban and rural) and primary divided roads** crash data needs to be available per direction of traffic. If this information is not readily available, but can be exported from the available records, then crashes should be allocated to the correct side of the road. If this is not feasible, then the analysis will not differentiate between the two directions of traffic.

For **primary undivided roads crash** data is needed for the entire road.

For crashes occurring at junctions it is needed to ensure that they are **allocated** in a consistent way to units of analysis (i.e., sections as formed using segmentation approach 1 or sections and junctions as formed using segmentation approaches 2 and 3). This is important for avoiding double counting crashes or analysing crashes that are located on roads that are not covered by the methodology.

The following points describe how to **allocate crashes** (of all road users) that have taken place on or in the vicinity of roads covered by the Directive 2008/96/EC:

- When a **motorway section** is assessed and there is an **interchange** that connects the assessed motorway with another motorway or primary road, crashes occurring on the interchange ramps should be added to the crashes (if any) of the nearest road (motorway or primary), in terms of crash location on ramp chainage, so that they are not double counted.
- When a **motorway section** is assessed and there is an **interchange** that connects the motorway with a road outside the scope of Directive 2008/96/EC, crashes occurring on the interchange ramps should be added to the crashes (if any) of the motorway.
- When a **primary rural road** section is assessed and there is an **interchange** that connects the assessed road with another primary rural road covered by the

Directive 2008/96/EC, crashes occurring at the interchange ramps are counted as crashes of the nearest road, so that they are not double counted.

- When a **primary rural road** section (divided or undivided) is assessed and there is an **at-grade intersection** with another rural road covered by the Directive 2008/96/EC, crashes occurring at the at-grade intersection should be allocated (a) to the junction if segmentation approaches 2 or 3 have been used or (b) equally to both intersecting roads if segmentation approach 1 has been used.
- When a **primary rural road section** (divided or undivided) is assessed and there is an **at-grade intersection** with another road **not covered** by the Directive 2008/96/EC (i.e., a secondary road), VRU crashes occurring at the at-grade intersection or at the secondary road are counted as crashes of the primary road, if they have occurred inside the broader intersection area, which includes, besides the primary road, also the length of the secondary road with modified cross section due to the intersection layout.

2.6.1.2 Traffic volume data

Traffic volume data is needed for the reactive methodology, preferably in the form of annual average daily traffic (AADT) or average daily traffic (ADT).

- For **motorways and primary divided rural roads** for which crash data is known per direction of traffic, traffic volume information should also be per direction of traffic. Traffic volume can either be known per direction of traffic or the total traffic volume for the road can be divided by two.
- For **motorways and primary divided rural roads** for which crash data is not known per direction of traffic, traffic volume information used for the analysis should correspond to both directions of traffic.
- For **primary undivided rural roads**, traffic volume data should be for both directions of traffic.
- For **junctions**, traffic volume data consists of vehicles entering and exiting the junction. Therefore, the traffic to be attributed to the junction is the traffic of the previous section minus the exiting traffic plus the entering traffic. If these data are not available, the average of the traffic of the preceding and the following section should be considered.

2.6.2 Reference population level

The reference population is **a set of roads with similar operational and design characteristics**. In the reactive assessment methodology, it is used a comparison group for the assessment of a road axis that is assessed. Depending on the road type and the way sections have been defined, i.e., using segmentation approach 1 or 2-3, various groups of reference population at the national level are defined (see Table 2.3):

Table 2.3: *Reference population groups depending on the road type and the unit of analysis.*

Road type	Segmentation approach	Reference population
Rural motorway	1	Sections in rural motorways
Rural motorway	2 or 3	Interchanges in rural motorways
Urban motorway	1	Sections in urban motorways
Urban motorway	2 or 3	Interchanges in urban motorways
*Divided road	1	Sections in primary divided roads
*Divided road	2 or 3	Grade-separated junctions in primary divided roads or at-grade junctions in primary divided roads
*Undivided road	1	Sections in primary undivided roads
*Undivided road	2 or 3	At-grade intersections in primary undivided roads

Primary* divided and ***primary* *undivided roads; if non-primary roads are considered then, additional reference groups should be defined.*

For each reference population group, the following **data** are needed:

1. **Crash data** across all roads (or junctions) within the group
   a. Total number of crashes for the same period of time
   b. Crash records consisting of crashes with casualties for all road users
2. **Length data** across all roads (or junctions) within the group
3. **Traffic volume data** average across all roads (or junctions) within the group. If traffic data are available for only for a subset of roads (or junctions) within the same reference population group, then **a new reference population** needs to be defined.

2.7 Safety performance metric calculation and threshold definition

By this step, the information known for each section (or junction) consist of the section start and end points, its total length, the total number of observed crashes during the analysis and if available, traffic volume information.

Using the **Poisson method**, an upper and lower threshold are estimated for the observed number of crashes of each section (or junction):

Lower confidence interval: $chisquare[\frac{\alpha}{2}, 2 \times k] / 2$

Upper confidence interval: $chisquare[1 - \frac{\alpha}{2}, 2 \times (k+1)] / 2$

Where:

k: is the observed number of crashes in a section/junction during the analysis period α: confidence level. It is recommended to use 0.05.

Using the number of crashes defined by the upper and lower confidence intervals, **two safety performance metrics** are calculated per section (or junction): **crash rate** and **crash density**. It is noted that if traffic volume data is not available for the section/junction then, crash rate cannot be estimated.

The crash rate is estimated as:

$$R_i = \frac{N_i * 10^8}{365.25 * AADTi * y * L_i}$$

Where:

N_i: number of crashes at road section/junction *i,* occurring in the analysis period

$AADT_i$: Average Annual Daily Traffic of the section/junction

y: analysis period (years)

L_i: length of section *i* (km)

The crash density is estimated as:

$$d_i = \frac{f_i}{L_i}$$

Where:

f_i: crash frequency at road section/junction *i,* that is the number of crashes (N_i) occurring per y which is the number of years in the analysis period

L_i = length of section/junction *i* (km)

Crash rate and crash density values are also estimated for each **reference population group**. These values serve as thresholds for assessing the safety level of each section (or junction).

2.8 Road safety ranking

A separate ranking is performed based on the crash rate and crash density thresholds. It is recommended to prioritize the crash rate-based ranking over the crash density-based one.

Based on the above, the three following classes are defined for ranking parts of a network using the developed reactive methodology:

- If the safety performance metric for the reference population is lower than the lower threshold, the corresponding section/junction is classified as **"High Risk"**.
- If the safety performance metric for the reference population metric is higher than the upper threshold, the corresponding section/junction is classified as **"Low Risk"**.
- Finally, if safety performance metric for the reference population is between the lower and upper thresholds, or it is equal to one of the thresholds, the corresponding section/junction is classified as **"Unsure"**.

Each section and junction (if junctions have been defined during the segmentation) of the network can be classified in one of those classes. This is end of the NWA-reactive.

3. THE PROACTIVE METHODOLOGY

This chapter describes in detail **the steps to be followed** for the implementation of the **in-built safety assessment of roads**. The overall process of the assessment is illustrated in the following flowchart (Figure 3.1), showing that the first step is to determine the road type to be assessed (i.e., urban or rural motorway, primary divided rural road, or primary undivided rural road), followed by the collection the needed data and network segmentation. For each part of the road, data for each parameters needs to be readily available and properly stored so that Reduction Factors can be estimated. When all Reduction Factors have been estimated, the final score for the section can also be calculated and based on that the section can be classified in one of three safety classes. The following sections provide details and illustrative examples on how to handle every step in the process of implementing the in-built safety assessment methodology.

To assist with the implementation of the methodology, an excel-based tool has been developed and is presented in **Annex D**.

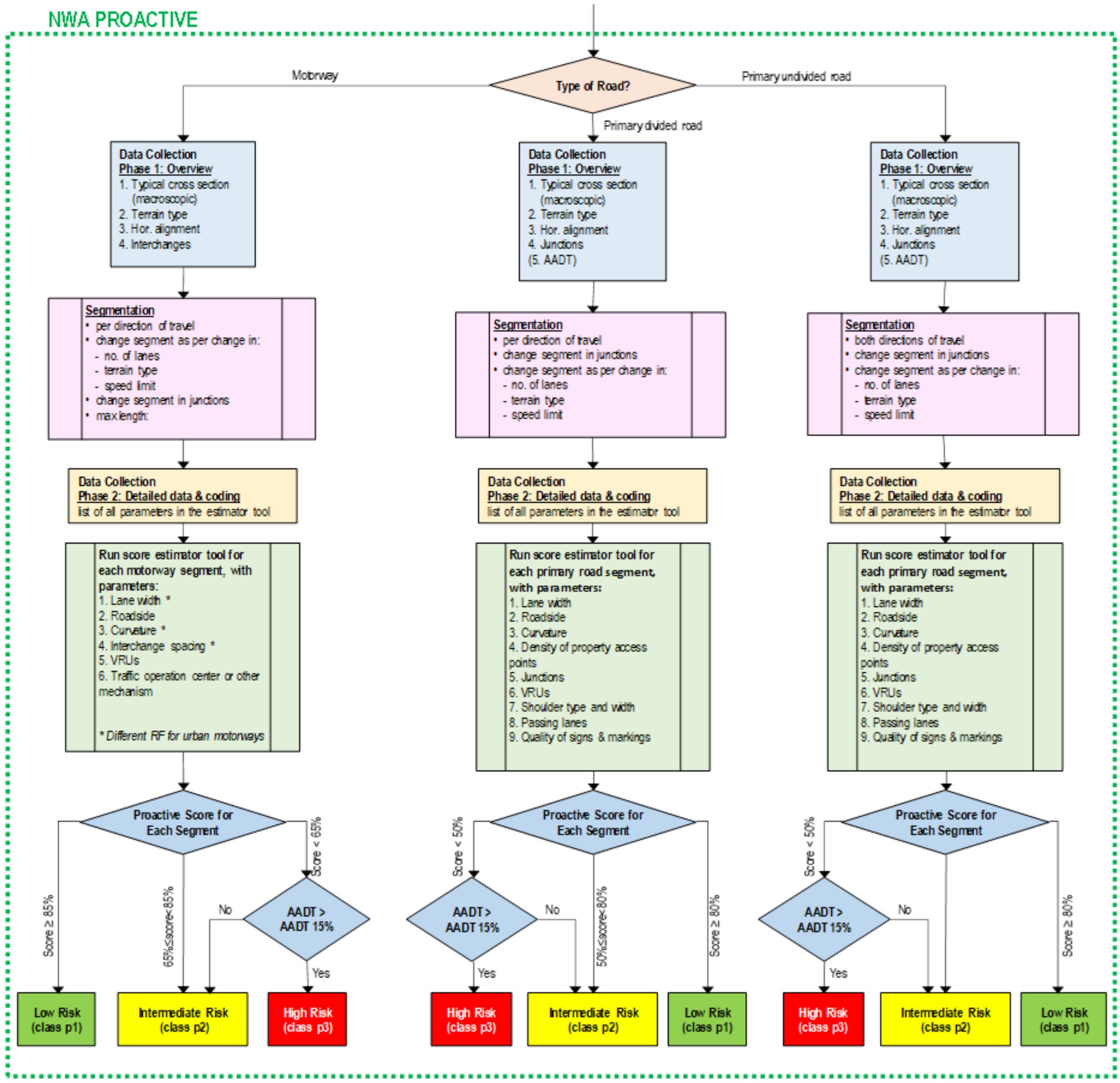


Figure 3.1: *Flowchart illustrating the steps of the in-built safety assessment of roads.*

3.1 Scope of application

The in-built safety assessment methodology, also mentioned as "NWA-proactive" is applicable for urban and rural **motorways** and **primary or other rural roads covered by the 2008/96/EC Directive**. In the case of non-primary rural roads, low-volume and/or low-functionality roads, they can potentially be assessed using the methodology for primary undivided roads however, proper re-calibration might be required to obtain reliable results.

The in-built safety assessment methodology assesses roads taking into consideration **all road users** that may be present on the road. In that sense, it is not limited to motorized vehicles only, but instead it also considers the safety of bicyclists and pedestrians, noted as **VRUs** (Vulnerable Road Users) that might be present on or near motorways and primary roads. However, it is clarified that:

- The **quality** of facilities for bicyclists/pedestrians (e.g., not clearly paved crosswalks or bike lanes) is out of scope of the network wide safety assessment.
- In **motorways**, due to safety concerns, the presence of pedestrians is reasonable only in rest / parking areas, while bicyclists should not be using the motorway at all. Within the scope of the methodology is to identify sections where the above conditions are not met and so, indicate that the section has safety deficiencies in terms of conflicts between VRUs and motorized vehicles.
- In **primary roads** (or other rural roads within scope of 2008/96/EC Directive), the scope of the methodology is to detect the presence of facilities to accommodate bicyclist/ pedestrian crossings and flows along the road. As stated above, the quality and condition of such facilities is not assessed.

With regard to **road tunnels**, the in-built safety assessment methodology is not applicable, since existing research results quantifying the impact of road geometric characteristics to road safety in tunnels are inadequate to develop reliable assessment models at a network wide level. It is also noted that tunnels with a length over 500m are also outside the scope of the Road Infrastructure Safety Management Directive 2008/96/EC. Therefore, road tunnels are expected to be excluded from the assessment.

With regards to **bridge** sections on motorways and primary roads, the in-built safety assessment methodology is applicable, as with other road sections.

With regards to **toll station areas**, the in-built safety assessment methodology is not applicable, as these areas are particularly complex and existing research results do not adequately quantify the impact of toll plaza geometry to safety. Therefore, toll station areas are expected to be excluded from the assessment.

3.2 Geographical limits of assessment

This section presents the limits of the assessment of the NWA-proactive methodology, and in turn of the integrated one. The focus is on **roads covered by the Directive 2008/96/EC**, while some extensions are foreseen in the area of junctions as explained below.

In **motorways**, either urban or rural, the following parts are considered:

- **Motorway segments**
  A set of motorway segments forms a section that may also include interchanges. Parameters like lane width, roadside, curvature, and operation of traffic operation centers (or other mechanisms to inform users on incidents) on the motorway axis rather than the interchange ramps.
- **Interchanges**

For interchanges, the assessment considers the location of exit and entry ramps to derive the spacing between consecutive ramps (within the same interchange or between successive interchanges).

- **Ramp segments**
  Ramp segments are considered for the parameter regarding **conflicts between VRUs and motorized vehicles**. The focus is to see whether VRUs are present in those parts of the network. In case that VRUs are present on ramp segments that:
  - connect two motorways, both motorway sections are penalized with respect to that parameter.
  - connect a motorway and a non-motorway road, the motorway section is penalized with respect to that parameter.

  Over- or underpasses of local roads above or below a motorway, where VRUs may be present are **not** assessed in relation to the near-by motorway.

In **primary roads** (or other rural roads within scope of Directive 2008/96/EC), the following parts are considered:

- **Road segments**
  The evaluation of primary roads (or other rural roads covered by the 2008/96/EC Directive) mostly concerns segments along the road axis. A set of segments forms a section that may also include junctions (at grade or grade separated). Parameters such as lane width, roadside, curvature, density of property access points, shoulder width and type, passing lanes, and quality of markings and signs are assessed considering only the segment characteristics.
- **Junctions**
  The assessment considers the type of junctions on primary roads (grade separated interchanges and/ or at-grade intersections), as well as the non-motorised users infrastructure at intersections. The detailed investigation of the junction's design/ operational characteristics is outside the scope of the network-wide assessment.
  With regards to the **assessment of VRUs safety** at junctions, if a **grade separated** interchange connects a primary road within the scope of the Directive and a road outside the scope of the Directive, the secondary road is not considered. On the other hand, if an **at-grade intersection** connects a primary road within the scope of the Directive and a secondary road outside the scope of the Directive, part of the secondary road will be considered in the assessment of the parameter on VRUs. This part is the section of the secondary road starting from the junction center and up to the point that the cross section of the secondary reinstates to its normal width (i.e. outside the influence area of the intersection).

3.3 Identification of road type

The first step to implement the in-built safety assessment methodology is to determine the road type of the road to be assessed, namely motorway or primary road. Furthermore, for motorways, it is important to denote whether the road is urban or rural motorway, whereas for primary roads (or other rural roads within scope of the Directive 2008/96/EC), it is required to identify whether the road is divided or undivided. Therefore, the following four road types are applicable:

1. Motorway - rural
2. Motorway - urban
3. Primary road - divided
4. Primary road - undivided

The following notes are also provided to assist in the road type identification process.

- For the identification of motorways and primary roads, the definitions of Directive 2008/96/EC shall apply.
- The road type might change along the same road axis. For example, a motorway connecting two major cities might be classified as urban for the first and last sections (inside or near city limits) and rural for the part crossing the countryside.
- The road type should not change inside a section (see also section 3.5 on segmentation). In the above example, a new section should start at the limit of the urban area.
- The identification of the exact point where the type of a motorway changes from urban to rural should rely on criteria such as (indicatively): applied design standards and design speed (if known), speed limit, land use next to the motorway, type and distance between interchanges. No specific values are defined for these criteria; road safety practitioners are expected to judge on a case-by-case basis applying engineering judgement.

3.4 Overview data collection and assessment

For the implementation of the network-wide in-built safety assessment methodology several data types are needed, that are collected at **two stages**:

1. before the segmentation (overview data), targeted to facilitate the segmentation process and correspond to an aggregate level of detail (see also section 3.5), and

2. after the segmentation (detailed data), at a higher level of detail. These data are collected per section of the examined road and provide the required information for the implementation of the proactive assessment models (see also section 3.6).

Stages 1 and 2 concern different data types and have a different scope (aggregate compared to detailed data per section). However, it is a good practice whenever possible to acquire all relevant data at once, for example, all data stored in road design files (e.g., CAD files (.dwg) or paper format), in road inventory databases (registries), or through targeted geometric data collections using online tools (e.g., Google Maps, Google Earth, OpenStreetMaps) or site surveys.

The following paragraphs provide further guidance for the 1st stage of overview data collection, prior to the segmentation process. Guidance for the 2nd stage is provided in section 3.6.

3.4.1 Motorways

For urban and rural motorways data is more likely to be available (e.g., through the road constructor or road operator) and so, it is more likely to be easily retrieved. In addition to the data types needed for the segmentation, it is recommended to search for available data (e.g., stored in database, in photos, project reports or CAD or GIS files) for data types not used for the segmentation.

3.4.2 Primary or other rural roads

Relevant road data for rural roads can also be derived from CAD files or other databases. In some cases, it is expected that data for rural roads is less organized and in this case, it may be required to retrieve road data using online tools (e.g., Google Maps, Google Earth, OpenStreetMaps) or even site surveys.

3.5 Segmentation

The segmentation process involves dividing the road into smaller parts. Detailed segmentation guidelines are presented in paragraph 3.5.1 for motorways and in paragraph 3.5.2 for primary and other rural roads.

For both road types **two alternative segmentation approaches** are considered:

1. sections that are roughly homogeneous based on traffic volume, number of lanes, terrain type and speed limit. For this case, maximum section lengths are at the range of 2-5Km (see also further guidance per road type in paragraphs 3.5.1 and 3.5.2), or

2. sections of fixed length, e.g. equal to 500m (indicatively). In this case, as the homogeneity is not explicitly considered, the fixed length of the section should not be very large, as this would inevitably merge non homogenous road characteristics.

In case of homogeneous sections, the following considerations apply for all road types:

- Sections consist of segments of the under-study road axis and the junctions along that axis.
- Junctions are part of section, unless there is a considerate change in traffic volume.
- Road tunnels are excluded from the assessment (see also section 3.1). Defined road sections in the segmentation process should end before the tunnel entrance and start after the tunnel exit.
- Toll Station areas are excluded from the assessment (see also section 3.1). Defined road sections in the segmentation process should end before the beginning of the toll plaza widening and start after the road assumes a uniform cross section after the toll plaza.
- With regards to bridge sections on motorways and primary roads, the in-built safety assessment methodology is applicable, as with other road sections. In case of long bridges (e.g. more than 200m), it is recommended to apply a separate section for the bridge.
- It is recommended to align the start and end points of sections for the proactive assessment to start and end points of sections for the reactive (crash based) assessment if they are close to each other (e.g., less than 100m apart), as this will reduce the effort of integrating the two methods results and eliminate short length segments in the final (integrated) results. Considering that the reactive methodology requires larger segments for reasons of statistical validity, it can be expected that segments for the crash-based assessment will normally include more than one proactive assessment segments.

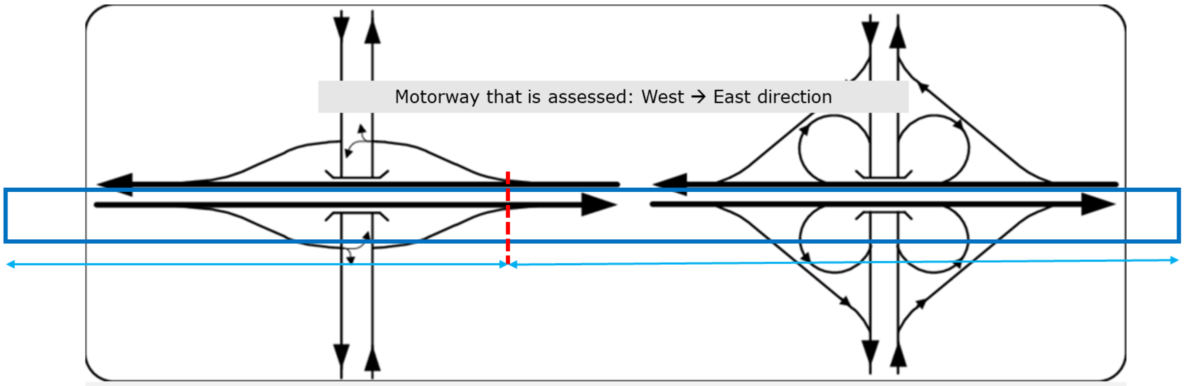
3.5.1 Motorways

Segmentation in motorways is performed **per carriageway / direction of travel**. Section start/ end points in one direction may not coincide with the respective points in the other direction.

For **fixed length segmentation**, for both rural and urban motorways it is recommended to use relatively small sections, of approximately 400m-600m long. A section can include a junction in addition to segments. Using even shorter sections may marginally improve the analysis resolution but will certainly increase the required workload, and is therefore not recommended.

To define **roughly homogeneous sections** the following characteristics are taken into account: traffic volume, number of lanes, speed limit, and terrain type. The term “roughly” indicates that small deviations from the following rules are acceptable as long as they apply to short parts of the section. In addition to the aforementioned characteristics, upper limits are provided for the section length.

Each motorway section consists of **segments** and **interchanges**. The methodology does not differentiate between motorway segment in the vicinity of an interchange versus away from an interchange (e.g., will not focus on the design of weaving section). In Figure 3.2 two sections that include interchanges are shown. If a new section needs to be defined then, this should either happen at an entrance or exit ramp; in Figure 3.2 this change is assumed to take place at an entrance ramp and it is noted that the exact point where the first section stops and the successive one begins, is the **gore point** of that ramp.



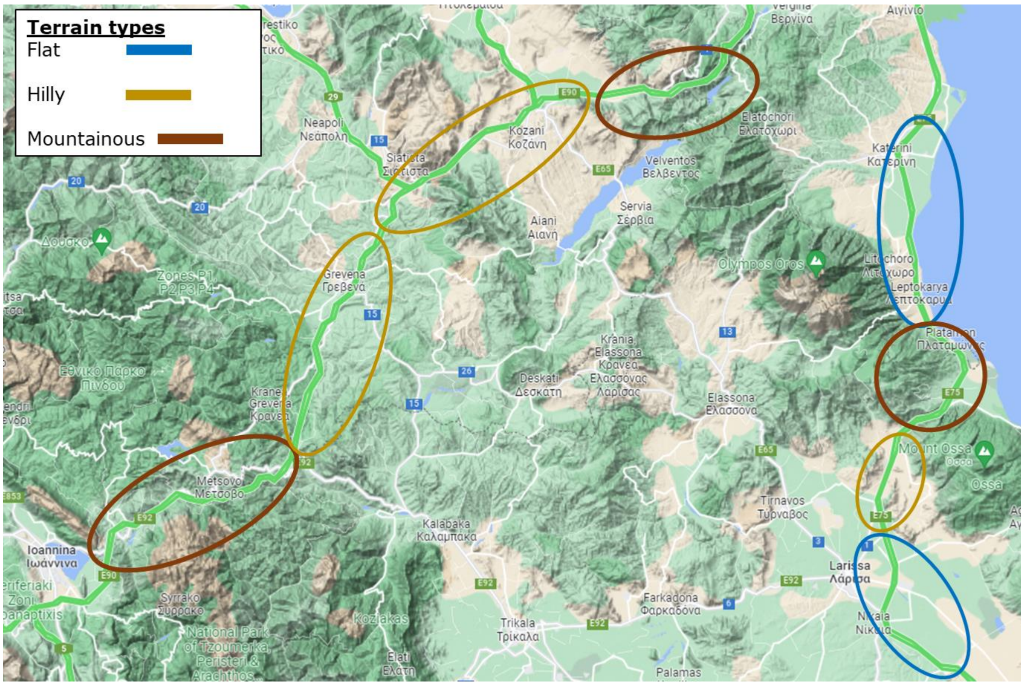
*If it is needed to change a section at the area of an interchange, then a **gore point** (dotted red line) should be the end point of the first section and the first point of the successive section. It can be the gore point of an entrance of exit ramp.*

Figure 3.2: *Sections consisting of segments and interchanges (Background Source: Hagen et al. (2006) - edited).*

- **Traffic volume:**
  Major changes in traffic volume (Annual Average Daily Traffic) should be used to define two different sections. These changes are expected to occur at the interchange area, downstream an exit ramp or entrance ramp. The point where the first section ends and the other one begins should be the gore point of the ramp.
- **Number of lanes:**
  If the number of basic lanes changes (e.g., from two to three or four to three, etc.) a new section should be defined. The addition or drop of auxiliary lanes at a junction (interchange, intersection) is not considered in the segmentation. It is very likely that traffic volume changes as well as changes in the number of lanes occur at the same parts of the road.
- **Speed limit:**
  If speed limit changes along the axis, then different sections should be defined. Local speed limit reductions (e.g., for lengths less than 200m) are suggested not to be considered.
- **Terrain type:**
  Terrain types can be roughly divided in flat, hilly, or mountainous.
  - Flat terrain is found in valleys and away from hills and mountains. In areas with flat terrain, the road does not have large differences in the elevation (i.e., difference between highest and lowest point) and road stretches are more likely to be straight.
  - Hilly terrain is found in areas with hills, usually located at the edge of flat areas. The road in a hilly terrain is more likely to have successive horizontal curves and experience changes in its vertical slopes.

- Mountainous terrain involves areas in mountains and due to this, the road is more likely to have changes in its vertical slopes.

A section is recommended to spread along a single terrain type. Google Maps terrain type mode may be helpful in visually detecting flat versus hilly vs mountainous parts of motorways, as shown in Figure 3.3.



Maps data: Google, ©2022

Figure 3.3: *Example of terrain classification in Central Greece (E75 and E92 motorways) relying on the Google Maps terrain view.*

In the case of homogeneous sections, upper limits for the **section length** (L) are recommended for rural and urban motorways:

- Rural motorways: L ≤ 5km
- Urban (and suburban) motorways: L ≤ 3km

Overall, it is highlighted that during the segmentation it is recommended to form sections that comply with all the aforementioned criteria, but it is also important to accept limited deviations in order to preserve the network-wide nature of the assessment. Therefore, for the case of homogeneous sections, it is recommended to avoid sections with short length, i.e., below 400m, as this would resemble a more detailed analysis of road safety conditions that is not supported by the scoring models. Safety and engineering judgment are needed to evaluate when such an exemption is necessary.

3.5.2 Primary or other rural roads

Segmentation of primary rural roads follows generally the same rules as in the case of motorways. Two alternative approaches are also considered, either sections of fixed length, indicatively 500m, or longer homogeneous sections in terms of traffic volume, number of lanes, speed limit, and terrain type.

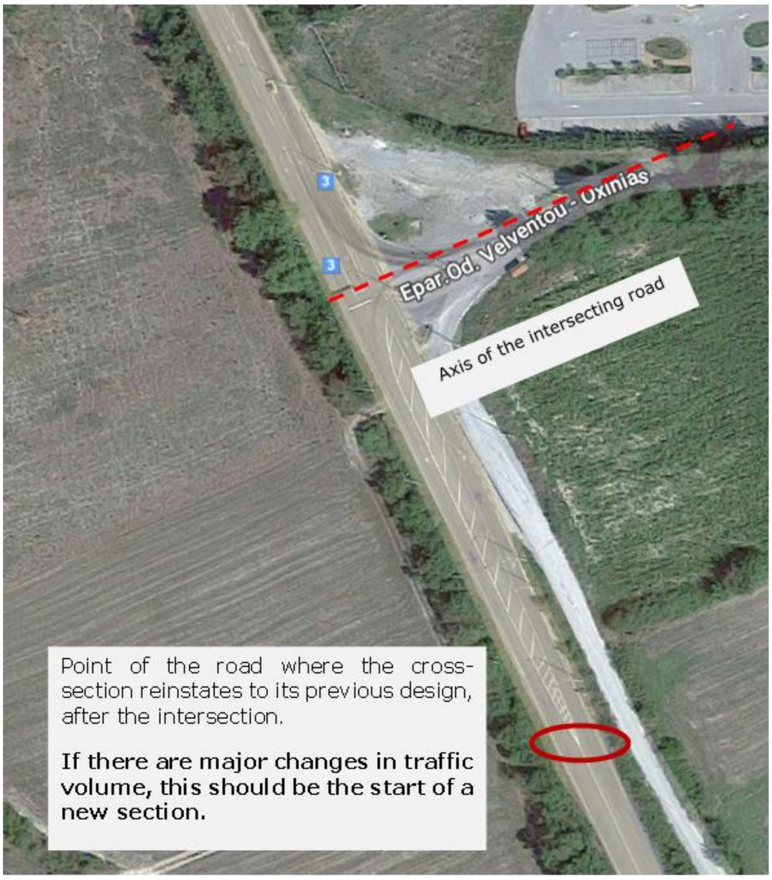
Regardless of the approach, the presence of an intersection does not necessarily require a change in section (unless it is related to large traffic volume changes) and so, a section consists of both road segments and intersections (at-grade or grade-separated).

Furthermore, it is noted that:

- Divided rural roads are assessed per direction of traffic and so, the segmentation needs to take place per direction of traffic.
- Undivided rural roads are assessed considering both directions of traffic at the same time.

The following **criteria** apply for the segmentation of primary (or other rural) roads into **homogeneous sections**:

- **Traffic volume:**
  Major changes in traffic volume (Annual Average Daily Traffic) should be used to define two different sections. These changes are expected to occur near a junction. In the case of an interchange, the change in traffic volume is expected to occur at a ramp segments and the gore point of the ramp should be used as the end of first section and the starting point of the successive section. In the case of an at-grade intersection the end point of the section should be the downstream the intersection at the point where the cross-section reinstates to its former design; see the example in Figure 3.4:



Maps data: Google, ©2023 Imagery Date: 8/30/2015

Figure 3.4: *Illustration of the point that the cross-section reinstates to its previous design, downstream an intersection.*

- **Number of lanes:**
  If the number of basic lanes changes (e.g., from two to three or four to three, etc.) a new section should be defined. The presence of passing lanes or other changes in the cross-section of the road are not considered for segmentation purposes.

- **Speed limit:**
  If speed limit changes along the axis, then different sections should be defined. It is noted though, that short segments with a different speed limit should not be seen as new sections. For example, it is a common safety countermeasure to add a speed limit sign right before a horizontal curve; this sign is not a reason for starting a new section as the "new" speed limit is for a short part of the road.
- **Terrain type:**
  Terrain types can be roughly divided in flat, hilly, or mountainous.
  - Flat terrain involves parts of the road that are located in a valley.
  - Hilly terrain involves parts of the road located near hills.
  - Mountainous terrain involves roads located in mountains.

  A section is recommended to spread along a single terrain type. Google Maps terrain type mode may be helpful in visually detecting flat versus hilly vs mountainous parts of rural roads.

While not a mandatory criterion for segmentation, it is recommended to form sections in a way that horizontal curves are either fully included or fully excluded from a section.

When homogeneous sections are formed, it is recommended that they **do not exceed 2km** in length. This applies for both primary divided and undivided roads.

Overall, it is highlighted that during the segmentation it is recommended to form sections that comply with all the aforementioned criteria, but it is also important to accept limited deviations in order to preserve the network-wide nature of the assessment. Therefore, for the case of homogeneous sections, it is recommended to avoid sections with short length, i.e., below 200m, as this would resemble a more detailed analysis of road safety conditions that is not supported by the scoring models. Safety and engineering judgment are needed to evaluate when such an exemption is necessary.

3.6 Detailed data collection

Collecting and properly organizing the data needed for the safety assessment is critical to ensure that the in-built safety assessment methodology will be completed in a timely manner and have a reliable outcome. Detailed data collection needs to take place before the assessment, and it would be highly beneficial for the assessors to store these data in digital format such as Excel files and GIS databases for future reference.

The stage of detailed data collection refers to data at section level for all parameters that are considered in the assessment. Some parameters are likely to vary along the section (e.g., lane width or roadside) and in this case, the section will be further divided into smaller parts, with different parameter values used as input to the assessment model.

The following paragraphs provide guidance on the detailed data collection for motorways (paragraph 3.6.1) and for primary roads (paragraph 3.6.2).

3.6.1 Motorways

For the assessment of rural or urban motorways data on six parameters is needed, as discussed below.

3.6.1.1 Lane width

The parameter requires the average lane width of the motorway carriageway to be estimated per direction of travel. Data is therefore needed on the width of each lane in order to estimate the average. Depending on whether the lane is at the edge of the road or not, the following apply for measuring lane width (see Figure 3.5):

- For lanes at the edge of road (left or right) lane width is measured from the inside edge of the marking line and ends in the middle of successive marking line. For example (for right side driving countries):
  - For the left lane, the measurement starts from the right-side edge of the left edgeline and ends in the middle of the first lane line; see green and blue circles in Figure 3.5.
  - For the right lane, the measurement starts from the middle of the second (right) lane line and spans to the left side of the right edgeline.
- For lanes in the middle of the road their width is measured from the middle point of the first lane line to the middle point of the second lane line.

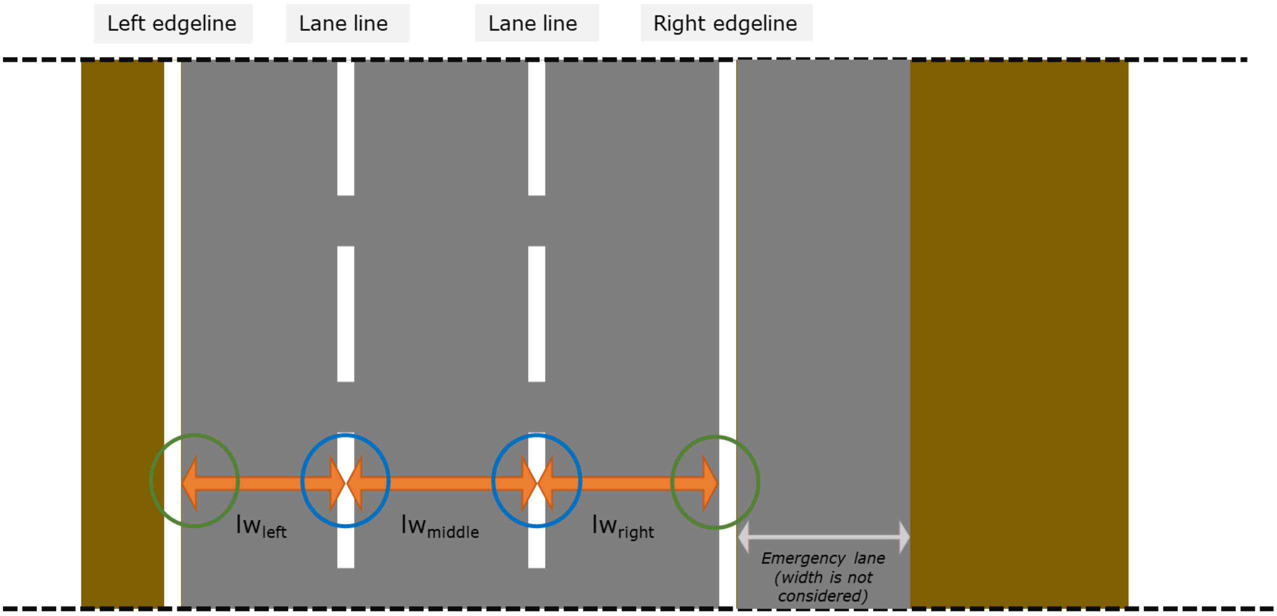


Figure 3.5: *Measuring lane widths on a three-lane motorway segment (emergency lane width is not considered).*

For a cross section with N lanes (not including the emergency lane) the **average cross section lane width** is estimated as:

$$Average\ Cross\ Section\ Lane\ Width = \left(\sum_{i=1}^{N} lw_i\right)/N$$

where: N = number of lanes
lw_i = lane width of the lane

Since lane width is not a criterion for segmentation, it is possible that across a section the average cross section lane width might vary. In this case, the **average section lane width** is estimated, as a length weighted average of the various values of average cross section lane width. The average section lane width should be rounded to the closest two digit decimal.

The width of **emergency lanes and acceleration/ deceleration lanes** at the area of interchanges is not considered in the estimation.

Example: Assuming a 4km length section of three-lane per direction motorway, with 1km with lane widths equal to 3,50m/3,50m/3,75m and 3km with lane widths 3,25m/3,50m/3,50m:

The average cross section lane width for the 1km part is: (3,50+3,50+3,75)/3 = 3,583m

The average cross section lane width for the 3km part is: (3,25+3,50+3,50)/3 = 3,417m

The average section lane width is estimated as the length weighted average of the above, i.e., (3,583 x 1 + 3,417 x 3) / 4 = 3,459m and approximately 3,46m

3.6.1.2 Roadside

The assessment of the roadside for motorways examines the outer shoulder area for each direction of travel, from the outer edge of the outer roadway edgeline and up to the closest non-traversable obstacle, as shown in Figure 3.6.

For the purpose of NWA proactive assessment in motorways, the roadside **includes the emergency lane** (if any) and **does not include any acceleration / deceleration lanes** in the area of interchanges.

For the assessment of the roadside **two types of data** are needed per section:

1. Clear zone (CZ) width
2. Type of obstacle (if any)

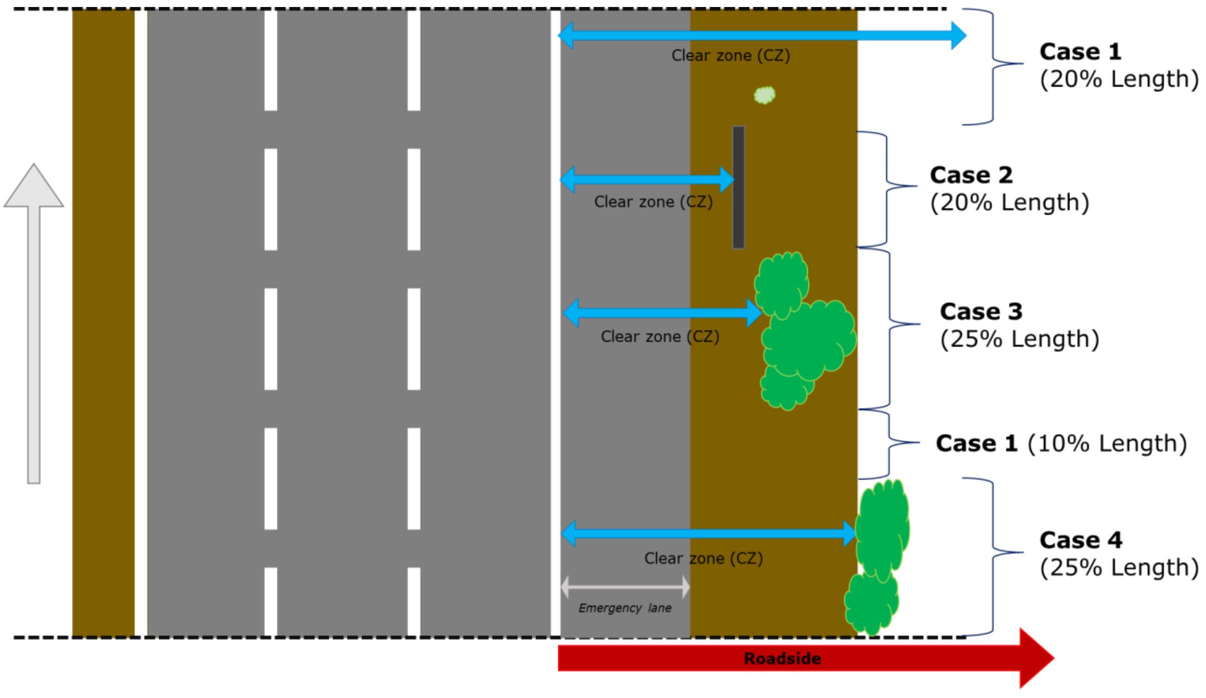


Figure 3.6: *Example of varying roadside. Clear zone width is indicated (per case) with blue arrows. Two types of obstacles are illustrated: the first one in gray color and the second one in green color.*

Starting from the start point of the section, CZ and obstacle type need to be recorded. Every time a **change in CZ or obstacle type** is observed, a new auxiliary **sub-section** should be marked. It is needed to measure the length of the sub-section (as percentage) for which a certain roadside type is present.

For the section illustrated in Figure 3.6, there are four different cases of roadside. Case 1 is present in two, non-successive parts of the section.

Regarding the **obstacle types**, it is highlighted that point obstacles are not important within the scope of network-wide assessment. What is important is a series of obstacles, i.e., obstacles that spread along a significant length compared to section's length. In Figure 3.6 the light yellow-coloured obstacle (top of the figure) is not considered, while the concrete barrier (in dark gray color) as well as the series of trees (in green color) are considered.

The section illustrated in Figure 3.6, assuming a length of 4km, is recommended to be coded as shown in Table 3.1, in order to be able, in the next step of the procedure, to estimate the respective Reduction Factor of the "Roadside" parameter:

Table 3.1: *Example of storing roadside information*

Section code	Section length	Clear zone width (average)	Obstacle type	Percentage of section's length
1	4km	10m	none	30%
1	4km	5m	concrete barrier	20%
1	4km	6m	series of rigid obstacles	25%
1	4km	8m	series of rigid obstacles	25%

3.6.1.3 Curvature

Data on curvature concerns the presence and radius of horizontal curves within the section. Spiral transition curves are not explicitly considered and relevant data do not need to be collected.

For each horizontal curve it is needed to record the following:

1. curve radius, measured at the motorway centerline (i.e. identical for both directions of travel).

2. length of the curve within the section. It is clarified that a single horizontal curve can spread along two sections. In case of spiral transition curves between the tangent and the circular arc, curve length is measured from the middle (approximately) of the spiral curve.

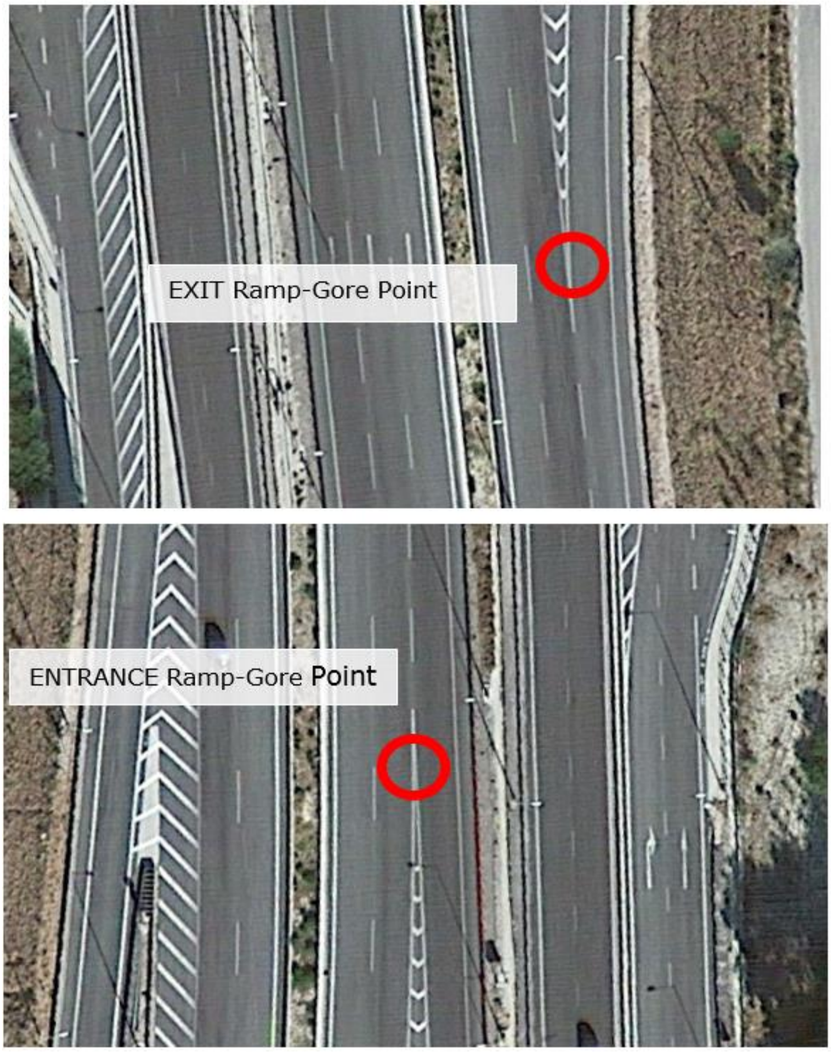
3.6.1.4 Interchanges

Data on interchanges concerns the following:

1. location of exit and entrance ramps (i.e., gore point's location)

2. distance between successive ramps (i.e., distance between successive gore points), either of the same interchange or between successive interchanges.

Figure 3.7 illustrates the gore points at exit and entrance ramps.



Maps data: Google, Google, ©2023 Imagery Date: 8/28/2020

Figure 3.7: *Exit and entrance ramps on a motorway. In red circle points the gore point of the ramp.*

<u>3.6.1.5 Conflicts between pedestrians/ bicyclists and motorized traffic</u>

In all parts of a motorway, pedestrians and bicyclists should not be present. Pedestrians are only allowed in rest/ parking areas.

The assessor/ data collection team must explore two types of data. First, whether there are:

- pedestrian and/or bicyclist flows along a motorway section
- crossing pedestrian and/or bicyclist flows
- pedestrian and/or bicyclist flows on ramp segments

In addition to the presence of flows, it should also be recorded the location where these flows are observed. Pedestrian/ bicyclist flows could be present:

- at overpasses or underpasses of local roads above or below a motorway
- in fully separated facilities along a ramp and/or motorway segments
- on the motorway segment or ramp.

3.6.1.6 Traffic Operation Centers and/ or mechanisms to inform users for incidents

Data collection for this parameter involves the information whether a motorway has an appropriate mechanism to inform road users of incidents with potential safety implications, such as (indicatively) a crash ahead, severe weather conditions, a stray animal on the roadway, an object (rock, cargo, etc.) on the roadway, the presence of roadworks.

This mechanism commonly includes a traffic monitoring and operation center, supported by ITS equipment (VMS - variable message signs, VSL - variable speed limit signs, etc.) but may also refer to automatic VMS - VSL signs without a manual operation center).

The parameter applies to all sections of a properly equipped and monitored motorway and not only to those sections that contain the specific ITS signs.

3.6.2 Primary or other rural roads

For primary roads (divided and undivided) data for nine parameters is collected as discussed below.

3.6.2.1 Lane width

Lane width for primary roads is measured for both directions of travel in an undivided road or per direction of travel in a divided road.

For **undivided roads**, the **average cross section lane width** is measured between the inner edge of the roadway edgelines, for both directions of travel, e.g., for a two-lane undivided road the average cross section lane width (Figure 3.8) would be (lw_1 + lw_2) /2.

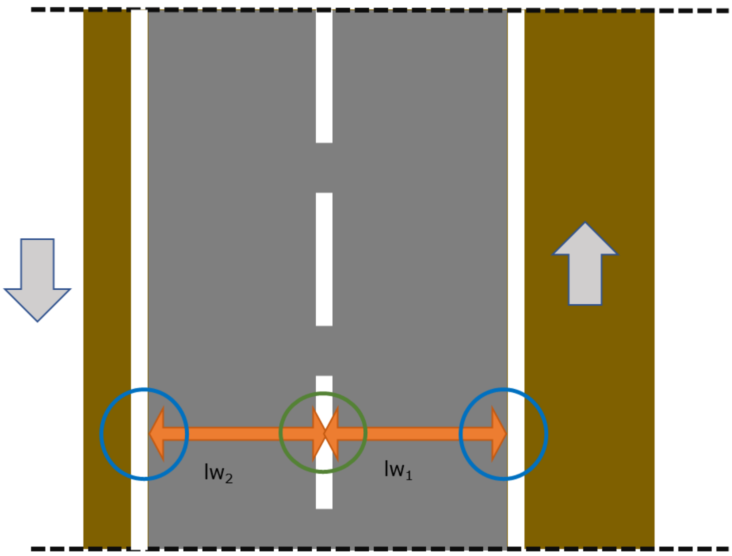


Figure 3.8: *Lane width measurement for undivided primary roads.*

For **divided roads**, the **average cross section lane width** is estimated as the sum of the width between the inner edge of the roadway edgelines per direction of travel, divided by the number of lanes per direction, e.g., for a two lane per direction divided road the average cross section lane width (Figure 3.9) would be (lw_{left} + lw_{righ}) /2.

In case of primary roads with three or more lanes per direction, the estimation is identical to motorways (paragraph 3.6.1.1).

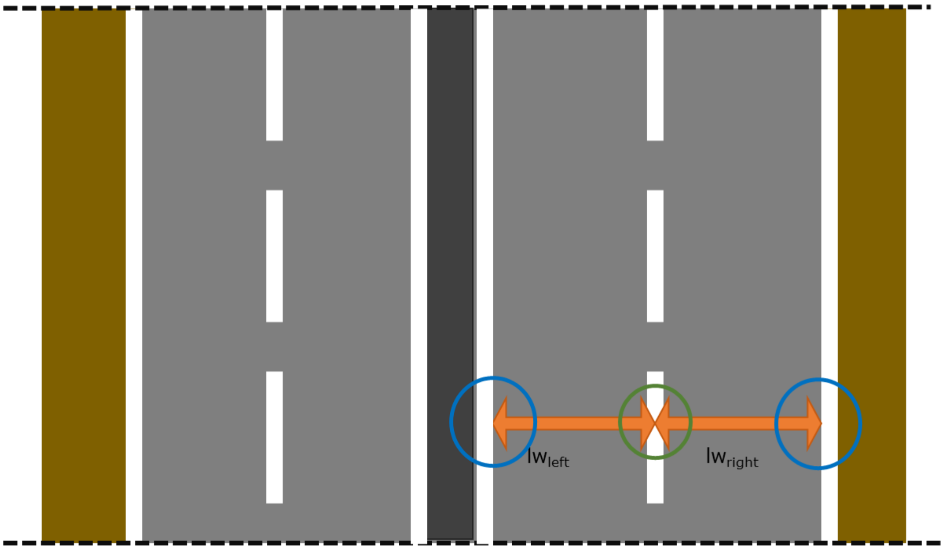


Figure 3.9: *Lane width measurements for divided primary roads, measured per direction of travel.*

Since lane width is not a criterion for segmentation, it is possible that across a section the average cross section lane width might vary. In this case, the **average section lane width** is estimated, as a length weighted average of the various values of average cross section lane width. The average section lane width should be rounded to the closest two digit decimal.

The width of **emergency lanes and acceleration/ deceleration lanes** at the area of junctions is not considered in the estimation.

Example: Assuming a 2km length section of two-lane per direction divided primary road, with 800m with lane widths equal to 3,50m/3,50m and 1200m with lane width 3,25m/3,50m:

The average cross section lane width for the 800m part is: (3,50+3,50)/2 = 3,500m

The average cross section lane width for the 1200m part is: (3,25+3,50)/2 = 3,375m

The average section lane width is estimated as the length weighted average of the above, i.e., (3,500 x 0,8 + 3,375 x 1,2) / 2 = 3,425m and approximately 3,43m

3.6.2.2 Roadside

The following types of **data** are required to assess the roadside of primary roads:

1. Clear zone width

2. Side slope and characteristics
3. Type of obstacles on the roadside

Collected data should allow the assessors to classify roadside in one of the following categories presented in Table 3.2. Each category corresponds to a different Roadside Hazard Rating (RHR) - see also Figures 3.10 to 3.16.

Table 3.2: *Roadside Hazard Rating (adopted from the Highway Safety Manual, Exhibit 13-32 (AASHTO,2010))*

RHR	Clear zone	Side slope	Roadside
1	CZ ≥ 9,14m	Flatter than 1V:4H; recoverable	N/A
2	6,10m ≤ CZ ≤ 7,62m	About 1V:4H; recoverable	N/A
3	CZ ~ 3,05m *also applicable for guardrail with offset >1,98m*	About 1V:3H or 1V:4H; marginally recoverable	Rough roadside surface
4	1,52m ≤ CZ < 3,05m *also applicable for guardrail with offset 1,52m to 1,98m*	About 1V:3H or 1V:4H; marginally forgiving, increased chance of reportable roadside crash	May have guardrail (offset 1,52 to 1,98m) May have exposed trees, poles, other objects (offset is about 3,05m)
5	1,52m ≤ CZ < 3,05m *also applicable for guardrail with offset <1,52m*	About 1V:3H; virtually non-recoverable	May have guardrail (offset up to 1,52m) May have rigid obstacles or embankment (offset 1,98m to 3,05m)
6	CZ ≤ 1,52m	About 1V:2H; non-recoverable	No guardrail Exposed rigid obstacles (offset up to 1,98m)
7	CZ ≤ 1,52m	1V:2H or steeper; non recoverable with high likelihood of severe injuries from roadside crash	No guardrail Cliff or vertical rock out

Figure 3.10: *Typical Roadway with Roadside Hazard Rating of 1: Clear zone greater than or equal to 30 ft side slope flatter than 1V:4H, recoverable (Source: AASHTO, 2010)*

Figure 3.11: *Typical Roadway with Roadside Hazard Rating of 2: Clear zone between 20 and 25 ft; side slope about 1V:4H, recoverable (Source: AASHTO, 2010)*

Figure 3.12: *Typical Roadway with Roadside Hazard Rating of 3: Clear zone about 10 ft; side slope about 1V:3H, marginally recoverable (Source: AASHTO, 2010)*

Figure 3.13: *Typical Roadway with Roadside Hazard Rating of 4: Clear zone between 5 and 10 ft; side slope about 1V:3H or 1V:4H, marginally forgiving, increased chance of reportable roadside crash (Source: AASHTO, 2010)*

Figure 3.14: *Typical Roadway with Roadside Hazard Rating of 5: Clear zone between 5 and 10 ft; side slope about 1V:3H, virtually non-recoverable (Source: AASHTO, 2010)*

Figure 3.15: *Typical Roadway with Roadside Hazard Rating of 6: Clear zone less than or equal to 5 ft; side slope about 1V:2H, non-recoverable (Source: AASHTO, 2010)*

Figure 3.16: *Typical Roadway with Roadside Hazard Rating of 7: Clear zone less than or equal to 5 ft; side slope about 1V:2H or steeper, non-recoverable with high likelihood of severe injuries from roadside crash (Source: AASHTO, 2010).*

Roadside data are collected at a detail level appropriate for a screening methodology, focusing on providing a general overview of roadside characteristics. Since roadside characteristics may vary along a section, it may be required however that the section is further divided to subsections with regard to roadside characteristics, and the overall RHR value is estimated as a length weighted average of subsection values (see also examples below). Specific isolated objects, e.g., one unprotected barrier end or one fixed obstacle should not be considered for the network-wide assessment of the roadside. Additionally, high accuracy measurements of the clear zone width or the side slope are not necessary; an approximation is adequate, e.g., less than 1,52m or between 1,52 and 3,05m, in line with the thresholds of Table 3.2.

For **undivided primary roads**, the procedure (for both directions of travel) involves the following steps (see also example that follows):

1. Classify the roadside of one direction of travel according to the categories listed in Table 3.2.

2. If roadside characteristics vary, a length weighted average RHR is estimated.

3. Classify the roadside of the other direction of travel according to the categories listed in Table 3.2.

4. If roadside characteristics vary, a length weighted average RHR is estimated.

The two RHR values (for left and right side of the road) will be used in the estimation of the roadside CMF and RF of the section (see also paragraph 3.7.2.2).

For **divided primary roads**, the procedure (for each direction of travel) involves the following steps:

1. Classify the outside roadside of the examined direction of travel according to the categories listed in Table 3.2.

2. If roadside characteristics vary, a length weighted average RHR is estimated.

The average RHR will be used in the estimation of the roadside CMF and RF of the section (see also paragraph 3.7.2.2).

Example: Figure 3.17 shows a section of a two-lane, undivided primary road is shown. One direction of traffic (left) has the same roadside environment across the entire section, while the other direction of traffic (right) has a varying roadside that consists of three different cases.

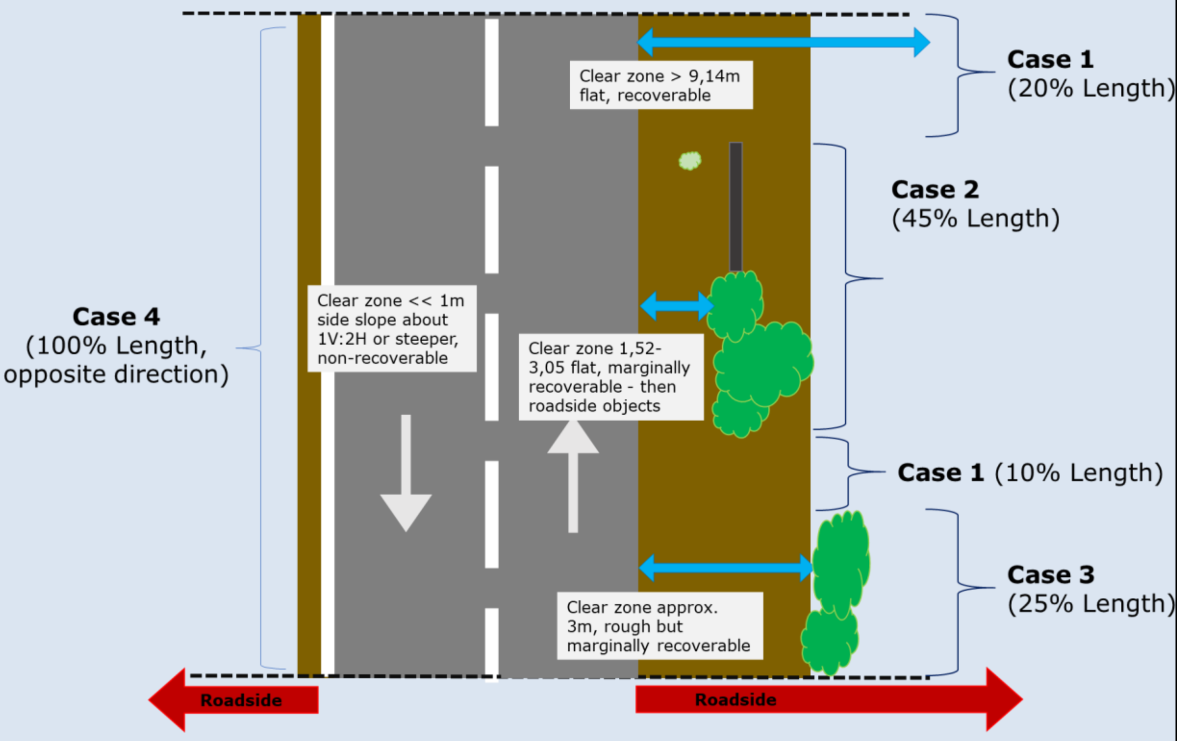


Figure 3.17: *Example of roadside environment on an undivided primary road.*

In the above case:

For the direction of travel to the south, RHR_S = 7 (from Table 3.2)

For the direction of travel to the north, RHR_N =(20%+10%)x1+45%x4+25%x3=2,85

3.6.2.3 Curvature

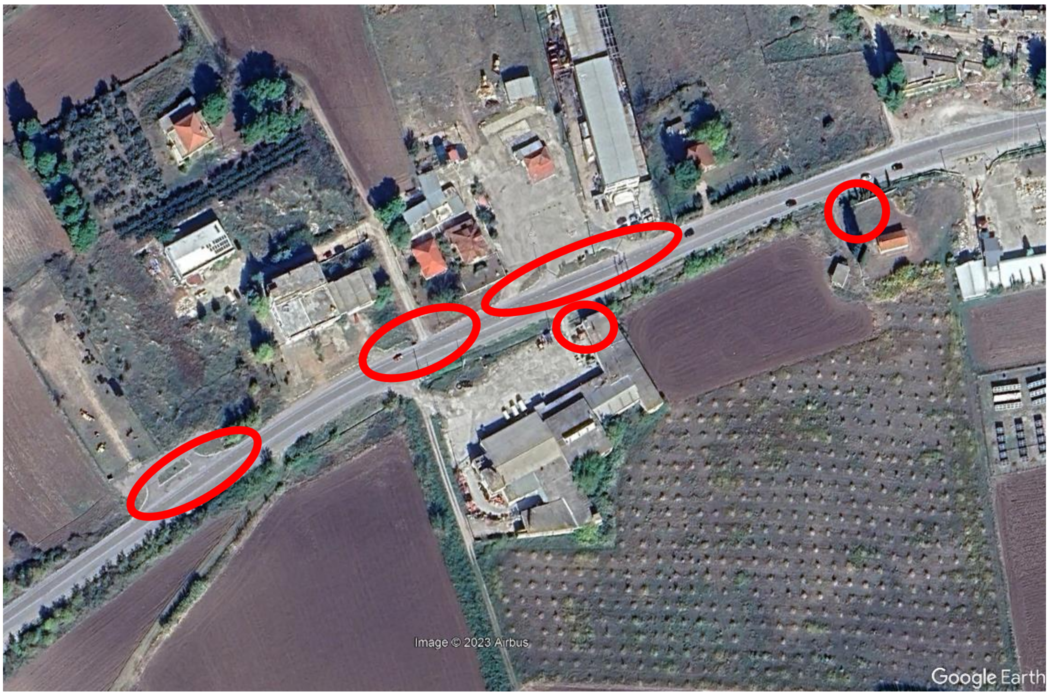
Data related to the horizontal curve parameter in primary roads concern the following:

1. Radius (in meters) of all horizontal curves in the section
   - If more than one curve exists, it is needed to record the radius of the **steepest one** (i.e., the curve with the lowest radius)
2. For the steepest curve, speed limit data is needed right before and along the curve
3. Presence of automated speed enforcement in the area of the steepest curve.

Data requirements are identical for both divided and undivided primary roads.

3.6.2.4 Density of property access points

For the purpose of the network wide safety assessment methodology, **all sites where a vehicle may enter/ exit the examined road section that are not junctions**, are considered as property access points. In case of a separate path for entrance and exist, the layout is considered as one property access point. Figure 3.18 provides some examples of property access points.



Maps data: Google, © 2023 Airbus

Maps data: Google, © 2023 Maxar Technologies

Figure 3.18: *Examples of property access points identification on an undivided primary road.*

For **undivided roads** the number of property access points is measured for both sides of the road. The total number of points is divided by the section's length in km, to obtain a value for property access points density, in points per km.

For **divided roads**, only the property access points that affect the examined direction of travel (i.e., on the right side of the road for right-driving countries) are considered. The total number of points is also divided by the section length in km, to obtain a value for property access points density, in points per km.

3.6.2.5 Junctions

The assessment of junctions across a section requires to record: (a) the type of junction, and (b) the length of it. The network-wide assessment methodology considers the following types of junctions (Table 3.3):

Table 3.3: *List of junction types considered in primary roads.*

Types of junctions
Grade-separated (any type)
Roundabout (any diameter)
3-leg signalized with turn lane
3-leg signalized without turn lane
3-leg unsignalized with turn lane
3-leg unsignalized without turn lane
4-leg signalized with turn lane
4-leg signalized without turn lane
4-leg unsignalized with turn lane
4-leg unsignalized without turn lane

Regarding the length of each junction within the segment, if it is known or can be measured, then the actual length should be recorded. Otherwise, typical junction dimensions can be used, as follows (identical to dimensions used in the reactive methodology - Tables 2.1 and 2.2):

- At-grade intersection (any type): 100m
- Single ramp interchange: 200m
- Trumpet interchange: 400m
- Diamond interchange: 500m
- U-turn interchange: 700m
- Cloverleaf interchange: 800m
- Clover stack interchange: 900m
- T-Bone interchange: 900m
- Complex geometry interchange: 1000-1200m

3.6.2.6 Conflicts between pedestrians/ bicyclists and motorized traffic

Data requirements for this parameter are identical for both divided and undivided primary or other rural roads.

The first step in the assessment of primary or other rural roads in terms of pedestrian and bicyclist safety is to identify (based on prior knowledge of the competent authority or site data) whether there are pedestrian and bicyclist flows in the examined road section. If this is not the case, then no more data are needed.

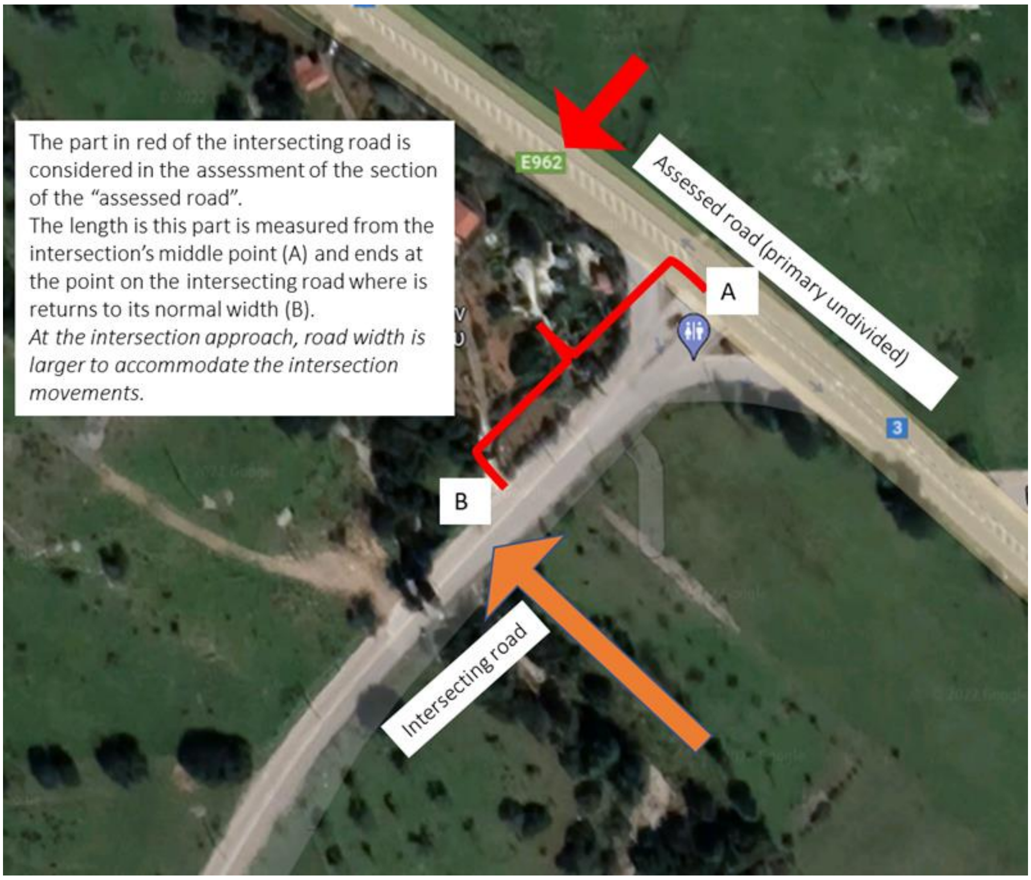
When pedestrians and bicyclists use the road section under examination, the following types of data are required: (a) pedestrian crossing facilities, (b) facilities to accommodate pedestrians along the road, (c) facilities to accommodate bicyclists along the road, and (d) speed limit (or operation speed if data are available). For points (b) and (c) it is also needed to measure the length of those facilities across the section. Table 3.4 presents the facility types for pedestrians and bicyclists.

It is noted that if the examined section includes one (or more) **at-grade intersections**, between primary roads and other rural (secondary) roads (i.e., roads not covered by the 2008/96/EC Directive), potential VRU conflicts on the secondary road are examined from the intersection's middle point to the point on the secondary road where the cross section of the secondary road is reinstated to its normal width. This length on the secondary road is therefore to be also added to the segment length. Figure 3.19 illustrates the area of interest for the at-grade intersections.

Table 3.4: *List of facilities for bicyclists and pedestrians that may be present in rural roads*

Feature
Pedestrians - crossing
Grade separated facility
Signalized crossing Note whether refuge is present or not
Unsignalized marked crossing Note whether refuge is present or not
Unsignalized marked crossing without refuge - *speed limit > 70km/h*
Pedestrians - along
Segregated pedestrian path (e.g., on shoulder, behind safety barriers) - the length of the path needs to be measured
Bicyclists - along
Segregated bicyclist path - the length of the path needs to be measured
Dedicated bicyclist lane on roadway - the length of the bike lane needs to be measured
Wide paved shoulder (width > 1m)

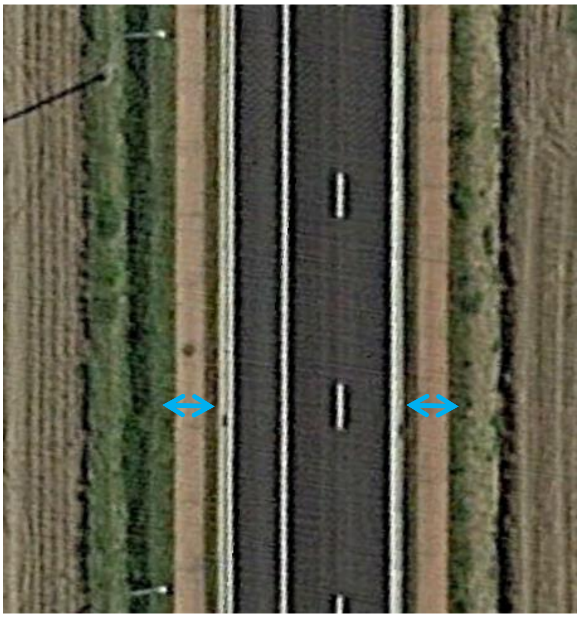
It is clarified that a segregated path along a primary rural road is considered appropriate for use by both bicyclists and pedestrians; however, the other types of bicycle facilities cannot be marked as pedestrian facilities as they are not proper to accommodate the later. Figure 3.20 shows an example of a bike lane on the road and a segregated path along the road.



Maps data: Google, © 2023 Maxar Technologies

Figure 3.19: *Area of interest at an at-grade intersection.*

Maps data: Google, © 2023
N3 road (connecting Leuven and Tienen, BE)



Maps data: Google, © 2023
N3 road (connecting Tienen and Gussenhoven, BE)

Figure 3.20: *Example of bike lanes (left side, noted with the red arrow) and segregated path (right side, noted with a blue arrow).*

3.6.2.7 Shoulder type and width

Data required for the parameter related to shoulder type and width is:

1. The overall shoulder width (paved or unpaved), measured from:
    a. the outer end of the edgeline marking, if one is present, or
    b. the end of the asphalt pavement if no edgeline is present.
2. A notation of whether the shoulder is paved or unpaved.

Figure 3.21 provides examples of paved and unpaved shoulders.

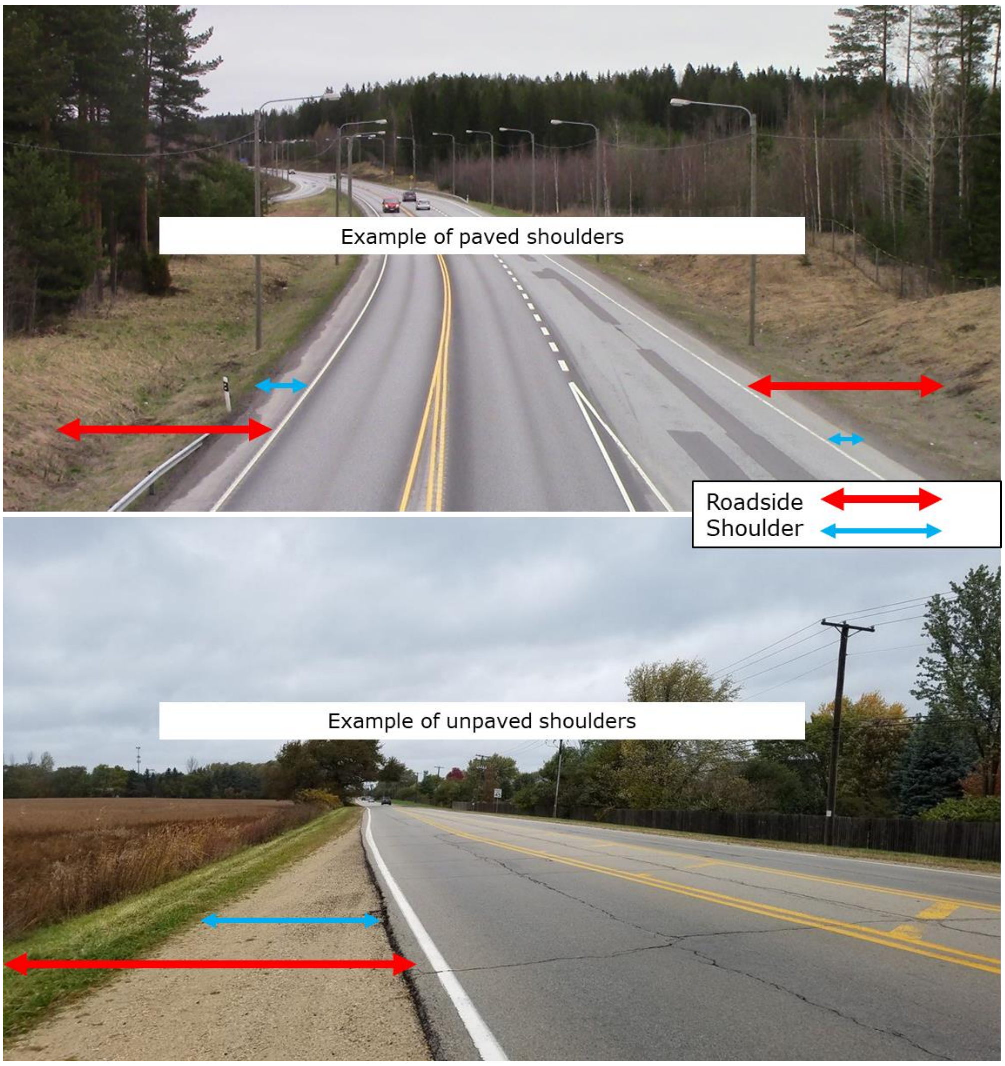


Figure 3.21: *Example of shoulder types. The figures also illustrate the placement of shoulder (blue arrows) within the roadside (red arrows) (Background Source: Wikipedia).*

For **composite shoulders** (i.e. part of the shoulder paved and part unpaved), the shoulder is considered of the same type as its largest part.

It is noted that this parameter is assessed differently for the case of divided and undivided rural roads.

For **undivided roads**, shoulder type and width should be measured and recorded for each direction of traffic and then consider both sides to score the section. If the shoulder is varying (width or sealing material) then, it is needed to also measure the length of the section's part where the shoulder has a certain configuration, in order to estimate an average value for each side of the road.

For **divided roads**, shoulder is assessed per direction of traffic. If the shoulder is varying (width or sealing material) then, it is needed to also measure the length of the section's part where the shoulder has a certain configuration in order to estimate an average value.

Example: An undivided primary road section of 3km has shoulders as follows:

Left side:	1km of 0,60m paved and 1,10m unpaved shoulder
	3kms of 0,60m paved and 0,70m unpaved
Right side:	4kms of 0,60m paved and 0,40m unpaved

For the left side, the shoulder is considered as unpaved, since the unpaved part is larger. The width is estimated (length weighted average) as (1x1,70 + 3x1,30) / 4 = 1,40m.

For the right side, the shoulder is considered as paved, since the paved part is larger, with a width of 1,00m.

3.6.2.8 Passing lanes

The presence of passing lanes is only important in the **case of two-lane undivided roads**. If the assessed road is (a) divided (regardless the number of lanes) or (b) undivided with more than one lane per direction, then no further data related to passing lanes are required.

When evaluating undivided rural roads with one lane per direction of traffic (i.e., two-lane roads) the following data is needed:

1. Slope of the road and specifically, it is needed to know and record whether the slope is higher than 4%

2. Length for which the road section has a slope > 4%

3. A notation of whether passing lanes exist on one or both directions of traffic within the section.

3.6.2.9 Signs and markings

Data on markings and signs consists of two components: presence of all required signs and markings, and quality and condition of signs and markings.

Three data attributes are used to describe the rating of signs and markings:

1. in place, high quality, good condition

2. in place, but poor quality or condition

3. critical signs/ markings missing

The **presence of signs and markings** (attribute: "critical signs/ markings missing") refers to the identification of obviously required signs with a high estimated impact for road safety (indicatively: speed limit signs, STOP signs at property access points or junctions with minor roads, curve warning signs in case of isolated curves of small radii, lane markings at intersections, lane markings separating opposite directions of travel, etc.)

If all critical signs are present, their **quality and condition** is qualitatively assessed, as "good" or "poor". It is noted that a poor quality/ condition sign may also be one that is of inappropriately small size for the speed and category of the examined road. Illustrative examples are presented in Figure 3.22 that follows.

It is noted that the rating should be representative of the examined section overall (e.g. a single missing sign should not characterize a 5km long section; assessors might reconsider the segmentation to capture the impact of such a sign, or, if not critical, choose not to consider it). Therefore, engineering judgment is required to classify the quality of markings and signs and provide the required data input.

Maps data: Google, © 2023 Maxar Technologies

Figure 3.22: *Example of segments and intersections where markings and signs are present, of good or low quality or not present*

3.7 Estimation of Reduction Factors per parameter

This section presents guidance on how to estimate Crash Modification Factors (CMFs) and Reduction Factors (RFs) for each parameter, based on the already collected data. NWA-proactive assessors may also use the provided Excel Tool (see Annex D) to facilitate the estimation of the final RF per parameter (per section).

Subsection 3.7.1 presents the parameters for motorway assessment and subsection 3.7.2 presents the parameters for primary (or other rural) road assessment.

3.7.1 Motorways

The following paragraphs describe the steps to be followed for the estimation of CMFs and RFs for motorway sections. Parameters related to lane width, horizontal curves, and interchanges are treated differently CMFs and RFs are considered for rural and for urban motorways.

3.7.1.1 Lane width

CMFs and RFs for lane width for rural and urban motorways are provided in Tables 3.5 and 3.5 respectively. Based on the value of the average section lane width (see also paragraph 3.6.1.1 for data collection guidance and estimation example), the respective CMF and the RF can be selected.

Table 3.5: *CMFs and Reduction Factors (RF) for lane width in rural motorways.*

Average lane width	CMF	Reduction Factor
LW ≥ 3,40m	1,000	1,000
3,15m ≤ LW <3,40m	1,025	0,976
LW ≤ 3,15m	1,050	0,952

Table 3.6: *CMFs and Reduction Factors (RF) for lane width in urban motorways.*

Average lane width	CMF	Reduction Factor
LW ≥ 3,25m	1,000	1,000
3,00m ≤ LW <3,25m	1,025	0,976
LW ≤ 3,00m	1,050	0,952

3.7.1.2 Roadside

Table 3.7 presents the CMF and the respective Reduction Factors for considered motorway roadside configurations. There is no differentiation in the Reduction Factors between urban and rural motorways.

Table 3.7: *CMFs and Reduction Factors for roadside environment in motorways.*

Clear zone width (m)	Roadside obstacle type	CMF	Reduction Factor
CZ ≥ 10m	barrier steel	1	1
	barrier concrete	1	1
	series of rigid obstacles	1	1
	fill/cut slope	1	1
	deep drainage ditch	1	1
CZ 7,5-10m	barrier steel	1,008	0,992
	barrier concrete	1,008	0,992
	series of rigid obstacles	1,701	0,588
	fill/cut slope	1,485	0,674
	deep drainage ditch	1,629	0,614
CZ 5-7,5m	barrier steel	1,016	0,984
	barrier concrete	1,016	0,984
	series of rigid obstacles	1,742	0,574
	fill/cut slope	1,516	0,660
	deep drainage ditch	1,667	0,600

Clear zone width (m)	Roadside obstacle type	CMF	Reduction Factor
CZ 3-5m	barrier steel	1,041	0,960
	barrier concrete	1,093	0,915
	series of rigid obstacles	1,866	0,536
	fill/cut slope	1,608	0,622
	deep drainage ditch	1,780	0,562
CZ 2-3m	barrier steel	1,082	0,924
	barrier concrete	1,144	0,874
	series of rigid obstacles	2,072	0,483
	fill/cut slope	1,763	0,567
	deep drainage ditch	1,969	0,508
CZ 1-2m	barrier steel	1,660	0,602
	barrier concrete	1,866	0,536
	series of rigid obstacles	4,960	0,202
	fill/cut slope	3,929	0,255
	deep drainage ditch	4,616	0,217
CZ 0-1m	barrier steel	2,485	0,402
	barrier concrete	2,897	0,345
	series of rigid obstacles	9,085	0,110
	fill/cut slope	7,022	0,142
	deep drainage ditch	8,397	0,119

It is clarified that the presence of sidewalk curbs is not considered to affect the CMF (and thus also the Reduction Factor) of the aforementioned clearzone - roadside objects combinations. A roadside consisting of a flush shoulder and one also including a curb will

As the roadside varies significantly along the section, it is needed to:

1. estimate a weighted average CMF ($CMF_{weighted}$) considering the percentage of the section that corresponds to different roadside conditions
2. estimate the final RF: RF = 1 / $CMF_{weighted}$

<u>3.7.1.3 Curvature</u>

The estimation of CMFs and respective RFs for the curvature parameter for motorways differs for **rural** and for **urban** motorways:

<u>A. Rural motorways</u>

- for segments with tangents and curves with R≥1500m: CMF=1,00=> **RF=1,00**
- if at least one curve with R<1500m exists in the segment:

$$\mathrm{CMF} = 1{,}00 + 0{,}03312 \times \sum_i \left(\frac{1746{,}5}{R_i}\right)^2 \times P_{c,i}$$

where:
R_i (m) = radius of curve i within segment
$P_{c,i}$ ()= proportion of segment length within curve i

and the respective RF = 1/CMF => **RF =** $\mathbf{1 \Big/ 1,00 + 0,03312 \times \sum_i \left(\frac{1746,5}{R_i}\right)^2 \times P_{c,i}}$

B. Urban motorways

- for segments with tangents and curves with R≥750m: CMF=1,00=> **RF=1,00**
- if at least one curve with R<750m exists in the segment:

$$CMF = 1,00 + 0,01656 \times \sum_i \left(\frac{1746,5}{R_i}\right)^2 \times P_{c,i}$$

where: R_i (m) = radius of curve i within segment
$P_{c,i}$ ()= proportion of segment length within curve i

and the respective RF = 1/CMF => **RF =** $\mathbf{1 \Big/ 1,00 + 0,01656 \times \sum_i \left(\frac{1746,5}{R_i}\right)^2 \times P_{c,i}}$

3.7.1.4 Interchanges

Different CMFs and RFs are used for the assessment of urban and rural motorways, as shown in Table 3.8.

Table 3.8: *CMFs and Reduction Factors for ramp spacing in motorways.*

Ramp Spacing (m) (gore to gore length)	Rural Motorway		Urban Motorway	
	CMF	Reduction Factor	CMF	Reduction Factor
1600	1,043	0,959	1,032	0,969
1400	1,049	0,953	1,032	0,969
1200	1,057	0,946	1,032	0,969
1100	1,063	0,941	1,032	0,969
1000	1,069	0,935	1,032	0,969
900	1,077	0,928	1,032	0,969
800	1,088	0,919	1,066	0,938
700	1,101	0,908	1,066	0,938
620	1,115	0,897	1,066	0,938
560	1,128	0,887	1,106	0,904
500	1,144	0,874	1,106	0,904
440	1,166	0,858	1,151	0,869
380	1,195	0,837	1,151	0,869
320	1,236	0,809	1,173	0,853
260	1,299	0,770	1,205	0,830
200	1,395	0,717	1,240	0,807

Ramp Spacing (m) (gore to gore length)	Rural Motorway		Urban Motorway	
	CMF	Reduction Factor	CMF	Reduction Factor
140	1,609	0,621	1,291	0,775

Considering an influence length of 1km (regardless of the actual spacing) for each set of gore points, the CMF formula for interchange spacing is:

$$CMF_{final} = \frac{\{(1km) \times \sum_{i}^{n}(CMF_i) + 1{,}00 \times (Length - n)\}}{Length}$$

Where:

n is the number of sets of gore points, with two gore points making one set.

CMF_i is the CMF between gore points set *i*. The values are obtained from Table 3.8.

Length is the section's length measured in km.

In case the number of sets of gore points *n* is larger than the length of the segment in km *Length*, which would result in *(Length - n)* being negative, CMF_{final} is estimated as the average CMF for all considered sets of gore points.

NWA-proactive assessors are encouraged to use the provided Excel Tool (see Annex D) to facilitate the estimation of the final CMF and RF.

Example 1: Rural motorway with several gore points inside a section.

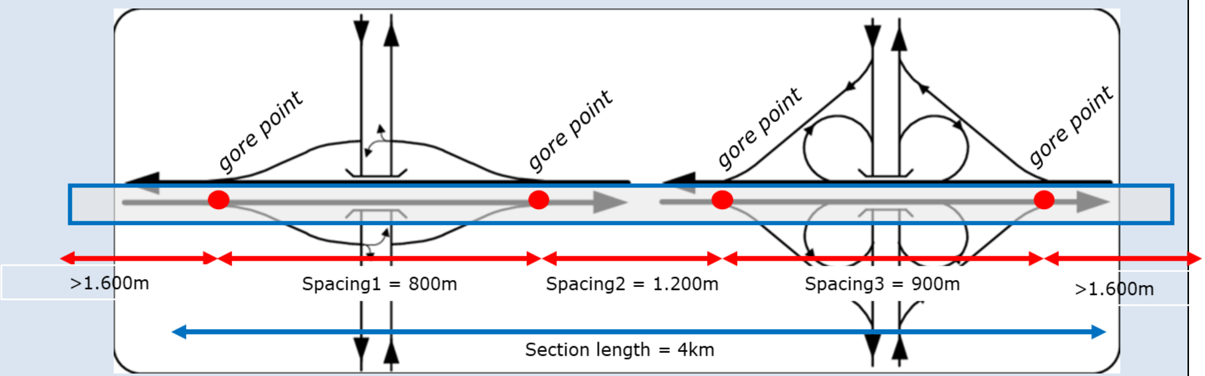


Figure 3.23: *Example of section with multiple ramps (Background Source: Hagen et al. (2006) - edited).*

CMF = {1km × (1,088 + 1,057 + 1,077) + 1,000 × (4km – 3km)} / 4km =>

CMF = 1,056, and

RF = 1 / CMF = 0,947

Example 2: Rural motorway with small (e.g., fixed length sections)

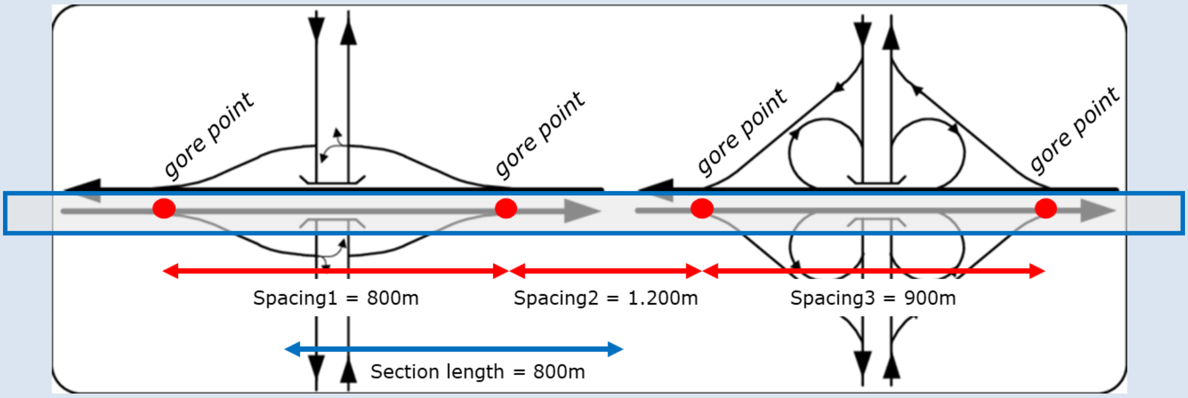


Figure 3.24: *Example of small section on rural motorway (Background Source: Hagen et al. (2006) - edited).*

n = 2 > Length of section = 0,8km

CMF = 1,088 + 1,057 / 2 => CMF = 1,073, and

RF = 1 / CMF = 0,932

3.7.1.5 Conflicts between pedestrians / bicyclists and motorized traffic

The Reduction Factors for assessing VRU safety on motorways are listed below (see paragraph 3.6.1.5 for further explanation of the relevant options):

- for sections where pedestrians and bicyclists do not approach the motorway carriageway:
  RF=1,00
- for sections where pedestrians and bicyclists near the motorway carriageway are on level-separated or fully protected facilities:
  RF=1,00
- for sections where there are potential conflicts between vehicles and pedestrians / bicyclists:
  RF=0,05

3.7.1.6 Traffic Operation Centers and/ or mechanisms to inform users for incidents

The Reduction Factors for this parameter are listed below (see paragraph 3.6.1.6 for further explanation of the relevant options).

- **Reduction Factor = 1,000**, for motorways with traffic operation centers and/ or mechanisms to inform users for incidents.
- **Reduction Factor = 0,950**, for motorways without traffic operation centers or mechanisms to inform users for incidents.

3.7.2 Primary or other rural roads

The following paragraphs describe the steps to be followed for the estimation of CMFs and RFs for primary (or other) rural road sections. Parameters related to lane width, roadside, density of property access points, shoulder type and width and passing lanes are treated differently for divided and for undivided roads.

3.7.2.1 Lane width

The CMFs and RFs for lane width in undivided roads are presented in Table 3.9:

Table 3.9: *CMFs and Reduction Factors (RF) for lane width in undivided primary roads.*

Lane width	CMF	Reduction Factor
LW ≥ 3,40m	1,000	1,000
3,15m ≤ LW <3,40m	1,050	0,952
2,70m ≤ LW <3,15m	1,120	0,893
LW ≤ 2,70m	1,190	0,840

The considered CMFs and RFs for lane width in undivided roads are presented in Table 3.10:

Table 3.10: *CMFs and Reduction Factors (RF) for lane width in divided primary roads.*

Lane width	CMF	Reduction Factor
LW ≥ 3,40m	1,000	1,000
3,15m ≤ LW <3,40m	1,021	0,979
2,70m ≤ LW <3,15m	1,080	0,926
LW ≤ 2,70m	1,120	0,893

In all cases, the average section lane width should be used as input (see also paragraph 3.6.2.1 for data collection guidance and estimation example).

3.7.2.2 Roadside

Based on the Roadside Hazard Rating (RHR) score that has been identified during the data collection part, the following CMFs and RFs are considered for divided and undivided rural roads (Table 3.11):

Table 3.11: *CMFs and Reduction Factors (RF) for roadside environment in undivided and divided primary roads.*

Roadside Hazard Rating	CMF undivided roads	Reduction Factor undivided roads	Reduction Factor divided roads
1	0,875	1,000	1,000
2	0,935	1,000	1,000
3	1,000	1,000	1,000
4	1,069	0,935	0,968
5	1,143	0,875	0,937
6	1,222	0,818	0,909
7	1,306	0,766	0,883

If roadside is varying, then the weighted average RHR score needs to be estimated first, as already presented in paragraph 3.7.1.2.

For **undivided roads,** the following formula is used to obtain the CMF:

$$CMF = \max\left\{1{,}00, \quad \frac{e^{(-0{,}6869+0{,}0668\times RHR)}}{e^{-0{,}4865}}\right\}$$

The formula is applied twice, once for each side of the road, and the average CMF for left and right side is obtained $CMF_{left\&right}$.

The final RF is equal to: RF = 1 / $CMF_{left\&right}$.

For **divided roads**, where a separate assessment is performed per direction of travel, the following formula is used to directly estimate the final RF:

$$RF = \min\left\{1{,}00, \quad 1{,}00 - \ 0{,}50 * [1{,}00 - \min(1{,}00, \quad \frac{e^{-0{,}4865}}{e^{(-0{,}6869+0{,}0668\times RHR)}})]\right\}$$

3.7.2.3 Curvature

The CMFs and respective **Reduction Factors** for curvature in primary (and other) rural roads are:

- for segments with tangents and curves with R≥1000m: CMF=1,00 => **RF=1,00**
- if at least one curve with R<1000m exists in the segment:

  $$CMF = 1{,}00 + 0{,}7937 \times (0{,}09134\ V)^4 \times \frac{(0{,}9134\ V)^2}{32{,}2 \times (R/0{,}3048)^2}$$

  where: R (m) = 1,5 x radius of the **sharpest curve** within the segment
  V (km/h) = <speed limit>, if automated speed enforcement is present,
  <speed limit + 20km/h> if automated speed enforcement is not present
  or
  <operation speed V_{85}) if data is available

  and the respective RF = 1/CMF =>
  RF = $1 \Big/ 1{,}00 + 0{,}7937 \times (0{,}09134\ V)^4 \times \frac{(0{,}9134\ V)^2}{32{,}2 \times (R/0{,}3048)^2}$

3.7.2.4 Density of property access points

The CMFs and respective Reduction Factors for access points density in primary (and other) rural roads are listed in Table 3.12. The same reference values are used for both divided and undivided roads, with the difference that for **undivided roads** property access points on both sides of the road are considered whereas for **divided roads** only those affecting the examined direction of travel are considered.

Table 3.12: *CMFs and Reduction Factors (RF) for property access points density in primary roads.*

Density of property access points (Points per km)	CMF	Reduction Factor
0	1,000	1,000
1	1,045	0,957
2	1,093	0,915
3	1,144	0,874
4	1,197	0,835
5	1,253	0,798
6	1,312	0,762
7	1,374	0,728
8	1,439	0,695
9	1,508	0,663
10	1,581	0,633
11	1,658	0,603
12	1,739	0,575
13	1,825	0,548
14	1,916	0,522
15 or more	2,000	0,500

3.7.2.5 Junctions

The CMFs and respective Reduction Factors for junctions in primary (and other) rural roads are listed in Table 3.13. The same values are used for both divided and undivided roads.

It is noted that when more than one junction exists per section, a weighted average CMF needs to be estimated considering the length of each junction. Based on the weighted average CMF the final RF will be estimated. For example, on a section 3km long, with a 0,5km 4-leg unsignalized with turn lane intersection and a 0,2km roundabout, the resulting average Reduction Factor would be:

Table 3.13: *CMFs and Reduction Factors for the different junction types.*

Junction type	CMF	Reduction Factor
No junction	1,000	1,000
Grade-separated	1,000	1,000
Roundabout	1,000	1,000
3-leg signalized with turn lane	1,000	1,000
3-leg signalized without turn lane	1,044	0,958
3-leg unsignalized with turn lane	1,130	0,885
3-leg unsignalized without turn lane	1,391	0,719
4-leg signalized with turn lane	1,000	1,000
4-leg signalized without turn lane	1,420	0,704
4-leg unsignalized with turn lane	1,515	0,660
4-leg unsignalized without turn lane	2,178	0,459

CMF_{final} = [0,5 x 1,515 + 0,2 x 1,000 + (3-0,5-0,2) x 1,000] / 3 =>

CMF_{final} =1,219

The final Reduction Factor will be: RF_{final} = 1/1,219 = 0,820.

3.7.2.6 Conflicts between pedestrians/ bicyclists and motorized traffic

CMFs and RFs for assessing the presence and type of pedestrian and bicyclist facilities in rural roads are provided in Table 3.14. Additionally, it is explained how to use the information from that table to CMF and RF for a section in cases where more than one facility is present.

- Step 1: Estimate CMF for pedestrian crossings ($CMF_{ped.cr}$), as weighted average of 100m length segments over the total length of the segment.

- Step 2: Estimate CMF for pedestrian movement along the segment ($CMF_{ped.al}$), as weighted average of actual length (e.g., with/ without pedestrian traffic and/ or related facility) over the whole length of the segment.

- Step 3: Calculate the CMF for potential pedestrian conflicts (CMF_{ped}) as the average of the two aforementioned CMFs, i.e., CMF_{ped} = 0,50 x ($CMF_{ped.cr}$ + $CMF_{ped.al}$).

- Step 4: Estimate CMF for bicycle movement along the segment (CMF_{bic}), as weighted average of actual length (e.g., with/ without bicyclist traffic and/ or related facility) over the whole length of the segment.

- Step 5: Calculate the overall CMF for potential pedestrian and bicyclist conflicts ($CMF_{combined}$) using the following equation, with weights derived from the respective crash numbers from CARE database:

  $CMF_{combined}$ = (3,1 x CMF_{ped} + 8,8 x CMF_{bic}) / (3,1+8,8)

- Step 6: Calculate the overall Reduction Factor as $RF_{combined}$ = 1/$CMF_{combined}$.

Table 3.14: *CMFs and Reduction Factors for pedestrian- and bicyclist-related features.*

Feature	CMF	Reduction Factor
Pedestrians - crossing		
No pedestrian traffic	1,000	1,000
Grade separated facility *(used as CMF estimation basis)*	1,000	1,000
Signalized crossing with refuge - *speed limit > 70km/h*	2,500	0,400
Signalized crossing without refuge - *speed limit > 70km/h*	3,100	0,323
Unsignalized marked crossing with refuge - *speed limit > 70km/h*	9,500	0,105
Unsignalized marked crossing without refuge - *speed limit > 70km/h*	12,000	0,083
No facility for pedestrians crossing- *speed limit > 70km/h*	16,750	0,060
Signalized crossing with refuge - *speed limit ≤ 70km/h*	2,000	0,500
Signalized crossing without refuge - *speed limit ≤ 70km/h*	2,500	0,400
Unsignalized marked crossing with refuge - *speed limit ≤ 70km/h*	8,000	0,125
Unsignalized marked crossing without refuge - *speed limit ≤ 70km/h*	10,000	0,100
No facility for pedestrians crossing- *speed limit ≤ 70km/h*	12,000	0,083
Pedestrians - along		
No pedestrian traffic	1,000	1,000
Segregated - protected pedestrian path (e.g. on shoulder, behind safety barriers)	1,000	1,000
No facility for pedestrians walking along	20,000	0,050
Bicyclists - along		
No bicycle traffic	1,000	1,000
Segregated bicyclist path *(used as CMF estimation basis)*	1,000	1,000
Dedicated bicyclist lane on roadway	12,000	0,083
Wide paved shoulder (width > 1m)	17,000	0,059
No facility for bicyclists	20,000	0,050

Example: 3km segment on a divided primary road, with speed limit of 70km/h, with the following VRU related characteristics:

- pedestrian traffic along the road for a length of 800m, on a pathway behind the safety barrier),
- one at grade intersection with a secondary road, considering 100m of length on the secondary road with altered cross section because of the intersection, with two signalized pedestrian crossings with refugee on the intersection location,
- one additional informal crossing, without any marking, and
- bicycle traffic on 1km on wide shoulder.

The network-wide Reduction Factor is then estimated as follows:

$CMF_{ped.cr}$ = [2x0,100x2,000+1x0,100x12,000 +1,000x(3,100-0,300)] / (3,100) = 1,419

$CMF_{ped.al}$ = 0,800x1,000 + (3,100-0,800)x1,000 / 3,100 = 1,000

CMF_{ped} = 0,50 x ($CMF_{ped.cr}$ + $CMF_{ped.al}$) = 0,50 x (1,419 + 1,000) = 1,210

CMF_{bic} = [1,00x17,000+(3,100-1,000)x1,000]) / 3,100 = 6,161

$CMF_{combined}$ = (3,1 x 1,210 + 8,8 x 6,161) / (3,1+8,8) = 4,871

$RF_{combined}$ = 1/ $CMF_{combined}$ = 1/4,871 = 0,205.

It is noted that the examination of results of the intermediate steps for the estimation of $RF_{combined}$ provides a useful indication of the nature of the road safety deficiency (if any). In the above example, it becomes obvious that the low scoring is due to the unprotected considerable bicycle traffic on a significant part (1km long) of the examined segment.

3.7.2.7 Shoulder type and width

The CMFs and RFs for the assessment of shoulder type and width are provided in the following tables. Different CMFs and RFs are considered for undivided roads compared to divided roads.

For **undivided roads** see Table 3.15 for paved shoulders and Table 3.16 for unpaved shoulders.

Table 3.15: *CMFs and Reduction Factors for the assessment of paved shoulders in primary undivided roads*

Shoulder width (m)	CMF	Reduction Factor
SW ≥ 1,83	1,000	1,000
1,23 ≤ SW < 1,83	1,063	0,941
0,91 ≤ SW < 1,23	1,097	0,912
0,61 ≤ SW < 0,91	1,127	0,887
0,00 ≤ SW < 0,60	1,211	0,826

Table 3.16: *CMFs and Reduction Factors for the assessment of unpaved shoulders in primary undivided roads.*

Shoulder width (m)	CMF	Reduction Factor
SW ≥ 1,83	1,017	0,983
1,23 ≤ SW < 1,83	1,077	0,929
0,91 ≤ SW < 1,23	1,106	0,904
0,61 ≤ SW < 0,91	1,136	0,880
0,00 ≤ SW < 0,60	1,211	0,826

For **divided roads** see Table 3.17 for paved shoulders and Table 3.18 for unpaved shoulders.

Table 3.17: *CMFs and Reduction Factors for the assessment of paved shoulders in primary divided roads.*

Shoulder width (m)	CMF	Reduction Factor
SW ≥ 2,44	1,000	1,000
1,83 ≤ SW < 2,44	1,040	0,962
1,23 ≤ SW < 1,83	1,090	0,917
0,91 ≤ SW < 1,23	1,110	0,901
0,61 ≤ SW < 0,91	1,130	0,885
0,00 ≤ SW < 0,61	1,180	0,847

Table 3.18: *CMFs and Reduction Factors for the assessment of unpaved shoulders in primary divided roads.*

Shoulder width (m)	CMF	Reduction Factor
SW ≥ 2,44	1,025	0,976
1,83 ≤ SW < 2,44	1,058	0,945
1,23 ≤ SW < 1,83	1,104	0,906
0,91 ≤ SW < 1,23	1,119	0,894
0,61 ≤ SW < 0,91	1,139	0,878
0,00 ≤ SW < 0,61	1,180	0,847

If the shoulder type and width change across the section, a weighted average CMF should be estimated first considering the respective CMF values from the above tables.

3.7.2.8 Passing lanes

The considered CMFs and RFs for the presence of passing lanes are listed in Table 3.19.

Table 3.19: *CMFs and Reduction Factors for the presence of passing lanes in primary roads*

Condition	CMF	Reduction Factor
Divided road	n/a	1,000
Undivided multi-lane road	n/a	1,000
Undivided 2-lane road with slope <4%, or slope >4% for length<500m	n/a	1,000
Undivided 2-lane road with slope >4% for more than 500m - passing lane in both directions	1,000	1,000
Undivided 2-lane road with slope >4% for more than 500m - passing lane in one direction	1,149	0,870
Undivided 2-lane road with slope >4% for more than 500m - No passing lanes	1,502	0,666

A weighted average CMF needs to be estimated taking into account the length of the section that has passing lanes. Based on this value, the final RF can be calculated.

Example: Section of 2km in an undivided two-lane rural road. The slope of the road along this section is 4,5% (more than 4%). Passing lanes are present in one direction of traffic for 700m (more than 500m. No passing lanes are present in the rest of the section. The weighted average (i.e., final) CMF is going to be equal to:

Final CMF = (1,149x700m + (2000m-700m)x1,502)/2000 = 1,378

Final RF = 1/ Final CMF = 1/1,378 = 0,726

3.7.2.9 Signs and markings

The following **Reduction Factors (RF)** are considered for assessing the presence and quality of markings and signs in rural roads.

- **Reduction Factor = 1,00:** when required markings and signs are in place, are of high quality and in good condition.
- **Reduction Factor = 0,95:** when required markings and signs are in place but are of medium or poor quality and/ or require maintenance.
- **Reduction Factor = 0,90:** when critical required markings and signs are missing.

3.8 Estimation of proactive score for each section

After estimating the final Reduction Factor (RF) for each parameter, the total score the section can be estimated. The score is calculated based on the following equation:

$$Score_i = 100 \times RF_{1i} \times RF_{2i} \times \ldots \times RF_{ni}$$

Where $Score_i$ is the safety score of the *i*-th road section. $Score_i$ is a function of the RF_{ji} where *j* denotes the different parameters used for the assessment. Depending on whether the road is a motorway or a primary rural (or other) road, the number of parameters and in turn, the number of RFs used in the previous formula changes.

The provided Excel Tool (see Annex D) may be used to facilitate the estimation of the final CMFs and RFs for each parameter and of the final proactive assessment score per section.

3.9 Score thresholds, traffic volume filter and classification

After obtaining the final score per section, the section is assigned to a safety class, based on the final score value. Different class thresholds have been defined for motorways (urban and rural) and primary (and other) rural roads (divided and undivided).

For **motorways**:

- Low Risk - class 1: score ≥ 85%, colour coded as green
- Intermediate Risk - class 2: 65% ≤ score < 85%, colour coded as yellow
- High Risk - class 3: score < 65%, colour coded as red

For **primary and other rural roads** (e.g., completed with EU funding):

- Low Risk - class 1: score ≥ 80%, colour coded as green
- Intermediate Risk - class 2: 50% ≤ score < 80%, colour coded as yellow
- High Risk - class 3: score < 50%, colour coded as red

Road sections classified as "High Risk" and "Intermediate Risk" will potentially be subject to follow-up actions, depending also on the results of the reactive (crash-based) assessment approach and on available funds. As road safety funds are not unlimited, it is important to effectively prioritize the further examination and/ or treatment (after the end of the NWA process) of segments that affect a larger number of road users.

The procedure therefore also includes in the safety ranking process a criterion related to the section's traffic volume. In order for a section to be classified in the worst class ("High Risk" - class 3), it is required that the Annual Average Daily Traffic exceeds a predefined threshold. If it does not, i.e. if it is a very low traffic road, it will be classified a "Intermediate Risk" - class 2 instead. This threshold has been defined at the lowest 15% in terms of AADT of the respective road type (rural motorway, urban motorway, primary divided road, primary undivided road).

Step by step, this procedure is applied (per section) as follows:

1. if the initial proactive assessment result for the section is "Low Risk - class 1", or "Intermediate Risk - class 2", then it is retained.

2. if AADT data for the entire road network type (in order to define the threshold) or for the specific road section are unavailable, the initial proactive assessment result is also retained.

3. if the initial proactive assessment result for the section is "High Risk - class 3", but the section's AADT lies in the lowest 15% of AADTs in the specific road type, the assessment result is shifted to "Intermediate Risk - class 2".

4. THE INTEGRATED APPROACH

This section briefly presents the concept of the integrated methodology, showing how to combine the outcome of the proactive and reactive methodologies for the same road.

4.1 Number of road safety "classes"

The considered methodology for the integration of results of the proactive and reactive methodologies is presented in Figure 4.1. The final assessment results in five classes as presented in Figure 4.2.

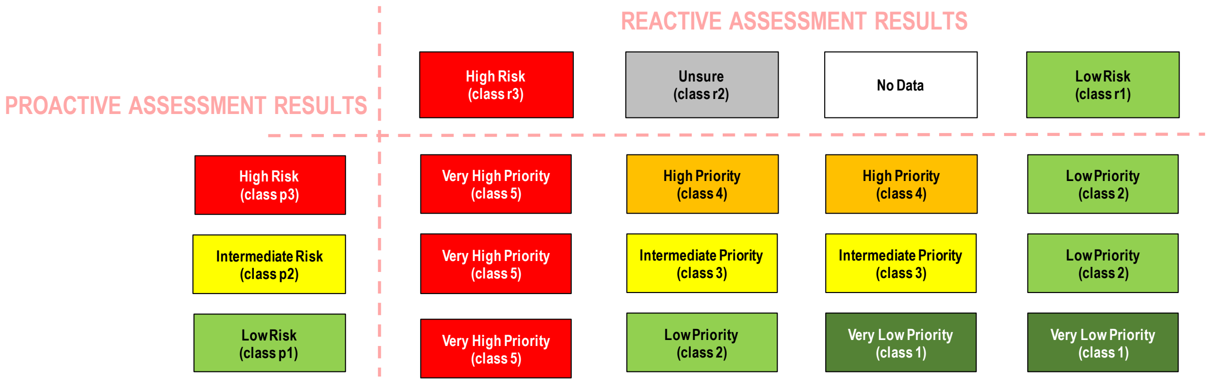


Figure 4.1: *Integration of NWA-proactive and NWA-reactive results.*

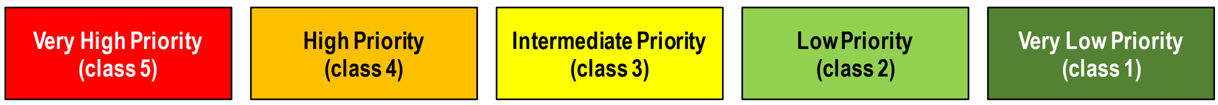


Figure 4.2: *Considered classes of integrated Network Wide Assessment.*

- Class 5 (worst performing): Very High Priority - colour: red
- Class 4: High Priority - colour: orange
- Class 3: Intermediate Priority - colour: yellow
- Class 2: Low Priority - colour: light green
- Class 1 (best performing): Very Low Priority - colour: dark green

4.2 Combination of results

In order to combine the results of the two approaches and provide an integrated assessment, every section change in either one of the two initial methodologies (reactive and proactive) dictates **a section change in the integrated assessment**.

Essentially, for the final ranking it is needed to have the outcomes of the proactive and reactive methodologies 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 methodologies.

In the indicative example of Figure 4.3, 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.

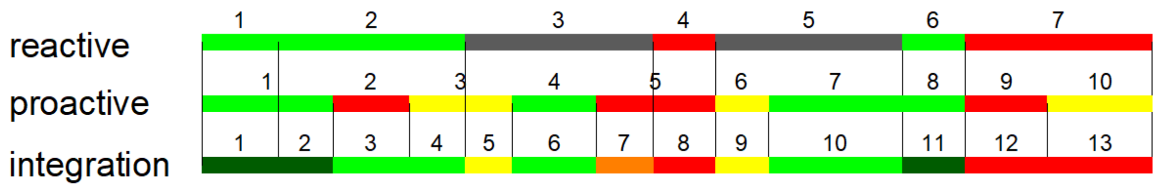


Figure 4.3: *Example of combining results with different segmentation in each method.*

In order to combine the results of the reactive and proactive methodology into the final integrated scoring, the guidance presented in Figure 4.1 is followed.

Within each integrated assessment class, i.e., within each cell of Figures 4.1 & 4.2, **further prioritization for detailed assessment and safety improvements may take place** using more detailed criteria and indicators, based on quantities such as traffic volumes, number of persons killed or killed and injured, or other, to the discretion of each Member State.

4.3 End of NWA

After the ranking of the integrated methodology, i.e., five-scale system, the NWA methodology has been completed.

A list of follow-up actions is presented (Figure 4.4), related to the final score of each section. Sections that have been classified as "Class 1 – Very low priority" will be evaluated in five years and no actions are needed until that time. Depending on the available road safety funds, sections that have been assigned to Class 2, 3, or 4 should undergo Road Safety Inspection (RSI) and then, based on the outcome of that process additional follow-up action can be determined. Lastly, sections that have been found to be in Class 5 ("Very high priority") should definitely be subject to RSI. Based on the outcome of the RSI, follow-up actions will be determined.

It is clarified that these actions are out of the scope of the NWA, therefore detailed guidelines on those are not presented in this Handbook. The final action plan is to be decided by each Member State.

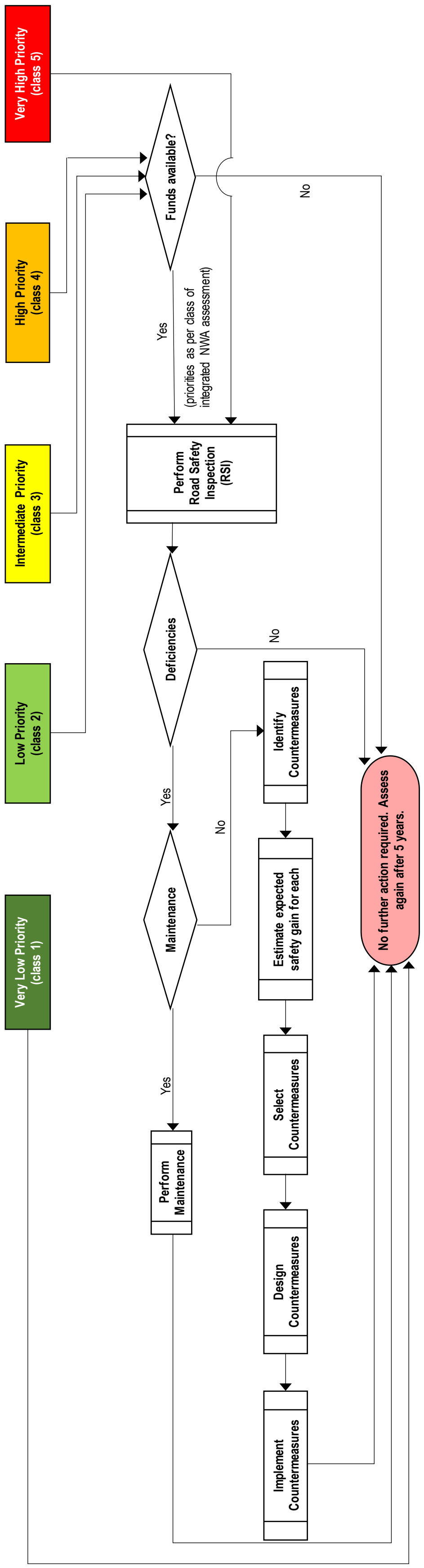


Figure 4.4: *Follow-up actions after the completion of NWA.*

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ANNEX A: DEVELOPMENT OF THE REACTIVE METHODOLOGY

Annex A presents the development process, assumptions and theoretic background of the reactive network-wide safety assessment methodology that is based on crash occurrence analysis. For detailed, step by step guidance on the practical implementation of the methodology, the reader is referred to Chapter 2 of the present Handbook.

A.1 Initial Considerations

A.1.1 Objectives

The methodology was developed with the aim to combine the strengths of already existing crash analysis methodologies while also considering the needs and limitations of Member States, e.g., related to data availability, as identified through a dedicated questionnaire survey. An additional objective was to provide a well-structured and reliable method that at the same time is user-friendly.

A.1.2 Crash underreporting

The existence of crash underreporting needs to be kept in mind and considered when using crash statistics. Generally, crashes are registered by the police and in 89% of the Member States the crash severity information is also provided by the police. The probability of a crash being reported to the police decreases rapidly with a decreasing injury severity, leading to high percentages of not reported crashes especially for crashes with slight injuries or with property damage only. This happens mainly because the police do not get informed, meaning that such kind of crashes is not represented in the official data. Moreover, underreporting rates are higher for cyclists and pedestrians and lower for car drivers (Derriks, Mak, 2007).

Even in relation to crashes with casualties there may be several factors contributing to this issue, e.g., it is possible that an injured person dies later than a predefined time after the road crash occurrence. According to the definitions of most European countries this kind of casualty will not be registered as a fatality, but as a seriously injured casualty (Bickel et al., 2006).

Another factor potentially influencing crash statistics is the risk of data loss or data manipulation during the administrative process. The reason is that a data entry does not get done by the police officer who registered the crash on site. A further reason for underreporting is the data transfer to a centralized database. As a result, and if data collection methods are not improved, the statistics on crash could be biased. Due to incomplete data the negative consequence of underreporting could be a wrong assessment of the crash risk.

Issues related to underreporting of crash data, both in terms of the number of crashes that are recorded and the clear differentiation between the injury severity types, have not been fully examined across the Member States. Only 26% of Member States reported having performed studies on crash underreporting and 19% of them have explicitly studied injury severity underreporting.

Possible solutions to mitigate this problem are to improve the processes of reporting, entering and transferring data into databases and to carry out studies at national level that can provide an estimate of underreporting so that it can be used to obtain a dataset that better reflects reality. However, this applies at the medium-long term scenario.

A.1.3 Input data considerations

The following paragraphs present considerations and assumptions related to input data for the methodology application, also related to data availability as reported by Member

States, providing explanation and justification of decisions taken during the methodology development process. Data types considered and discussed below include crash data, road data, traffic volume data and crash cost data.

A.1.3.1 Crash data

Crash analysis methodologies may be based on the number of crashes or on the number of casualties (i.e., number of persons killed, seriously or slightly injured), or both. The number of crashes has been identified as a more appropriate metric for the NWA-reactive methodology compared to the number of casualties, as the latter depends also on factors such as vehicle fleet characteristics and travel patterns. For instance, the number of crashes is independent of vehicle safety devices (e.g., airbag, seat belt, etc.), or travel patterns (e.g. average number of persons in each vehicle), which on the other hand influence the number of casualties. Furthermore, the occurrence of a fatality could be due solely to chance (Government of Ireland, 1996).

Regarding road crashes, the following aspects have also been considered.

Crash location

Crash location is a crucial information to link the crash to a specific road segment or junction. The following ways are used across the Member States to record crashes:

- road code and chainage,
- GPS location,
- road segment numbering,
- road name and address.

It is important to note that there is a certain level of approximation for the first two ways of crash location. In particular, the chainage to which the crash is attributed can be approximated to the nearest metre (even if it is quite unusual) down to the nearest kilometre. This means that either a very precise location or an error of up to 0,5kilometre can be expected. Regarding GPS localisation, there is certainly a variable error related to the device used to record GPS coordinates, and then an approximation error due to the chainage to which the crash will be attributed.

The accuracy of the information provided by the “road segment numbering” depends on the segmentation of the road network that has been made and on the size of the segments. However, Member States that record crashes using the road segment numbering also collect the GPS location of the crash.

The “road name and address” is only applicable in urban areas and thus not suitable for motorways and primary roads.

Thus, the “road code and chainage” could certainly lead to greater approximations than GPS localisation. Sixty-three (63%) of Member States use the “road code and chainage”, 78% use GPS and 48% use both in combination. However, both methods provide an adequate level of detail to link the crash to its location. In fact, regardless of the network segmentation and the name of the roads, crashes can be linked to the position in which they occurred.

An additional source of data that could be used in the future is the eCall system, which could provide the precise location of the vehicle that has been involved in a crash. This system generates an emergency call that allows to send to the eCall operator a minimum set of data containing information about the crash including time, precise location, vehicle identification, eCall status (as a minimum, indication if eCall has been manually or automatically triggered) and information about a possible service provider (CEC, 2005).

Time period of crash data

Member States use different numbers of years for crash data to assess the road safety in their network. Most of them refer to 3 years of crash data, while some countries use 5 years to get more reliable outcomes. However, there are a few that use only 1 year.

Both the analysed crash data methodologies and the international literature (Nguyen et al., 2016; Cheng & Washington, 2005; Land Transport New Zealand, 2004; AASHTO, 2010; AUSTROADS, 2015) mainly refer to three years period of data since:

- It is long enough to provide a sufficient number of crashes for meaningful results.
- It is short enough to limit the number of traffic and environmental changes that may bias results.
- It helps remove statistical fluctuation and reduce the impact of the Regression To the Mean (RTM) effect.
- It provides a consistent base for before and after comparisons.

According to relevant literature and applied practices, a longer period of time (e.g., 5 years) is recommended when few crashes per year are recorded. Smaller periods than three years do not ensure a large enough sample size for a robust statistical analysis; the results would be too much susceptible to RTM bias.

Therefore, it was decided that a minimum of at least three years of crash data is required for application of the NWA-reactive methodology.

Crash Severity

Considering crash severity, most Member States (69%) rely on fatal and injury (severe and slight) crashes, followed by fatal and severe crashes and all crash types; no Member State was found to rely only on fatal crashes.

Most of the existing methodologies for determining the risk of road traffic crash occurrence primarily focus only on fatal and serious crashes since such crashes are likely to be reported more consistently than those falling in the "slight injuries" and "damage only" categories. Moreover, the "damage only" crashes are collected by just half of Member States.

Excluding the "damage only" crashes, also the definition of crashes with casualties should be considered, since it varies between Member States. At this stage, since there is no homogeneous definition of the different distinction between the severity of injuries, using only a subset of crashes with casualties would produce results that are not comparable across Europe. Therefore, the methodology considers all crashes with casualties, i.e., to include in the statistical sample road crashes with minor injuries, serious injuries, and fatalities.

In the medium-long term, when a common definition of injury severity will be applied across Europe (AIS), it will be possible to only consider crashes with serious injuries (MAIS 3+4) and fatalities. This will also allow reducing the impact of the underreporting of crashes with minor injuries. Therefore, for the medium-long term, it is recommended to shift from using crashes with all casualty types to those involving serious injuries (as per the MAIS 3+) and fatalities.

Road user categories and crash types

Most Member States collect information on the road users involved in crashes and on the crash type (e.g., collision with an obstacle, rear-end collision, side collision, etc.). The NWA-reactive methodology considers on all road users and all crash types.

A.1.3.2 Traffic volume data

Many studies use traffic volume as an exposure measure and their results indicate that the relationship between traffic volume and the number of crashes is not likely to be linear. There is hardly any doubt that traffic volume is the single most important factor that influences the number of road crashes. This is likely to be the case all over the world, although of course the precise shape of the relationship between traffic volume and the number of crashes is expected to vary from place to place (Elvik, 2009).

Traffic volume is generally expressed as the Annual Average Daily Traffic (AADT). It can be considered either directly (e.g. using crashes per veh.km.year as a potential metric), or indirectly, by comparing only roads of the same type (e.g. motorways, primary divided roads, primary undivided roads) that are expected to have roughly similar traffic volumes, at least inside a similar environment (e.g. a country). However, the direct consideration of traffic volume is necessary in order to make comparisons across Europe. Most Member States have AADT data available for their motorways (88%) and primary rural road network (76% for divided roads and 72% for undivided roads). Only one country has no AADT data.

It is therefore recommended to use traffic volume when analysing crash data across a network. Therefore, the NWA-reactive methodology considers traffic volume data, if it is available.

Concerning traffic volume recorded by type of vehicles, great differences have been found across the Member States. For instance, only half of the Member States record the percentage of powered two-wheelers traffic.

In some cases, it may be appropriate to consider seasonal traffic due to significant variations from the AADT. This may be caused by the presence of attractive locations, which could lead to a significant increase in traffic during summer or winter.

A.1.3.3 Road geometry and design data

Regarding road design data, most countries have information only on basic data such as number of lanes, road width, shoulder type (paved/unpaved), central median and presence of safety barriers; other, more detailed road design data (horizontal and vertical curvature, roadside design, etc.) are available in a smaller number of countries.

Road data is more likely to exist for motorways rather than primary roads. When road data are available, it was mostly reported that these data are of high or medium quality.

Eighty-five percent (85%) of Member States stores road data in databases and 85% uses some sort of a mapping tool such as GIS, CAD, online maps. A smaller percentage (56%) use photographs to store road data information. Essentially, it is common that data is kept in different storing systems.

For road safety assessment based on crash occurrence, this type of data is needed for the segmentation of the network into road sections and junctions. Specifically, there are two main purposes for which the use of these data is required:

- to identify sections that are homogeneous in terms of geometric characteristics,
- to locate junctions along the network.

A.1.3.4 Crash cost data

More than 70% of Member States have carried out studies to estimate the social cost of crashes. However, these costs vary greatly across countries, even by a considerable rate.

Costs per fatality tend to be higher in North-West Europe than in South and East Europe. According to "Crash cost estimates for European countries" (SafetyCube, 2017), the total costs of crashes vary between 0,4% and 4,1% of the Gross Domestic Product (GDP) across Member States. This variation depends not only on the cost of life, national prosperity and welfare, but also on the methodological differences to estimate the costs, the weight of each cost component and the number and type of components taken into account. Not all countries have information for all cost components and/or all severity levels. Moreover, not all countries calculate cost estimates according to the international guidelines. Other possible explanations for this variation include differences in definitions of severity levels and in reporting rates.

Based on the above and on the fact that the use of different costs between countries would lead to distortions in risk mapping, it was not decided not to consider the cost of crashes as a metric for the NWA-reactive methodology.

A.1.4 Steps of NWA-reactive

As shown in Figure A.1, the methodology consists of four steps:

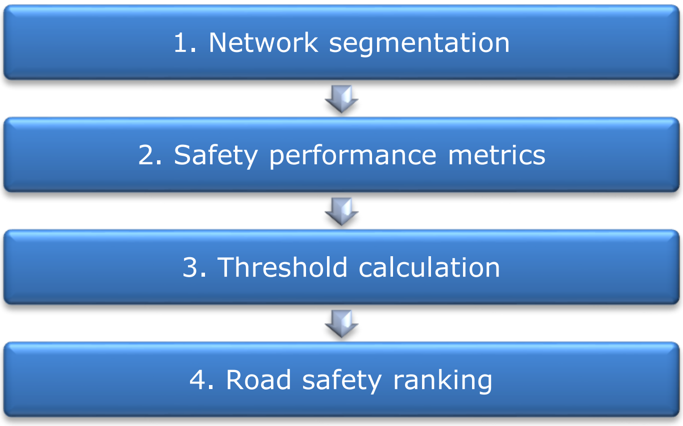


Figure A.1: *Conceptual methodological framework for the reactive network-wide assessment.*

The methodology has been structured in a way to offer **some level of flexibility** with the objective to accommodate data-related and other limitations that have been identified across various Member States (e.g., lack of detailed and reliable traffic data). In addition to offering flexibility, there is a recommendation in each step on which approach would be the most appropriate one, i.e., the one that would yield more accurate and reliable results. Therefore, Member States are provided with instructions on how to proceed and they are encouraged to choose the approach that is most appropriate for them. Moreover, it is noted that in the coming years these limitations are not expected to be present as Member States will eventually address them. In practice this means that eventually, all Member States will be in the position to apply the most advanced and detailed form of the methodology (e.g., always incorporate traffic data in the analysis or work with crash data for which the exact location is known).

Methodological framework and considerations for each of the aforementioned steps are presented below.

A.2 Network segmentation

The first step of the reactive methodology is the segmentation of the road network; the network is segmented in smaller parts noted as **sections and junctions**. Three main issues are discussed with respect to segmentation:

- How to deal with **divided vs undivided roads**.
- The definition of **homogeneous road sections** and elements to be included in each section, and specifically road segments and junctions.
- The overall **section length** and the length of junctions.

A.2.1 Divided vs undivided roads

Concerning the **segmentation and the presence of a median** different segmentation criteria have been developed for the case of divided and undivided roads. For motorways and primary divided roads (which all have a median) it is recommended to perform the segmentation for **each direction of traffic**. This is because, due to the median presence, the occurring crashes are only related to the vehicles traveling to the direction of the road. On the contrary, in undivided roads crashes can be due to or involve vehicles moving in the opposite direction of travel. Therefore, for urban and rural motorways and primary divided roads the segmentation is performed in each direction of travel separately if this is feasible; this implies that crashes are recorded per direction of travel. In primary undivided roads (or other undivided roads covered by the Directive 2008/96/EC) the segmentation is performed for **both directions of travel** and so, each section includes both directions of travel.

It is possible that crash data per direction of travel are not available for divided roads. In this case, the segmentation will inevitably include both directions of travel. It is expected that as crash data collection improves over the years, all divided roads will be segmented per direction of travel.

A.2.2 Homogeneous road sections

This section describes the way to define **homogeneous sections** along a road network. To begin with, this methodology defines as a road section the stretch between two junctions, which are either interchanges or at-grade intersections. Between the two junctions several characteristics of the road section may change, and, in this case, the section is no longer considered homogeneous. Several criteria are described below on how to define a homogeneous section, which are different for motorways and primary roads.

For **motorways and primary divided roads**, the criteria for homogeneous sections are the number of lanes and the horizontal alignment. Along a section it is intended to have the same number of lanes and curvature characteristics. Regarding curvature, the idea is to differentiate between parts of the road that tend to be curvy vs those that mainly consist of straight stretches. For **primary undivided roads** traffic volume is an additional criterion for defining homogeneous sections. There may be several at-grade intersections of different size and relevance along the primary network. As road sections must have a statistically significant length, not all at-grade intersections can be considered for section segmentation. However, to take into account a possible increase in traffic due to a number of small consecutive intersections along a section, traffic has also been included as a criterion for subdivision of the section. This does not apply for the segmentation of motorways and primary divided roads where there are only interchanges (the traffic can only enter and exit through them). The criteria that are considered to define a homogeneous section for motorways, divided and undivided primary roads, are summarised in Figure A.2.

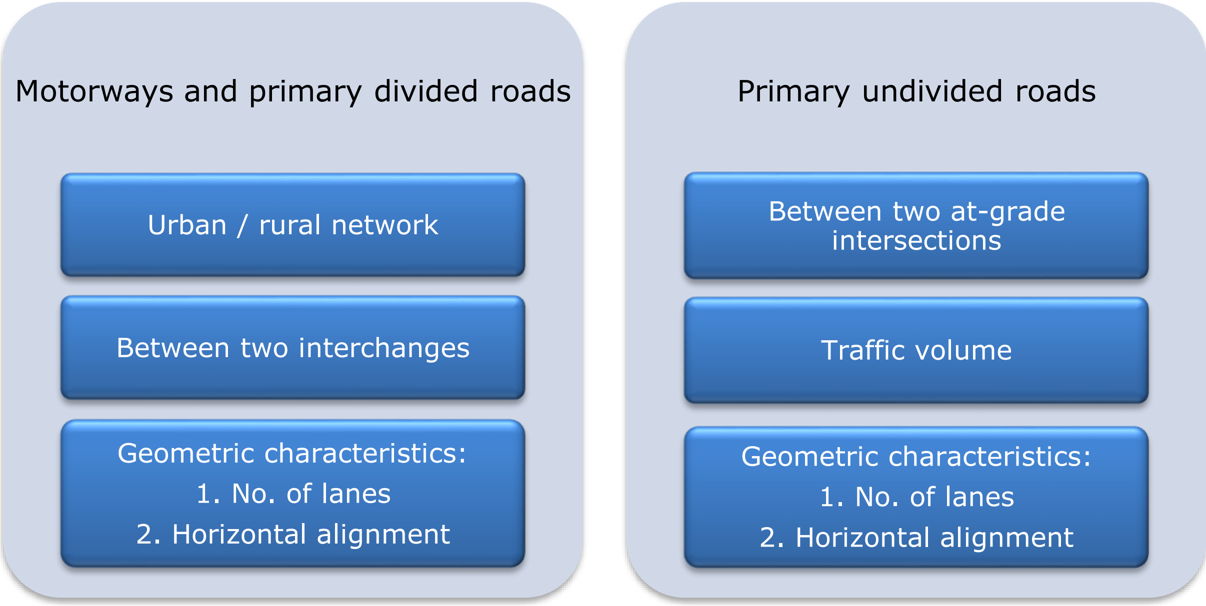


Figure A.2: *Criteria for defining homogeneous road section by road category.*

Additionally and with the objective to provide a general indication of the magnitude, the following road section lengths are provided according to the road category and the environment (Figure A.3).

Figure A.3: *Recommended section lengths per road category.*

It is essential to stress that these lengths are only indicative, to give an order of magnitude, and so, they do not represent mandatory segmentation. However, it is not recommended to have very short sections either. For example, it is not advised to have sections of around 1km or less as (1) the accurate crash location is not always known and (2) an analysis based on short section lengths (e.g., ~1km) deteriorates the network-wide aspect of the assessment; the assessment will more likely resemble a hot-spot analysis. At the same time, exceeding by far the recommended section lengths is not advised either as (1) it is likely that the sections are no longer homogeneous, (2) it will no longer be easy to detect the potential unsafe conditions along a section and (3) it will no longer be cost-effective to inspect such a large section, if need be.

The network can be divided according to one of the three approaches shown in Figure A.4, based on the availability of roadway data and accurate crash location data from the different Member States.

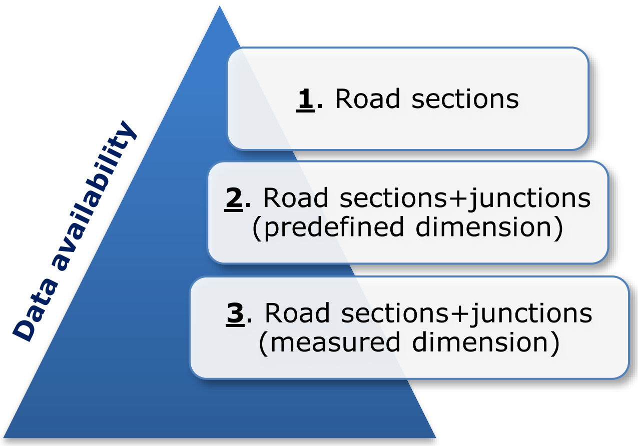


Figure A.4: *Considered network segmentation approaches.*

The **first approach** is the **simplest** and can be adopted if the necessary data for the identification of junctions' dimension are not available. In the second approach, predefined dimensions are assigned to the junctions. The last approach is the most complex as it requires a greater effort to correctly identify the area of influence of the junctions. The first approach is described in the following paragraphs while the second and third segmentation approaches are described in the following section (A.1.3 Junctions).

<u>1st approach – Homogeneous road sections</u>

This segmentation approach does not consider junctions. It is recommended to be used when the following conditions apply: (a) there is no roadway data available to define the area of junctions and (b) the crashes recorded are located with a high degree of approximation (e.g., crash per km). This approach is also appropriate for cases where a **less data-intensive** implementation of the methodology is the objective.

In this case, a first rough segmentation results in road sections delimited by the chainage of the **midpoint of the junctions**. Then, using the criteria described above, a more accurate segmentation should be carried out, obtaining a sequence of homogeneous road sections.

A.2.3 Junctions

A road network consists of road segments and junctions. Three groups of junctions can be associated to the four roads' categories: rural motorways, urban motorways, primary divided roads and primary undivided roads. Junctions not listed in Table A.1 should not be assessed by the methodology.

Table A.1: *Criteria for the identification of junctions within the scope of the NWA.*

Motorways (rural /urban)	Primary divided roads	Primary undivided roads
All interchanges separately	All interchanges separately At-grade intersections: – *with upper category roads* – *with the same category roads* – *with lower category roads*	At-grade intersections: – *with upper category roads* – *with the same category roads* – *with lower category roads*

In addition to the information presented in Table 3.2, it is noted that:

- For motorways and primary divided roads, all interchanges are selected.
- As regards at-grade intersections, both for primary divided and undivided roads, only those with upper, equal and lower category roads are considered, excluding minor intersections, such as those with local roads.
- Overpasses and underpasses of roads that do not have a direct connection with the road being assessed should not be taken into account.
- The information required for each junction is the chainage to locate them along the network.

For junctions that are covered by the Directive 2008/96/EC, and there is the intention to form sections that consist solely of junctions the following ways to measure junction's dimension are discussed.

<u>2nd and 3rd Approaches – Homogeneous road sections and junctions</u>

Under the second and third segmentation approaches, the network is divided into homogeneous road sections, that consist only of a series of road segments, and junctions. As regards the identification of road sections, there is no difference compared to the 1st approach.

Concerning the **definition of the junction dimension**, the two approaches differ based on the availability of roadway data to measure the junction size, as described below: defining a fixed dimension (2nd approach) and obtaining the exact dimensions of the junctions (e.g., from the available databases, 3rd approach); see Figure A.5. Both approaches can be implemented, either individually or in combination, using the fixed dimension when the required data to measure the exact size of the junction are not available. The two following subsections describe how to work with junctions in the cases where their actual dimensions are known or not.

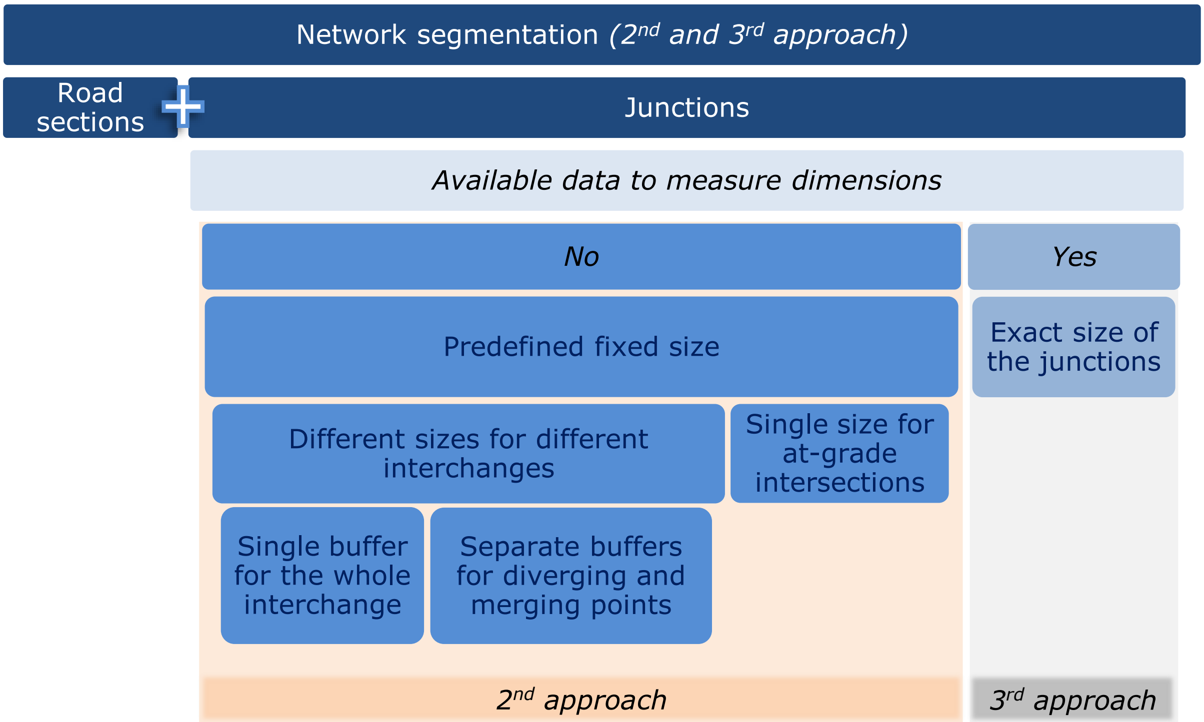


Figure A.5: *Network segmentation approaches with details for junctions.*

<u>2nd Approach: Junctions with predefined fixed size</u>

The roadway data needed to measure the dimension of junctions is more likely to be available for motorways, although not everywhere, but is more difficult when dealing with primary road junctions because the level of detail of the roadway data decreases with the road category. In these cases, fixed dimensions could be used.

Therefore, it is necessary to decide how this dimension should be defined. Obviously, the dimensions for interchanges and those for at-grade intersections are defined in two separate processes dealing with different sizes and geometries.

As regards interchanges, their dimensions can vary greatly depending on their configuration and assuming a single fixed dimension, that appears as a buffer located in the centre point, for all interchanges would lead to a number of errors in assessing road safety on the basis of crash occurrence.

If an interchange is smaller than the buffer some crashes that are not due to the interchange would be included in it, resulting in an overestimation of crash risk. On the contrary, if an interchange is bigger than the predefined dimension, some crashes that are due to the interchange would not be included in it, resulting in an underestimation of crash risk (Figure A.6). Opposite effects (underestimation and overestimation) would be observed on the road sections adjacent to the specific interchange.

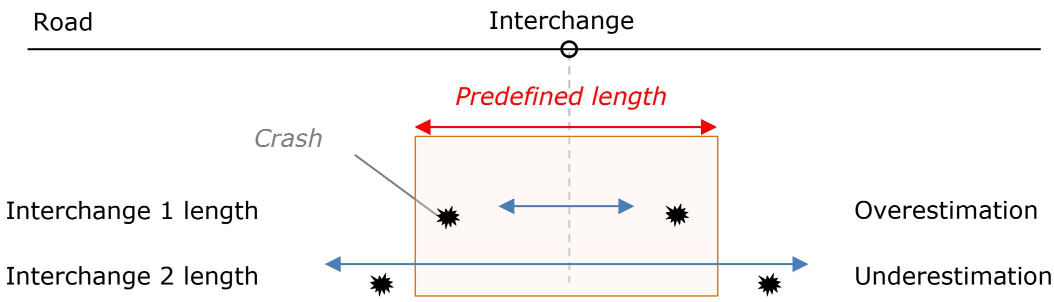


Figure A.6: *Example of possible cases.*

To obtain a more reliable assessment, it would be necessary to provide different dimensions for different types of interchanges. The variables that can be considered are:

- interchange type (e.g. trumpet, cloverleaf, etc.),
- category of intersecting road,
- number of lanes of the two intersecting roads.

Interchanges are wider for higher road categories and their dimension also increases with the number of lanes of the two intersecting roads.

Following this approach, it could happen that for wide interchanges, the section between the diverging and merging points smooths out the density of crashes. This problem is particularly evident at interchanges where the critical points, and therefore the greatest number of crashes, are unequally concentrated at the diverging and merging points, whereas there are no crashes along the central section (Figure A.7).

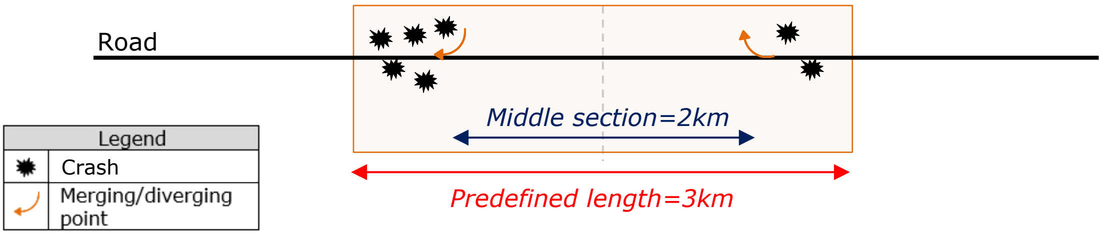


Figure A.7: *Illustrative numerical example No 1*[3].

Looking at Figure A.7, it appears that in the three components of the interchange the distribution of crashes is not homogeneous and so should be the safety assessment result. But considering the buffer of predefined length represented, the crash density would be homogeneous and smoothed over the whole length.

A possible solution to mitigate this effect could be to consider the diverging and merging points as two separate junctions. In this way, a length must be defined such that,

[3] Numerical example:

5 crashes at merging point and 2 crashes at diverging point: total number of crashes: 7
Predefined length: 3 km
Crash density: 2.3 cr./km

starting from the centre of the junction, it can include separately the point of divergence and the point of convergence as shown in Figure A.8.

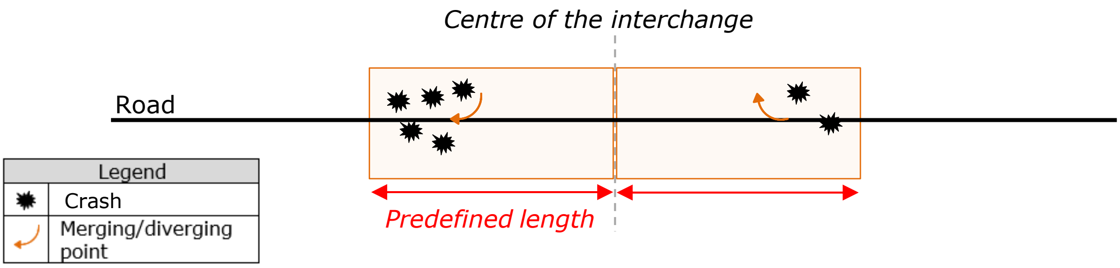


Figure A.8: *Illustrative numerical example No 2.*

This method allows to assess separately the crash risk of the two points, resulting in a different level of risk that may be more suitable for prioritising investments.

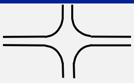
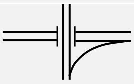
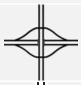
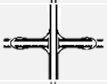
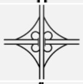
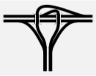
Notwithstanding the considerations made about a single buffer for the whole interchange or two different buffers for the two diverging and merging points, Member States may choose the approach which best fits their needs and satisfies them.

As regards at-grade intersections, the sizes are certainly smaller, so that defining a single buffer dimension to be used for all intersections should be suitable.

In a preliminary pilot phase, for the roads selected as case studies, all junctions have been measured and classified according to type. All information about them has been entered into a database and predefined dimensions have been defined. Only in very rare cases have long junctions found whereby the two points of divergence and convergence were treated separately considering the predefined dimension of the "single ramp" (Table A.2).

Overall, this initial analysis showed that there is great variability in the size of interchanges, even between those of the same type. Moreover, the sample size of junctions is limited, therefore the following dimensions may need to be slightly adapted to specific cases (Table A.2). These dimensions can be considered as a guide and do not necessarily have to be used as they are, each Member State can decide to increase or decrease them according to its knowledge of its own road network.

Table A.2: *Junctions' predefined dimensions.*

Junction type	Sketch representation	Predefined dimension
At-grade intersection		100 m
Single ramp		200 m
Trumpet		400 m
Diamond		500 m
U-turn*		700 m
Cloverleaf		800 m
Cloverstack		900 m
T-Bone		900 m
Complex geometry	-	1000-1200 m

* this type of junction is not a simple U-turn, but also includes the flow from the intersecting road

At the end of this phase, a list of all the junctions considered is obtained including the dimension of their area of influence.

<u>3rd Approach - Junctions with exact, measured size</u>

Due to the variety of databases and details collected by each Member State, this approach cannot always be followed.

For motorways, the exact chainage of the starting point of the diverging lane and of the ending point of the merging lane must be known, while for at-grade intersections of primary roads, the chainage of the starting and ending point of their area of influence.

Once these points have been determined, the whole area between them is considered as a junction (Figure A.9).

Junction location and dimension			
Midpoint chainage	***Start point***	***End point***	***Junction length (km)***
km 5.0	km 4.6	km 5.4	0.8
…	…	…	…

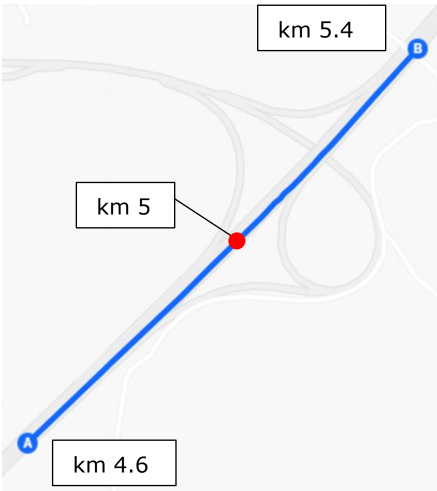


Figure A.9: *Example of measuring the dimension of a junction.*

Overall, **the minimum recommended approach for the common EU road assessment methodology based on crash occurrence is the division of the road network into road sections only (not distinguishing junctions)** - as per the 1st approach described above. If data are available and a more detailed output is desirable, Member States are encouraged to implement increasingly detailed (but inevitable more complex) approaches, such as the separation of predefined size junctions (2nd approach) or of actual size junctions (3rd approach).

Step outputs

At the end of the network segmentation, a list of homogeneous road sections (and eventually junctions) is produced.

A.3 Safety performance metrics

The next step in the methodology is the estimation of the safety level of each section (or junction). The number of crashes per section (or junction) are needed. Additionally, it is needed to define one/more appropriate safety performance metric(s) to be used in the analysis and then, estimate this metric for each section (or junction). These aspects are discussed in the following paragraphs; when it is relevant, there is also a discussion on why a specific decision was made.

A.3.1 Number of crashes and crash allocation

Firstly it is necessary to **allocate crashes** to each road element (section or junction) and this process can become challenging in some cases. It is emphasized that the reactive methodology uses only crashes with injuries and fatalities. With regard to crashes recorded at junctions, it is important to emphasise that only those occurring on the road being assessed and not on the intersecting road should be taken into account. In the event that the information regarding the location of a crash is not adequate enough to allocate the crash to the correct part of the road, it is recommended to analyse the available information relating to the crash record to try to allocate it. From the description of the crashes, if available, it is possible to extract some more information useful for this purpose. In the specific case of interchanges, the crashes to be considered are only those occurring along the assessed road and the exit and entrance ramps. All crashes occurring on the intersecting road from the end point of the ramp are therefore excluded.

A.3.2 Determination of the safety performance metric

Once all crashes have been allocated to network components, safety performance metrics can be calculated. There are some considerations regarding the type of the safety performance metrics to be used in the methodology.

First, according to the revised Directive 2008/96/EC, art. 5, "*network-wide road safety assessments shall evaluate crash and impact severity risk, based on 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 crashes in proportion to the traffic flow have occurred*". The assessment must therefore be carried out by relating crashes to traffic flow, thus using crash rates to describe the safety level of road sections and junctions. However, as traffic data are not always available across the EU roads, alternative safety performance metrics should be provided, too. The objective is that eventually all Member States will have reliable traffic data and so, will establish crash rates (or another exposure-based safety performance metric) as the main safety performance metric.

Crash rate is the number of crashes that occur at a given site during a certain time in relation to a particular measure of exposure (e.g., per 100 million vehicle km of travel for a roadway segment or per 100 million entering vehicles for an intersection). The crash rate takes account of exposure and may be interpreted as the probability (based on past events) of being involved in a crash per instance of the exposure measure. For example, if the crash rate on a road section is one crash per 100 million vehicle km per year, then a vehicle has a one-in-100 million chance of being involved in a crash for every km travelled on that road section.

The formula to calculate the crash rate is:

$$R_i = \frac{N_i * 10^8}{365.25 * AADTi * y * L_i}$$

Where:

N_i: number of crashes at road section/junction *i,* occurring in the analysis period

$AADT_i$: Average Annual Daily Traffic of the section/junction

y: analysis period (years)

L_i: length of section *i* (km)

If traffic data are not available for junctions and/or sections, crash rates cannot be used as a safety performance metric. In this case the **crash density** needs to be used to enable safety assessments to be made in such cases.

The crash density is the number of crashes per year per kilometre of road during the analysis period. This safety performance metric does not take traffic flows into account and the calculation formula is:

$$d_i = \frac{f_i}{L_i}$$

Where:

f_i: crash frequency at road section/junction *i,* that is the number of crashes (N_i) occurring per y which is the number of years in the analysis period

L_i = length of section/junction *i* (km)

Crash rate and crash density are the only **two metrics** to be considered for the methodology. As the review of the literature as well as the questionnaire survey analysis revealed there are many more metrics currently used however, they are not appropriate for the common, EU-wide methodology. For example, there is no consistent definition and data collection procedure across the EU for crashes with injuries and so, a safety metric that incorporates the different crash injury classes would not be appropriate.

Concerning the process of selecting the appropriate performance metrics for the reactive methodology, several aspects were discussed during the EGRIS meetings as well as with representatives of some Member States. In those discussions, the importance of both metrics (i.e., crash rate and crash density) were emphasized and it was mentioned that they both represent different risks. In particular, crash rate expresses the personal risk, while crash density expresses the collective risk.

Personal risk is estimated when using crash rates and as a result, takes into account the traffic volumes on each section of road and shows the likelihood of a vehicle, on average, being involved in a road crash on a particular road stretch. Personal risk is of most interest to the public, as it shows the risk to road users, as individuals. Personal risk is typically higher in more difficult terrain where traffic volumes and road standards are often lower. In many cases, infrastructure improvements on these roads are unlikely to be cost effective.

Collective risk, represented by crash density metric, highlights which road section have a high number of fatal and serious crashes on it and it can be used to help determine where the greatest road safety gains can be made from investment in safety countermeasures. Collective risk is perhaps of most interest to the road controlling authorities as it highlights where infrastructure improvements are most likely to be cost effective.

At the same time, there is the argument that crash rates offer a clearer picture of the safety situation across a network as traffic volume is considered; generally, more crashes are expected where traffic is higher. For these reasons, it is recommended to calculate both metrics so that road authorities can have a greater information available to them but for cases where traffic data is available, it is recommended to **prioritize crash rates** compared to crash densities.

Step outputs

At the end of this step, the list with road sections (and eventually junctions) produced in the previous stage is completed with (a) the number of crashes, (b) the length and (c) the AADT data (if available) for each section (or junction).

A.4 Threshold calculation

To determine the safety level of a road network, safety performance metrics need to be calculated for each section/junction. Additionally, a set of appropriate threshold values needs to be defined. According to the existing literature, fixed or flexible thresholds can be used, while there are other approaches, ranging from simplistic, preliminary estimations (e.g., double the average number of crashes/km) to statistical methods (Poisson, Quality Control, etc.).

The rationale behind the statistical techniques is that they take random variations in crashes counts into consideration due to their stochastic nature. Thus, these methods use crash models or functions to estimate the expected number of crashes at a specific network component.

Thresholds should be defined for crash rates and for crash densities for sections and junctions if the latter are considered in the analysis. The reactive methodology uses two types of thresholds:

- thresholds for each section/junction
- thresholds for the reference population.

A.4.1 Thresholds for sections and junctions

For every section (and junction) the number of the observed number of crashes (N_i) during the *y* years of analysis is known. It is assumed that crashes follow the Poisson distribution. Using the Poisson method with the observed number of crashes, the upper and lower confidence intervals for the expected number of crashes per section (or junction) are defined. According to the Poisson distribution, the probability of *k* crashes occurring at a road section/junction is given by the relation:

$$p(k;\lambda) = \frac{e^{-\lambda}\lambda^k}{k!}$$

Where:

p(k; λ) = the probability that *k* crashes will occur at a road section/junction

λ = the mean of the Poisson distribution, i.e., the expected number of crashes at the road section/junction under consideration

The cumulative probability $F(X_\alpha;\lambda)$ of X_α crashes occurring at a road section/junction is given by:

$$F(X_\alpha;\lambda) = \sum_{k=0}^{k=X_\alpha} \frac{e^{-\lambda}\lambda^k}{k!}$$

For each value of *k* it is possible to estimate the expected lower and upper values, known as confidence intervals (formulas 5 and 6):

Lower interval: $chisquare[\frac{\alpha}{2}, 2 \times k] \big/ 2$

Upper interval: $chisquare[1 - \frac{\alpha}{2}, 2 \times (k+1)] \big/ 2$

Where:

k: is the observed number of crashes in a section/junction during the analysis period

α: confidence level

The resulted lower and upper intervals, after they are rounded to the next integer value, denote the minimum and maximum number of crashes that could occur in the section/junction of interest with a certain level of confidence. As the level of confidence increases the range between the two values increase as well. Commonly, α is equal to 0,05.

The lower and upper intervals will be used to estimate the minimum and maximum values for crash rate and crash density for the section (or junction), using the formulas presented in paragraph A.3.2.

A.4.2 Thresholds for the reference population

PIARC[4] considers a reference population as a subset of network components that have similar features and, as such, are expected to have similar safety performance. Grouping into reference populations should be done separately for road sections and junctions, using all sections and junctions that exist at the national level and are covered by the Directive 2008/96/EC. The four categories indicated in the first step of the methodology can be considered as reference populations, namely:

- Rural motorways.
- Urban motorways.
- Primary divided roads.
- Primary undivided roads.

Further subdivisions within each of the four categories based on traffic levels and road geometric characteristics would lead to a more accurate definition of the reference populations.

[4] PIARC (2019) – *Road Safety Manual* (roadsafety.piarc.org)

The grouping into reference populations is intended to conduct the safety assessment on homogeneous groups and thus avoid analysing network components with very different geometrical and operational characteristics. The subdivision must in any case ensure the significance of the sample created, avoiding too small a sample size.

For every group of the reference population it is needed to estimate the crash rate and the crash density. These two values will be used as the thresholds for the reference population.

Step outputs

The crash density and crash rate thresholds for each section/junction used in the analysis and for the reference population groups.

A.5 Road safety ranking

From the previous step of the reactive methodology, the following values have been obtained:

1. Lower interval for the expected crash density and rate of a section (or junction)
2. Upper interval for the expected crash density and rate of a section (or junction)
3. Crash density and rate values for the reference population groups.

If traffic volume data are available and so, crash rates have been estimated then these values will be used for the final ranking of a section. Otherwise, the final ranking will rely on crash density values.

The road safety ranking is described below:

- If both the upper and lower intervals for crash rate (or density) are lower than the crash rate (or density) of the reference population, the corresponding section/junction is classified as **"low risk"**.
- If both the upper and lower intervals for crash rate (or density) are higher than the crash rate (or density) of the reference population, the corresponding section/junction is classified as **"high risk"**.
- If the crash rate (or density) of the reference population is between the lower and upper thresholds of the section/junction, the corresponding section/junction is classified as **"unsure"**.

Essentially, the reactive methodology classifies each section/junction in one out of three classes, namely: low risk, unsure and high risk. Some additional remarks regarding the implementation of the methodology are listed below.

As both safety performance metrics have important aspects, while it is recommended to prioritize crash rate over crash density, road authorities may choose to work the other way. Member States are free to decide which of the two rankings to consider.

It is important to observe that, if the number of recorded crashes is very low or if the crash data is unreliable (e.g., largely inaccurate location data), the reactive method cannot be applied. In such cases the safety classification of the road component will depend solely on the proactive assessment.

A differentiated classification by user type could be produced in those countries where the traffic flows and crashes of the different categories of users are known. To date, just over 50% of Member States collect powered 2-wheelers traffic flow on motorways and primary roads, but this percentage could increase in the coming years, possibly including the flow of vulnerable users.

ANNEX B: DEVELOPMENT OF THE PROACTIVE METHODOLOGY

Annex B focuses on the development process, assumptions and theoretic background of the proactive methodology. For detailed, step by step guidance on the practical implementation of the methodology, the reader is referred to Chapter 3 of the present Handbook.

B.1 Assessment model

B.1.1 Scope of network-wide safety assessment

Overall, the developed road safety assessment methodology covers motorways (urban and rural) and primary or other rural roads that may be divided or undivided. In addition to primary rural roads, the methodology for rural roads is also applicable for the assessment of other road infrastructure outside urban areas that is co-funded from EU funds (Article 1, paragraph 3 of the 2008/96/EC Directive). The methodology can also be used for the assessment of rural roads not covered by the 2008/96/EC Directive if this is desired, however in low-class and low-design characteristics roads, the impact of assessment parameters may require re-calibration in order to produce a reliable scoring result.

When assessing the safety of VRUs on roads covered by the 2008/96/EC Directive, it is important to consider the following:

- With regards to motorways, and particularly at interchange areas, the assessment covers the motorway segment (including any auxiliary/ additional lanes) and the interchange ramps for potential conflicts between VRUs and motorized vehicles. The secondary road, including any intersections with the ramps (if present) are outside the scope of the assessment, unless the secondary road is also within the scope of 2008/96/EC Directive (e.g., being a primary road). In that case, potential conflicts with VRUs will affect the scoring of the secondary road and not the motorway.
- Over- or underpasses of local roads above or below a motorway, where VRUs are present are not assessed in relation to the near-by motorway.
- With regards to primary roads, in the case of grade separated intersections, overpasses and underpasses, the same criteria described for motorways are valid.
- In case of at-grade intersections between primary roads and other rural (secondary) roads (i.e., roads not covered by the 2008/96/EC Directive), potential VRU conflicts are examined at the area from the crossing of centerlines up to the point where the cross section of the secondary road is reinstated to its normal width.

B.1.2 Safety scoring formula

Internationally, there are different approaches for scoring a road based on its design characteristics, however, there is not a consensus in the mathematical formula. The only thing in common is that all methods use positive scores. A safe road section in terms of in-built characteristics should receive a high score, while a road section with safety deficiencies should receive a lower score. For the present in-built safety assessment methodology, it is considered that a section receives 100 points when it is safe based on the assessment parameters that concern its design and operational characteristics. For less safe roads, the score will be lower than 100 points.

Road sections are assessed based on a set of parameters. Each parameter corresponds to a design/operational characteristic of the road section and the concept of Reduction Factors (RFs) is adopted to quantify the safety level of each characteristic. Reduction Factors are positive, non-zero numbers with a maximum value equal to one. A parameter that has a Reduction Factor equal to one corresponds to safe design. Lower values than one corresponds to less safe conditions. The following **formula** expresses the score estimation for the road section *i* when it is being assessed using ***n*** **parameters** and in turn, ***n*** **Reduction Factors**:

$$Score_i = 100 \times RF_{1i} \times RF_{2i} \times \ldots \times RF_{ni}$$

A **"ideally safe" road** section receives **100 points**. Its design characteristics reduce the risk of crashes and in the case of a collision, the severity of it is minimized. In a safe road the number of head-on, run-off-road, rear-end, side-swipe etc., crashes should be the minimum possible which means that road's design characteristics address all of the above categories.

It is clarified that the above formula is used for scoring both of motorways and primary road sections (or other rural roads completed using EU funding). As presented in section B.2, rural motorways, urban motorways, divided primary (or other rural) roads and undivided primary (or other rural) roads are assessed based on different parameters. As a result, the scoring is different and **not comparable between rural motorways, urban motorways, divided primary roads and undivided primary roads**. For example, a motorway segment with score 75/100 is not necessarily less safe compared to a divided primary road section with score 92/100.

Based on existing scientific literature and related guidance from EGRIS (see also detailed presentation in section B.2) a **motorway section** is considered **"ideally safe"** when it aligns with the following design characteristics:

- Lane width: to allow for a safety buffer around its vehicle, rural motorways should have average lane width equal to or greater than 3,40m and urban motorways equal to or greater than 3,25m. Smaller lane width is related to an increase in crash risk.
- Roadside: two aspects are essential to ensure that roadside is safe in a motorway section. The first the presence and width of the clear zone and the second is the presence and type of barriers or presence of obstacles along the section. Across the entire length of the section, clear zone needs to be equal to or greater than 10m and so, in this case a run-off-road vehicle will have adequate space to stop before colliding with a roadside obstacle or barrier (i.e., steel or concrete barriers, series of rigid objects, fill/cut slope, or deep drainage ditch). Run-off-road vehicles may collide with an obstacle or barrier when the clear zone width is smaller than 10m and depending on the obstacle type, the collision can be more or less severe. It is further noted that:

    1. the width of emergency lane (if present) is included in the estimation of roadside clear zone, thus contributing in increasing the safety score of the motorway, and
    2. in the case of safety barriers, for usual clear zone widths (e.g., 5m or more including the emergency lane), any estimated negative impact on safety scoring is very low (e.g., RF=0,98 for safety barrier at a distance of 5m from the outer lane edge).

- Curvature: if horizontal curves are present in a motorway section, then the radius should be equal to or greater than 2000m for rural motorways and 750m for urban motorways. The presence of horizontal curves with smaller radii is expected to reduce the safety of the section.
- Interchanges: if interchanges are present in a motorway section, ramp spacing (i.e. distance between successive gores of entrance/exit ramps is required to be greater than 1600m).
- Conflicts between pedestrians/bicyclists and motorized vehicles: due to the high operating speeds and traffic, pedestrians and bicyclists are not allowed in

motorways. Safe motorways must eliminate all points where there are potential conflicts between motorized vehicles and pedestrians/bicyclists.
- Presence of Incident Warning Systems: warnings regarding the weather (e.g., rain, fog, wind), emergencies on the road ahead (e.g., crash) increase driver alertness and allow them to adjust their behavior (e.g., reduce speed) timely to prevent additional incidents. The presence of a system that monitors road operation and provides such warnings to users (commonly Traffic Operation Center and VMS signs, but any other appropriate means may also be considered) makes the road safer.

For **primary or other rural roads**, an **"ideally safe" road section** at the network-level has the following characteristics:

- Lane width: wider lanes create a wider buffer around moving vehicles and so, roads with wide lane widths are safer. For primary or other rural roads, lane widths equal to or greater than 3,40m are considered safe.
- Roadside: wide clear zones in addition to flat side slopes ensure that run-of-road vehicles can stop safely without colliding with a roadside object or turning around. Road sections in primary roads are considered safe when a Roadside Hazard Rating of maximum three (as per the AASHTO HSM classification) is identified, which roughly corresponds to a clear zone width equal to or greater than 3,40m, side slopes are flatter than 1V:3H and at least marginally recoverable.
- Curvature: the presence of horizontal curves may increase the number of crashes, especially when these curves have a small radius. For primary road sections, the presence of tangents and curves with a radius equal to or greater than 1000m are considered safe. Smaller radii are related to an increase in crash risk, also depending on the section's speed limit and presence of speed enforcement.
- Density of property access points: access points along a primary road increase the number of vehicles entering or existing the road from uncontrolled points. A road section with no access points is considered ideally safe, while as the number of points increases, the safety level of the road is reduced.
- Junctions: Junctions are associated with a higher number of conflicting points compared to road segments, as vehicle paths cross. However, some junction types have zero or lower number of conflict points, meaning that are overall safer. In primary rural roads, a section is considered safe when it has no junctions, grade-separated junctions or roundabouts.
- Conflicts between pedestrians/ bicyclists and motorized vehicles: With regards to the crossing of pedestrians, a primary rural road is considered "ideally safe" if there is no pedestrian traffic or pedestrian crossings are accommodated through grade separated, fully protected facilities. Regarding pedestrians walking along the segment, the road is considered safe, similarly, if there is no pedestrian traffic or if there is a segregated (e.g. protected by barriers) pathway. With regards to bicyclists moving along the segment, the road is considered safe if there is no cycle traffic or if a segregated, fully protected bicycle way is present. Scoring Reduction Factors are applied for all other conditions, depending on the type of facility present and the speed limit.
- Shoulder type and width: Shoulders of primary roads are considered "ideally safe" if they are paved and have a minimum width of 2,44m for divided roads or 1,83m for undivided roads. Scoring Reduction Factors are applied for unpaved shoulders and/ or narrower shoulders.
- Passing lanes: The presence of passing lanes provides the opportunity to safely overpass slow moving vehicles, e.g., trucks, particularly in uphill sections. For the purpose of the proactive network-wide safety assessment, a road segment receives maximum score in this parameter if at least one of the following is true:

    1. it is a divided road, or

2. it has more than one lane per direction (multi-lane road), or
3. it's longitudinal slope is less than 4%, or
4. the length with longitudinal slope greater than 4% does not exceed 500m, or
5. if it is undivided, two lane with slope >4% for more than 500m, it has a passing lane in both directions.

- Signs and markings: The presence of clear, appropriate and well-maintained signs and markings in primary roads are required for a high level of safety. A qualitative assessment (rating) of the presence and quality of signage is considered for the proactive network-wide safety assessment of primary roads.

B.1.3 Estimation of Reduction Factors

Reduction factors for each considered parameter have been estimated based mostly on existing research and literature for Crash Modification Factors (CMFs), but also considering national design guidelines, iRAP Star Rating fact sheets or other sources of information on the safety impact of road infrastructure related parameters (see section B.2). CMFs have (positive) values higher or lower to one and so, a CMF may represent either a positive or a negative impact on crash frequency. As shown in section B.2, for each individual parameter, CMFs are converted to Reduction Factors (RFs) in order to have a homogenous, compatible scale for all safety conditions (in relation to the ideally safe road segment) and to represent the safest condition with an RF = 1,000 and all other conditions with RFs lower than one.

Two aspects in the calculations performed within section B.2 require further explanation: normalization of CMFs and estimation of average RFs.

Normalization of CMFs

For a given parameter, let us assume that it can be in one of conditions (C1, C2, and C3) each one corresponding to a CMF (CMF1, CMF2, and CMF3):

- C1: CMF_1 = 0,90

- C2: CMF_2 = 1,35

- C3: CMF_3 = 1,50

It is desired that all CMFs for a given parameter take positive values up to one (CMF=1,00 should represent the "safe" condition, in terms of network wide assessment). Therefore, a normalization of CMFs is needed before converting them to RFs. The normalization formula is shown in (1):

$$CMF_{j,norm} = {}^{CMF_j}\!/_{CMF_{min}} \quad (1)$$

Where CMF_{min} is the lowest CMF value for the given parameter.

For the previous numerical example, the respective normalized CMFs are:

- C1: CMF_1 = 0,90 → $CMF_{1,\ norm}$ = 1,000

- C2: CMF_2 = 1,35 → $CMF_{2,\ norm}$ = 0,667

- C3: CMF_3 = 1,50 → $CMF_{3,\ norm}$ = 0,600

Then the Reduction Factor (RF) for each CMF value will be estimated as shown in formula (2):

$$RF_j = {}^{1}/_{CMF_j} \quad (2)$$

<u>Estimation of average RFs</u>

Across a road segment it is possible that the value on an assessment parameter (e.g., lane width or roadside elements) changes. These changes might correspond to different CMF values that are applicable for a stretch of the section. In this case, the final CMF for the section needs to be estimated as the weighted average of all CMFs for the different lengths that they correspond to, following the formula (3):

$$Weighted\ average\ CMF_j = \frac{\sum_k^n w_k CMF_{kj}}{\sum_k^n w_k} \quad (3)$$

Where w_k is the weight and is inserted in the equation as a percentage of the section's length. Therefore, the denominator in the above formula is always equal to one. corresponds to length.

The weighted average CMF will be then converted to RF based on formula (4). This is the final, section-wide RF.

$$RF_{section} = {}^{1}/_{Weighted\ average\ CMF} \quad (4)$$

It is particularly noted that the weighted average should be estimated for CMFs (i.e., prior to the estimation of RFs). If three respective RFs are estimated and the formula for weighted average is executed on the RFs, a different (incorrect) Reduction Factor will result.

B.1.4 Segmentation

An important aspect of the practical implementation of the in-built safety methodology is the segmentation process, i.e., how to divide the examined road network into appropriate segments for road safety assessment. In order to provide guidance for the segmentation, the following considerations are taken into account:

1. The developed methodology considers **road segments and junctions in a combined way**, in order to preserve the network-wide general nature of the assessment.
2. In **motorways and divided primary (or other rural) roads**, the assessment is performed **separately for each direction of travel**, in order to be able to obtain a more focused localization of potential road safety deficiencies, as well as to be compatible with the methodology for assessment of crash occurrence.
3. In **undivided primary (or other rural) roads**, as it is not uncommon that a road safety deficiency on one direction causes crashes that may involve vehicles of both directions of travel, a **single assessment is performed for both directions of travel**.
4. According to relevant practice in crash prediction modelling, segments, of all road types, need to be **roughly homogenous**: changes in major cross section characteristics (number of basic lanes, etc.), significant changes in traffic volumes, changes in the terrain type (e.g., from flat to mountainous) should result in a change in segment.
5. The presence of an intersection/ interchange does not necessarily require a change in segment (unless it is related to large traffic volume changes).
6. If the start/ end points of segments for the in-built safety assessment methodology are in a short distance (indicatively 200m or less) from start/ end points of segments for the crash analysis methodology, it is recommended to shift the start/ end points of either (or both) methods so that they coincide. This will simplify the integration of both methodologies to produce a combined assessment result.

7. As an overall consideration, assuming large segment lengths will require less resources and effort, but will produce less detailed assessment results, as average values will be used as input to the examined parameters. Short segment lengths will increase the required workload, but offer more detailed results. As a rule of thumb, even if homogeneity is not an issue, it is recommended that segment lengths do not exceed the following **maximum values**:
   - Motorways - rural areas: 5km
   - Motorways - urban & suburban areas: 3km
   - Primary (or other rural) roads: 2km

In order to better understand and provide further insights on the practical implication of the segmentation process and on the potential impact of segment length in the assessment results, preliminary pilot implementation of the methodology for motorways was performed assuming **two segmentation scenarios** :

a. Scenario 1: Large homogenous sections following the above principles.

b. Scenario 2: Fixed length (600m) segments. In case of major changes in infrastructure characteristics, violating the homogeneity principle, the 600m segments were further divided into smaller segments.

From the preliminary pilot it was concluded that the segmentation lengths do not bias the average scoring. Smaller lengths provide more detailed results, with an increase in the required work effort.

For primary roads, in which the differences in segmentation lengths are limited, only one scenario was examined, with maximum length of 2km (finally resulting in average segment length of 1km, when all other criteria are jointly considered).

B.1.5 Consideration of traffic volume, collective and personal risk

Existing road safety practice indicates that for the purpose of road safety assessment, two different measures of risk can be considered: collective risk and personal (or individual) risk (see also: http://www.kiwirap.org.nz/measures_risk.html#).

Collective risk is related to the total number of fatal and serious injury crashes per kilometre over a section of road, also described as crash density. Collective Risk highlights road segments with a high number of fatal and serious injury crashes on them, and it is generally expected that roads with higher traffic volumes tend to have a higher collective risk. Infrastructure improvements on sites with high collective risk affect a larger number of road users.

Personal risk (or individual risk) is a measure of the danger to each individual using the assessed road being assessed, i.e., it shows the likelihood of a road user to be involved in a fatal or serious injury crash on this segment. Personal risk is typically higher in more difficult terrain where traffic volumes and road standards are often lower, and it is of interest to road users if they wish to select a safer route towards their destination. Infrastructure improvements on such roads affects a lower number of road users and may, in some cases, not prove cost effective due to the low traffic volumes.

In the case of proactive, in-built safety assessment methodologies, the assessment/ estimation of collective risk, either as an approximate indicator or as a detailed, quantitative estimation of predicted crash numbers, would require consideration of existing traffic volumes in each segment and very extensive original scientific research to identify and analyze how an increase in traffic may affect the influence of other parameters. An example of such an approach is the US Highway Safety Manual, which has been gradually developed in the last 20 years with contributions from several scientific committees and based on literally hundreds of research projects in various US states. Even then, research has shown that in many cases the Highway Safety Manual models may fail to accurately predict crash rates and calibration is required or even development of different case-specific Safety Performance Functions to capture the impact of traffic volumes to crash rates.

State-of-the-art road safety knowledge in Europe is not adequately advanced to provide a reliable, detailed predictive model of crash frequency for EU motorways and primary roads, considering in-built safety characteristics and traffic volumes. Therefore, the proactive assessment score does not consider traffic volumes and depicts the road segment in-built safety characteristics, i.e., related to personal risk for the individual road user.

B.2 Parameters used for the in-built network wide safety assessment of roads

This section presents the parameters used for the in-built safety assessment of motorways and primary rural roads (divided or undivided). It is clarified that the methodology is applicable to both urban and rural motorways and with respects to rural roads it can be applied to primary rural roads or roads in rural areas of a lower functional class. Parameters considered for the in-built safety assessment of roads differ for motorways and for primary (or other) rural roads and are presented in Table 1.1.

An issue of particular interest in the NWA proactive models is the **consideration of speed**. Several measures of speed are potentially relevant to the assessment, namely:

- Design speed: It is a selected speed used by engineers to determine the various geometric design features of the roadway. It may or may not be equal to the posted speed limit. It is not considered appropriate for consideration in the NWA models, because:
  - (a) it is a selected, assumed speed, not known to road users and not directly relevant to their behaviour.
  - (b) it usually is not known for old, existing roads, and the process of assuming (in a backwards way) the design speed from the geometric characteristic is arduous, time consuming and with questionable accuracy.

- Operating speed (V_{85}): Operating speed is the speed at which drivers are observed operating their vehicles during free-flow conditions, with the 85th percentile of the distribution of observed speeds being the most frequently used measure. Operating speed most accurately represents the actual conditions on a road, however its mandatory use in NWA models is not suggested, because:
  - (a) it cannot be considered an "in-built" safety only related parameter, as it is affected by several other factors not related to infrastructure (such as: enforcement, traffic synthesis, weather conditions, time of day, etc.)
  - (b) data availability is limited, as identified in relevant questionnaire survey to Member States.
  - (c) if there is need to complete the missing data, a difficult, time- and resource consuming survey is usually required.

- Speed Limit: It refers to the maximum allowed speed for road users, either communicated through signs or being the maximum speed (e.g., defined in the Traffic Code) for each road type.

Considering the above, in the NWA models, the following approach is applied with regards to speed:

For the proactive safety assessment of **motorways**, speed has not been considered as a parameter. It has been reasonably assumed that motorways are high speed roads, they are more or less consistent with regards to speed, and the potential consideration of speed would add complexity to the model without any measurable benefits in the accuracy of results.

With regards to **primary roads**, or other rural roads completed with EU funding, a greater diversity in speeds can be expected which is also expected to affect the safety impact of other parameters. For example, the horizontal curvature impact on safety is related to speed, as it affects not only the probability of vehicle loss of control but also, most importantly, the consequences of a road departure crash. Therefore, in the model for primary roads, speed is used as an input. It is not represented by a Reduction Factor (as it is not an infrastructure, "in-built" safety characteristic), but speed affects the Reduction Factor of parameters "Curvature" and "Conflicts between pedestrians/ bicyclists and motorized traffic".

Regarding the measure of speed to be used in the assessment, it is advised to use:

- either the operating speed (V_{85}), if speed data of sufficient detail (for the particular road segment) and actuality (collected during the last three years) are available,
- or (in most cases) the speed limit (which is in most cases known or at least easily collected, even through Google Earth Street View images). In order to better approximate driver behaviour, the presence of automated speed enforcement in the examined road is jointly considered with the speed limit, as further discussed (per parameter) in the following paragraphs.

B.2.1 Motorways: Lane width

The effect of lane width on the safety performance of roads has been studied in multiple cases internationally. Overall, literature suggests that narrow lanes provide less space for manoeuvres and drivers have less margin for an error. The impact on safety is greater when traffic increases.

Research conducted for the development of the Highway Safety Manual (AASHTO, 2010, AASHTO, 2014) suggests that wider lanes are overall safer, for both rural roads ("highways") and motorways ("freeways"). For motorways, the base condition (CMF=1,00) is a 12-ft lane (3,66m); the range of CMFs for various lane widths are presented in Table B.1 below. The iRAP Star Rating Protocol also considers a positive relationship between crash risk reduction and the lane width, common for motorways and rural roads, as shown in the Table below. Yet, an extensive meta-analysis of previous studies (Elvik et al., 2009) reported a non-conclusive relationship between lane width and road safety.

Table B.1: *CMFs for lane width in motorways, according to existing literature*

Source	CMF value	Comments
Highway Safety Manual (AASHTO, 2014)	LW > 3,96m: 0,963 LW = 3,75m: 0,989 LW = 3,50m: 1,020 LW = 3,25m: 1,052	*CMF values estimated from Equation 18-25 and Table 18-15 of the HSM*
iRAP Star Rating Protocol	LW ≥ 3,25m: 1,0 LW ≥ 2,75m and < 3,25: 1,2 LW ≤ 2,75m: 1,5	*Values included in relevant iRAP factsheet, obtained from other previous studies*
Elvik et al. (2009)	Non-conclusive results	*Meta-analysis of previous studies*

In addition to the above research findings, useful input from various national design guidelines is shown in Table B.2 that follows:

Table B.2: *Recommended lane width for rural and for urban motorways according to design guidelines*

Country	Rural					Urban				
	Speed limit	Left	Middle*	Right	Average	Speed limit	Left	Middle*	Right	Average
France	110-130	3,50	3,50	3,50	3,50	90	3,00	3,00	3,50	3,17
						110	3,25	3,25	3,50	3,33
Germany	none	3,50	3,50	3,75	3,58	80-100	3,25	3,25	3,50	3,33
Greece	130	3,50	3,50	3,75	3,58	100	3,50	3,50	3,50	3,50
Italy	140	3,75	3,75	3,75	3,75	140	3,75	3,75	3,75	3,75
Spain	80-140	3,50	3,50	3,50	3,50	80-140	3,50	3,50	3,50	3,50
USA	Recommended lane width = 12 ft = 3,66 m									

** Average lane width is estimated for three-lane roads*
**Middle lane in the case of three lanes*
**When more than three lanes exist, middle lanes have the left or the right lane width depending on %Heavy vehicles*
- Spanish guidelines do not differentiate between urban and rural motorways

The following additional points are also worth considering:

- US roads overall tend to have wider lanes than European roads, and this explains the requirement for larger lane width values in the US Highway Safety Manual that correspond to CMF equal to one compared to most EU design guidelines.
- A construction and measuring allowance of 10cm is considered appropriate for assessment purposes; therefore, Reduction Factor limits are set at 10cm lower than common design thresholds (e.g. at 3,40m for the design threshold of 3,50m).
- According to Table B.2, the recommended lane width in urban motorways is as an average approximately 5% less than in rural motorways (10% in France, 7% in Germany, 2% in Greece, no difference in Italy and Spain).

Based on the above input, the following values are finally selected as **Reduction Factors** for lane width in the assessment methodology for motorways, different for urban and rural settings:

Table B.3: *CMFs and Reduction Factors (RF) for lane width in rural motorways*

Average lane width	CMF value	RF value
LW ≥ 3,40m	1,000	1,000
3,15m ≤ LW <3,40m	1,025	0,976
LW ≤ 3,15m	1,050	0,952

Table B.4: *CMFs and Reduction Factors (RF) for lane width in urban motorways*

Average lane width	CMF value	RF value
LW ≥ 3,25m	1,000	1,000
3,00m ≤ LW <3,25m	1,025	0,976
LW ≤ 3,00m	1,050	0,952

Across a considered road segment, the average lane width may vary. In this case, it is first needed to estimate the weighted average CMF for the section and then calculate the final RF. The steps for this process are described in paragraph B.1.3.

B.2.2 Motorways: Roadside

A forgiving roadside environment is essential to prevent severe injury crashes in case of a driver losing control of the vehicle and departing from the road. A key aspect of the roadside environment is the creation of a clear zone, a traversable area where a vehicle leaving the road can travel without colliding to an obstacle (e.g., tree, lighting post, etc.). Barriers may also be present on the roadside in order to protect run-off-road vehicle occupants from crashing to rigid objects or protect others (road users or facilities near the road) from errant vehicles.

Comprehensive research results on the impact of the roadside environment in the safety of motorway segments are limited to the Highway Safety Manual (AASHTO, 2014) and the iRAP Star Rating Protocol. Existing CMFs are summarized in Table B.5:

Table B.5: *CMFs for roadside environment in motorways, according to existing literature*

Source	CMF values	Comments
Highway Safety Manual (AASHTO, 2014)	$$CMF = (1{,}0 - P_{ob}) \times \exp\big(-0{,}00451 \times (W_{hc} - W_s - 20)\big) + P_{ob} \times \exp\big(-0{,}00451 \times (W_{ocb} - 20)\big)$$ Where: P_{ob}: proportion of effective segment length with a barrier present on the roadside W_{hc}: clear zone width (ft) W_s: shoulder width W_{ocb}: distance from edge of outside shoulder to barrier face (ft)	*Outside clearance*
	$$CMF = (1{,}0 - P_{ob}) \times 1{,}0 + P_{ob} \times \exp(0{,}131/W_{ocb})$$ Where: P_{ob}: proportion of effective segment length with a barrier present on the roadside W_{ocb}: distance from edge of outside shoulder to barrier face (ft)	*Barrier presence – for single vehicle crashes*

Source	CMF values	Comments
iRAP Star Rating Protocol	CMF values for different clear zone (CZ) widths: CZ < 1m: CMF=1,00 1m ≤ CZ < 5m: CMF=0,80 5m ≤ CZ < 10m: CMF=0,35 CZ ≥ 10m: CMF=0,10	*Values included in relevant iRAP factsheet, obtained from other previous studies. The listed CMFs concern run-off-road crashes*
	Risk factors associated with the presence of roadside objects: Safety barrier - wire rope: Risk factor=9 Safety barrier – metal: Risk factor=12 Safety barrier – concrete: Risk factor=15 Downwards slope: Risk factor=45 Upwards steep slope (>75º): Risk factor=40 Upwards slope (15 º to 75º): Risk factor=45 Deep drainage ditch: Risk factor=55 Cliff: Risk factor=90 Aggressive vertical face: Risk factor=55 Frangible structure or building: Risk factor=30 Tree (>=10cm diameter): Risk factor=60 Non-frangible sign/post/pole (≥10cm diameter): Risk factor=60 Non-frangible structure/bridge or building: Risk factor=60 Unprotected barrier end: Risk factor=60 None (or object >20m from road): Risk Factor=35	*Values included in relevant iRAP factsheet, obtained from other previous studies* *The listed Risk factors are not CMFs, they represent a relative risk of each type of hazard*

The Highway Safety Manual (AASHTO, 2014) includes two CMFs related to roadside, one for outside clearance and one for barrier presence. The CMFs in both cases can be estimated taking into account the following variables: barrier presence and proportion of the segment's length where a barrier is present, clear zone width, shoulder width, and the distance from the edge of outside shoulder to barrier face. It is noted that barrier presence is important and positively affects safety, however, the barrier should also be placed "away" from the edge of the road. Particularly, to achieve reductive CMFs, the barrier face needs to have a distance greater than 20ft (~6,10m) from the edge of the outside shoulder.

iRAP Star Rating Protocol methodology provides CMFs for run-off-road crashes taking into account the clear zone width. Clear zone is defined as the distance between the edge of the right-most travel lane to the nearest object. As this distance increases, the CMF value becomes smaller, indicating a positive effect between safety and clear zone width. iRAP Star Rating Protocol additionally provides Risk Factors (different than CMFs) that express the impact of colliding with an object present in the roadside (e.g., metal barrier vs tree) or the presence of certain roadside features (e.g., slope). The scale has been defined to align with the Star Rating Score model used by the methodology. The values of the risk factor suggest that the safest case is the implementation of wide clear zone with no objects. Then, if objects are near to the road, they should be fragile and non-rigid, to absorb the collision energy. More rigid objects are less safe, and the least safe case is the presence of a cliff.

For the purpose of estimating a Reduction Factor for the roadside environment to be used in the network-wide assessment of motorways, the Highway Safety Manual approach is considered overly detailed as it includes four variables that all need to be accurately measured. On the other hand, the iRAP approach is based on the clear zone width and the type of objects, parameters that are reasonable and straightforward. It is therefore suggested that the iRAP approach is used as a basis, properly adapted to suit the needs of a larger scale (hence network-wide assessment), with long segments instead of the typical 100m segments of the iRAP protocol.

A combined CMF for the clear zone width and the type of the typical roadside obstacles is suggested as analyzed below. It is noted that the CMF for the clear zone width is noted as CMF_{CZ} and the CMF based on the obstacles risk factor information is noted as CMF_{RH}, where "RH" stands for roadside hazard. The two CMFs are combined (multiplied) to demonstrate the effect of an object near the road on the outcome of a collision. For this approach, the clear zone width (CZ) is measured from the right edge of the right-most travel lane to the object's face. Therefore, clear zone also includes the emergency lane (when one is present) and benefits road sections that have emergency lane.

a. Clear Zone CMF - based on iRAP Risk Factors

iRAP Risk Factors include four ranges of clear zone width (CZ), namely: <1m, 1-5m, 5-10m and >10m, with respective risk factor values from 1,00 to 0,10, i.e., the base case (risk factor = 1,00) is the least safe scenario of CZ <1m. For the purpose of the Network - Wide assessment of motorways, two transformations are required:

1. addition of intermediate clear zone widths to ensure more gradual transitions between CMF ranges, and
2. inverse normalization of values, so that the base case (CMF = 1,00) is the safest scenario (larger clear zone width) and all other cases have CMFs greater than 1,00 (i.e., increase in crash frequency).

With regards to the **clear zone ranges**, the following initial approach was examined for the NWA methodology:

- CZ < 1m: NWA risk factor: 1,00 (respective iRAP risk factor: 1,00)
- 1m ≤ CZ < 2,5m: NWA risk factor: 0,80 (respective iRAP risk factor: 0,80)
- 2,5m ≤ CZ < 5m: NWA risk factor: 0,60 (respective iRAP risk factor: 0,80)
- 5m ≤ CZ < 7,5m: NWA risk factor: 0,35 (respective iRAP risk factor: 0,35)
- 7,5m ≤ CZ < 10m: NWA risk factor: 0,15 (respective iRAP risk factor: 0,35)
- CZ ≥ 10m: NWA risk factor: 0,10 (respective iRAP risk factor: 0,35)

The transformation to change the assumed base case scenario (from the least safe in iRAP to the most safe in NWA methodology) is performed as a **normalization of the CMF values over the minimum risk factor**. The resulting CMF_{CZ} values for each range in this initial approach are therefore:

- CZ < 1m: CMF_{CZ} = 1,00/0,10 => CMF_{CZ} = 10,00
- 1m ≤ CZ < 2,5m: CMF_{CZ} = 0,80/0,10 => CMF_{CZ} = 8,00
- 2,5m ≤ CZ < 5m: CMF_{CZ} = 0,60/0,10 => CMF_{CZ} = 6,00
- 5m ≤ CZ < 7,5m: CMF_{CZ} = 0,35/0,10 => CMF_{CZ} = 3,50
- 7,5m ≤ CZ < 10m: CMF_{CZ} = 0,15/0,10 => CMF_{CZ} = 1,50
- CZ ≥ 10m: CMF_{CZ} = 0,10/0,10 => CMF_{CZ} = 1,00

Yet, after initial pilot testing of the model, it was realized that the finally resulting Reduction Factor for motorway roadside (used in the model) was too demanding and the model was overly sensitive to this parameter. For example, a typical condition for motorways with a steel barrier at 4,5m from the road edge line (including the emergency lane, i.e., barrier face at approximately 2m from the asphalt edge), would result in a very low RF of 0,548. This observation is also inline with comments received from Member States through EGRIS meetings. Therefore, in order to compensate for this, modified CMF_{cz} are assumed for middle clear zone width values, as follows:

- CZ < 1m: CMF_{CZ} = 1,00/0,10 => CMF_{CZ} = 10,00
- 1m ≤ CZ < 2m: CMF_{CZ} = 0,80/0,10 => CMF_{CZ} = 5,00
- 2m ≤ CZ < 3m: CMF_{CZ} = 0,80/0,10 => CMF_{CZ} = 1,50

- 3m ≤ CZ < 5m: CMF_{CZ} = 0,60/0,10 => CMF_{CZ} = 1,25
- 5m ≤ CZ < 7,5m: CMF_{CZ} = 0,35/0,10 => CMF_{CZ} = 1,10
- 7,5m ≤ CZ < 10m: CMF_{CZ} = 0,15/0,10 => CMF_{CZ} = 1,05
- CZ ≥ 10m: CMF_{CZ} = 0,10/0,10 => CMF_{CZ} = 1,00

It is clarified that the clear zone is measured from the edge of the outer traffic lane marking line; therefore, if a paved shoulder (e.g., emergency lane) is present on a motorway segment, its width is considered part of the clear zone and it increases the safety scoring of the segment.

b. Roadside Obstacle CMF - based on iRAP Risk Factors

Regarding the roadside objects, the following categories of typical objects on motorway roadside are considered:

1. barrier steel (iRAP Risk factor=12,00)
2. barrier concrete (iRAP Risk factor=15,00) - also vertical retaining wall
3. series of rigid obstacles (e.g., trees, poles with a diameter >10cm) (iRAP Risk factor=60,00)
4. fill/cut slope (iRAP Risk factor=45,00)
5. deep drainage ditch (iRAP Risk factor=55,00)

Point objects, such as an unprotected barrier end, are not meaningful for network-wide analysis, where the analysis unit is a long (e.g., 2-5 km) segment. If several such objects are present, they should be considered as a series of objects (i.e., item no. 3 in the above list).

Similarly to the clear zone CMF, a normalization is performed to change the assumed base case scenario (from the least safe in iRAP to the most safe in NWA methodology) by dividing their value with the minimum value (i.e., $CMF_{RH,i}$ = $RiskFactor_i$ / $RiskFactor_{min}$). However, in some cases there is the need for an additional correction of the CMF_{rh} value. For large clear zone widths, i.e., greater than 7,5m, it is very unlikely that the run-off-road vehicle interacts with a roadside object, and if this object is a barrier, it will probably be very effective in the safe retainment of the errant vehicle. Therefore, for (a) clear zone width greater than 10m, (b) the combination clear zone width of 5m or more and barrier (of any type) the CMF_{RH} is set equal to one.

The assumed CMF_{CZ} and CMF_{RH} values are presented in Table 5.7. The combined effect of these CMFs (multiplicatively) is presented in column 5 of the Table. This CMF however refers only to single vehicle run-off-road crashes, and an **adjustment is required to account for all fatal and injury crashes**. Single vehicle run-off-road crashes are a subset of single vehicle crashes, which are a subset of all crashes.

Considering that the available data for EU motorways from CARE database regarding crash type are inconclusive, this conversion is facilitated firstly using the AASHTO (2014) crash type distributions (see exhibit 18-8, AASHTO, 2014), according to which run-off-road crashes correspond to 56,7% of all single vehicle crashes (column 6 of Table 5.5). Secondly, to convert from single vehicle crashes to all crashes, the actual recorded distribution of crashes in EU motorways for years 2015-2019, as included in CARE database (see Annex B), is considered: single vehicle: 29,1%, multi vehicle: 70,9%.

Following these conversions, the “All crashes – CMF” column in Table B.6 shows the CMF that corresponds to the total crash number. This value is then converted to a Reduction Factor, based on the formula: Reduction Factor=1/CMF.

Table B.6: *CMFs and Reduction Factors for roadside environment in motorways*

Clear zone width (m)	Roadside obstacle type	CMF_{CZ}*	CMF_{CZ}	CMF_{RH}	SV run-off-road crashes CMF**	SV all crashes CMF*	All injury crashes CMF	Reduction Factor (RF)
1	2	3	3	4	5	6	7	8
CZ ≥ 10m	barrier steel	1,000	1,000	1,000	1,00	1,00	1,000	1,00
	barrier concrete	1,000	1,000	1,000	1,00	1,00	1,000	1,00
	series of rigid obstacles	1,000	1,000	1,000	1,00	1,00	1,000	1,00
	fill/cut slope	1,000	1,000	1,000	1,00	1,00	1,000	1,00
	deep drainage ditch	1,000	1,000	1,000	1,00	1,00	1,000	1,00
CZ 7,5-10m	barrier steel	1,500	1,050	1,000	1,05	1,03	1,008	0,99
	barrier concrete	1,500	1,050	1,000	1,05	1,03	1,008	0,99
	series of rigid obstacles	1,500	1,050	5,000	5,25	3,41	1,701	0,59
	fill/cut slope	1,500	1,050	3,750	3,94	2,67	1,485	0,67
	deep drainage ditch	1,500	1,050	4,583	4,81	3,16	1,629	0,61
CZ 5-7,5m	barrier steel	3,500	1,100	1,000	1,10	1,06	1,016	0,98
	barrier concrete	3,500	1,100	1,000	1,10	1,06	1,016	0,98
	series of rigid obstacles	3,500	1,100	5,000	5,50	3,55	1,742	0,57
	fill/cut slope	3,500	1,100	3,750	4,13	2,77	1,516	0,66
	deep drainage ditch	3,500	1,100	4,583	5,04	3,29	1,667	0,60
CZ 3-5m	barrier steel	6,000	1,250	1,000	1,25	1,14	1,041	0,96
	barrier concrete	6,000	1,250	1,250	1,56	1,32	1,093	0,92
	series of rigid obstacles	6,000	1,250	5,000	6,25	3,98	1,866	0,54
	fill/cut slope	6,000	1,250	3,750	4,69	3,09	1,608	0,62
	deep drainage ditch	6,000	1,250	4,583	5,73	3,68	1,780	0,56
CZ 2-3m	barrier steel	7,000	1,500	1,000	1,50	1,28	1,082	0,92
	barrier concrete	7,000	1,500	1,250	1,88	1,50	1,144	0,87
	series of rigid obstacles	7,000	1,500	5,000	7,50	4,69	2,072	0,48
	fill/cut slope	7,000	1,500	3,750	5,63	3,62	1,763	0,57
	deep drainage ditch	7,000	1,500	4,583	6,88	4,33	1,969	0,51
CZ 1-2m	barrier steel	8,000	5,000	1,000	5,00	3,27	1,660	0,60
	barrier concrete	8,000	5,000	1,250	6,25	3,98	1,866	0,54
	series of rigid obstacles	8,000	5,000	5,000	25,00	14,61	4,960	0,20
	fill/cut slope	8,000	5,000	3,750	18,75	11,06	3,929	0,25
	deep drainage ditch	8,000	5,000	4,583	22,92	13,43	4,616	0,22
CZ 0-1m	barrier steel	10,000	10,000	1,000	10,00	6,10	2,485	0,40
	barrier concrete	10,000	10,000	1,250	12,50	7,52	2,897	0,35
	series of rigid obstacles	10,000	10,000	5,000	50,00	28,78	9,085	0,11
	fill/cut slope	10,000	10,000	3,750	37,50	21,70	7,022	0,14
	deep drainage ditch	10,000	10,000	4,583	45,83	26,42	8,397	0,12
Comments		*Based on iRAP Star Rating Risk Factors*	*Adjusted*	*Based on iRAP Star Rating Risk Factors*	*CMF_{CZ} * CMH_{RH}*	*CMF*=1-(1-CMF**) x 56,7%*	*CMF=1-(1-CMF*) x 29,1%*	*RF=1/CMF*

Across a segment, roadside characteristics may vary. In this case, it is first required to estimate the weighted average CMF for the segment, using the values of column "All Injury Crashes CMF" from Table B.6, and then, calculate the RF ($RF_{final} = 1/CMF_{final}$). The steps for this process are described in paragraph B.1.3

Assuming that a motorway section has:

(a) a clear zone of 7,5m ≤ CZ < 10m, with a steel barrier at 80% of its length, and

(b) a clear zone of 2m ≤ CZ < 3m, with a concrete barrier at 20% of its length.

Then, an CMF equal to 1,008 and a CMF equal to 1,144 corresponds to case (a) and (b) respectively. Then the section-level RF will be equal to:

$$Weighted\ average\ CMF = \frac{0{,}80 \times 1{,}008 + 0{,}20 \times 1{,}144}{0{,}80 + 0{,}20} = 1{,}035$$

The weighted average CMF will then be converted to RF: RF = 1/1,035 = 0,966.

Following the initial results and feedback from the pilot implementation of the methodology, the potential impact of **sidewalk curbs** (e.g., on motorway bridges) to the roadside parameter and ultimately to the proactive assessment score was also examined. It is recognized that the installation of curbs instead of flush shoulders (i.e., at the same level with the pavement) appears to increase crashes of all types and severities (AASHTO, 2010). On the other hand, existing research has not yet established the magnitude of the effect in crashes. Specifically:

- In the AASHTO Highway Safety Manual (AASHTO, 2010) the trend is recognized but the uncertain magnitude of the effect is mentioned (section 13A.3.2.3) and no CMF is proposed.
- In the iRAP methodology, the presence of sidewalk curbs is not considered for roadside risk factors.
- In the FHWA CMF Clearinghouse, a single study (Lienau, 1996) is mentioned for CMF of barrier curb on the road edge; however the study refers to suburban multilane highways, it has been rated as low quality (1 out of 5 stars), and most importantly the range of estimated CMFs is large (from 0,64 to 3,57) and with large standard error in the statistical analysis. As a result, the estimated CMFs are considered unreliable.

Taking all the above into consideration, while also considering that sidewalks are uncommon in motorways and are found mostly in tunnels (i.e., outside the scope of the present methodology) and on bridges (i.e., limited length compared to the entire network) it has been decided that the presence of sidewalk curbs is not taken into consideration. A roadside consisting of a flush shoulder and one also including a curb are therefore receiving the same Reduction Factor, if all other roadside elements are identical).

B.2.3 Motorways: Curvature

Several studies have found that more crashes occur in curves with a smaller radius than in curves with a larger radius, and the effect of curvature has been incorporated in crash prediction models around the world. Table B.7 provides a synopsis of the impact of curvature on crash rates (including studies and models for motorways only or for all types of roads).

Table B.7: *CMFs for curvature (motorways), according to existing literature and models*

Source	CMF value / function		Comments
Highway Safety Manual (AASHTO, 2014) *for motorway segments*	$CMF = 1.0 + 0.0172 \cdot \left[\sum_i \left(\frac{5730}{R_i^*}\right)^2 \cdot P_{c,i}\right]$ $CMF = 1.0 + 0.0719 \cdot \left[\sum_i \left(\frac{5730}{R_i^*}\right)^2 \cdot P_{c,i}\right]$		*for multivehicle fatal & injury crashes* *for single vehicle fatal & injury crashes* *where: R_i* = equivalent radius of curve i (ft)* *$P_{c,i}$ = proportion of segment length within curve*
iRAP Star Rating Protocol *for all road types*	Straight/gentle curve (R>900m): Moderate curve (R=500m-900m): Sharp curve (R=200m-500m): Very sharp curve (R<200m):	1,00 1,80 3,50 6,00	*CMFs for run-off-road and head-on crashes*
Elvik et al. (2009)	R1<200m to R2=200-400m R1=200-400m to R2=400-600m to R1=400-600m to R2=600-1.000m to R1=600-1.000m to R2=1.000-2.000m R1=1.000-2.000m to R2>2.000m	0,50 0,67 0,77 0,82 0,88	*Meta-analysis of previous studies for converting curves from R=R1 to R=R2*

Source	CMF value / function		Comments
for all road types	R1>2.000 to greater R1>1.000 to straight road	1,00 1,10	

From the above it can be concluded that, according to relevant **research** (mostly however in the US) curves with radii larger than 2000m have approximately similar crash rates to tangents; Elvik et al. (2019) even suggest that gentle curves (R>1500m) are even preferable to tangents as they exhibit slightly lower crash rates. The comparison of available curvature CMFs applicable in motorways (Table B.8 and Figure B.1 below), for typical values of curve radius, indicates similar values in AASHTO (2014) and Elvik et al. (2009), and significantly higher values (more exaggerated effect of curvature) in the iRAP model, which is to be expected since the iRAP CMF refers to run-off-road and head-on crashes only.

It is noted that the HSM CMFunctions for multivehicle and single vehicle crashes have been combined (in Table B.8) in order to provide a single CMF value for all crashes. A weighted average has been estimated according to the actual recorded distribution of crashes (single vehicle: 29,1%, multi vehicle: 70,9%) in EU motorways for years 2015-2019, as included in CARE database.

Table B.8: *Comparison of CMFs for curvature in motorways*

R (m)	R (ft)	HSM (AASHTO, 2014)	HSM (AASHTO, 2014)	Weighted HSM CMFunction	iRAP	Elvik et al. (2009)
2000	6.562	1,013	1,055	1,025	1,000	1,000
1500	4.921	1,023	1,097	1,045	1,000	1,136
1000	3.281	1,052	1,219	1,101	1,000	1,136
900	2.953	1,065	1,271	1,125	1,800	1,386
800	2.625	1,082	1,343	1,158	1,800	1,386
700	2.297	1,107	1,448	1,206	1,800	1,386
600	1.969	1,146	1,609	1,281	1,800	1,386
500	1.640	1,210	1,877	1,404	3,500	1,800
400	1.312	1,328	2,371	1,631	3,500	1,800
350	1.148	1,428	2,790	1,825	3,500	2,686
300	984	n/a	n/a		3,500	2,686
200	656	n/a	n/a		6,000	2,686
Comments	*1ft = 0,3048m*	*for multivehicle crashes (motorways)*	*for single vehicle crashes (motorways)*	*Weighted for 70,9% multi-vehicle and 29,1% single-vehicle crashes*	*for run-off-road and head-on crashes*	*all crashes*

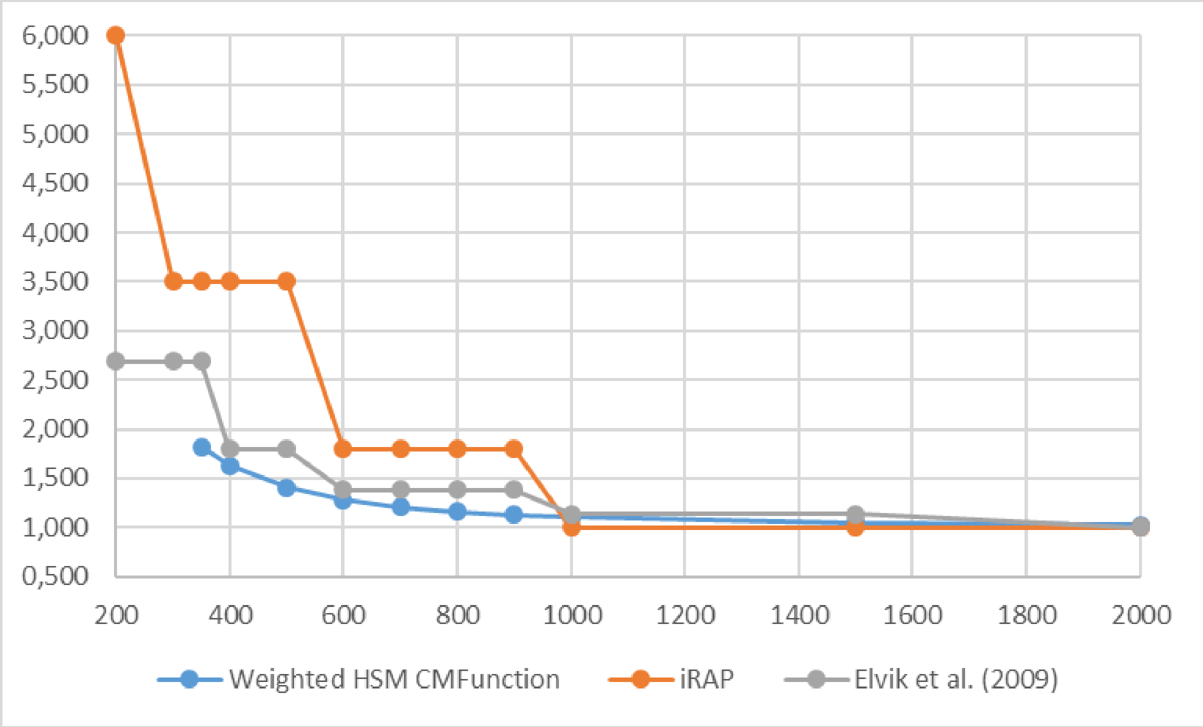


Figure B.1: *Comparison of CMFs for curvature in motorways*

From the aforementioned approaches, **the Highway Safety Manual function is overall considered the most appropriate** for use in the NWA methodology for motorways, as:

- it is the only one developed specifically for motorway segments,
- it is more appropriate for assessing segments that combine tangents and curves, or for segments with several curves (as it incorporates the variable Pc,i: proportion of segment length within curve) and thus better suited for a network-wide assessment with long segments. On the contrary, the iRAP model can be implemented on fixed 100m long sections.

However, during **EGRIS discussions and received feedback** on the first version of the proactive methodology, the following two issues were stressed:

- The threshold for curve radius of 2000m for an "ideally safe" motorway (as per the Highway Safety Manual CMFs) is considered too high for European Roads.
- A less demanding approach needs to be considered with regards to urban motorways, in which speed limits and vehicle speeds in general are lower.

In order to be able to quantify the impact of the above observations, motorway design guidelines from EU countries were examined with regards to the minimum curvature, as in Table B.9 that follows:

Table B.9: *Minimum radius for rural and for urban motorways according to design guidelines.*

Country	Rural		Urban	
	Speed limit	minR	Speed limit	minR
France	110	400	90	240
	130	600	110	400
Germany	120	720	80	280
	130	900		
	no SL	1300		
Italy	90	339	80	252
Spain	80-120	250-700		
	130	850		
	140	1050		
USA		350		

- Spain does not list whether values are for urban/rural motorways

It is noted that the minimum allowed curve radius as per design guidelines represents a compromise between safety and cost/ feasibility; a Reduction Factor of 1,00 should never be defined at the minimum radius value, since a motorway designed according to minimum requirements cannot be considered an "ideally safe" road, and safety scoring reductions should be applied. However, by jointly considering all above input, the CMFs and respective **Reduction Factors** for the in-built safety assessment methodology for motorways are defined as follows:

<u>Rural Motorways</u>

- for segments with tangents and curves with R≥1500m: CMF=1,00 => **RF=1,00**
- if at least one curve with R<1500m exists in the segment:

  CMFunction from HSM, weighted for EU crashes distribution and converted from feet to meters:

$$\mathrm{CMF} = 1{,}00 + (0{,}709 \times 0{,}0172 + 0{,}291 \times 0{,}0719) \times \sum_{\mathrm{i}} \left(\frac{5730 \times 0{,}3048}{\mathrm{R_i}}\right)^2 \times \mathrm{P_{c,i}}$$

  and finally:

$$\mathrm{CMF} = 1{,}00 + 0{,}03312 \times \sum_i \left(\frac{1746{,}5}{R_i}\right)^2 \times P_{c,i}$$

  where: R_i (m) = radius of curve i within segment

  $P_{c,i}$ ()= proportion of segment length within curve i

  and the respective RF = 1/CMF => **RF =** $\mathbf{1 \Big/ 1,00 + 0,03312 \times \sum_i \left(\frac{1746,5}{R_i}\right)^2 \times P_{c,i}}$

Urban Motorways

Both the radius threshold and the impact of small radius curves should be considered at half (50%) of the respective values for rural motorways. Criteria are as follows:

- for segments with tangents and curves with R≥750m: CMF=1,00 => **RF=1,00**

- if at least one curve with R<750m exists in the segment:

CMFunction from HSM, weighted for EU crashes distribution and converted from feet to meters (impact reduced at 50%):

$$\mathrm{CMF} = 1{,}00 + 0{,}5 \times (0{,}709 \times 0{,}0172 + 0{,}291 \times 0{,}0719) \times \sum_{\mathrm{i}} \left(\frac{5730 \times 0{,}3048}{\mathrm{R_i}}\right)^2 \times \mathrm{P_{c,i}}$$

and finally:

$$\mathrm{CMF} = 1{,}00 + \ 0{,}01656 \times \sum_{i} \left(\frac{1746{,}5}{R_i}\right)^2 \times P_{c,i}$$

where: R_i (m) = radius of curve i within segment

$P_{c,i}$ ()= proportion of segment length within curve i

and the respective RF = 1/CMF => **RF =** $\mathbf{1} \Big/ \mathbf{1{,}00 + 0{,}01656 \times \sum_i \left(\frac{1746{,}5}{R_i}\right)^2 \times P_{c,i}}$

Table B.10 that follows provides an indication of RF estimations for segments consisting of a single horizontal curve, for various values of the curve's radius, thus showing the difference in scoring between rural and urban motorways.

Table B.10: *RF estimations for segments consisting of a single horizontal curve, for various values of the curve's radius.*

R (m)	Rural Motorways	Urban Motorways
2000	1,000	1,000
1500	1,000	1,000
1300	0,944	1,000
1200	0,934	1,000
1100	0,923	1,000
1000	0,908	1,000
900	0,889	1,000
800	0,864	1,000
750	0,848	1,000
700	0,829	0,907
600	0,781	0,877
500	0,712	0,832
400	0,613	0,760
350	0,548	0,708
300	0,471	0,641
200	0,284	0,442

B.2.4 Motorways: Interchanges

Interchanges in motorways are always grade-separated, in order to allow unobstructed, safe and efficient traffic flow and reduce vehicle conflicts. Existing literature for interchange safety assessment includes the following:

- In the Highway Safety Manual (AASHTO, 2014) SPFs for many interchange elements are available, namely, speed-change lanes, ramp segments, ramp terminals, and distributor-collector roads, along with several detailed CMFs. Application of these models requires extensive datasets and deep knowledge of the specific characteristics of each site and is thus outside the scope of a network-wide assessment.
- Elvik et al. (2009) has proposed a generic safety ranking among the different types of interchanges based on meta-analysis of existing studies. The diamond design was found to be the safest in terms of crash rates, and the rest have been classified as follows in terms of % change in expected number of crash compared to diamond interchanges:
  - diamond instead cloverleaf:
    -2% (95% confidence interval: -19% to +18%)
  - diamond instead loop:
    -9% (95% confidence interval: -95% to +10%)
  - diamond instead junction with direct access ramps:
    -25% (95% confidence interval: -59% to +40%)
  - diamond instead of trumpet:
    -38% (95% confidence interval: -59% to -7%)

  However, the result of Elvik's meta-analysis is also not usable for the purpose of network-wide in-built safety assessment for the following reasons:

  1. The 95% confidence intervals are very wide and include 0%, which indicates that the best estimate results are inconclusive. For example, replacing a with direct access ramps junction with a diamond interchange is expected (at 95% certainty) to result in a change in crash rates from -59% (i.e., great road safety improvement) to +40% (great road safety deterioration).
  2. Original research studies examined by Elvik are based on comparisons of crash rate between different types of intersections. None of the studies evaluated the effects of converting interchanges into a different type of interchange. Therefore, there is a potential bias in results due to the fact that some interchange types are normally used in cases with higher traffic volumes (and thus expected crashes) than others. In other words, a diamond interchange, normally constructed to connect a lower-class road to a motorway, is expected to have lower crash rates compared to a direct access ramps interchange, that normally connects two motorways, due to lower traffic volumes.
  3. Specific characteristics and potential safety deficiencies (e.g., short speed change lanes, sharp curve in interchange ramps) are not considered in this approach.

However, interchange spacing on motorways constitutes an element that affects, according to existing literature, road safety and can more conveniently be assessed in the in-built safety assessment methodology for motorways. In a network-wide perspective, interchange spacing is an important road safety related factor and is highly correlated with crash probability. Interchange spacing is the distance between two interchange centres as shown in Figure B.2.

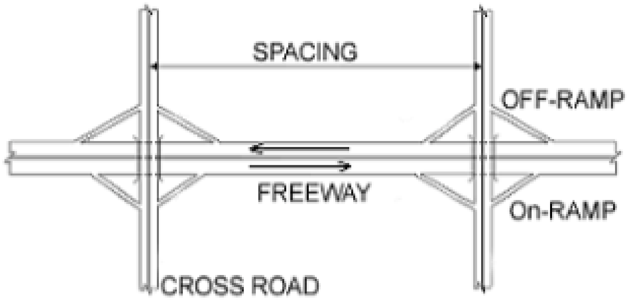
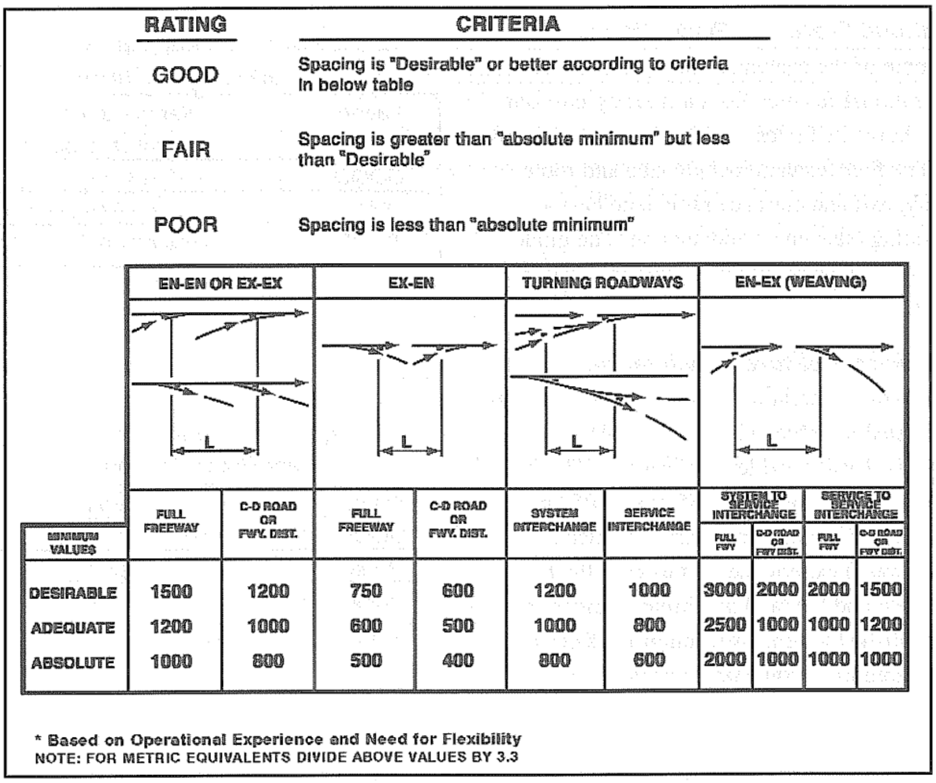


Figure B.2: *Interchange Spacing (Bared et al., 2007)*

Guidelines from the U.S., Australia, European countries, etc. recommend appropriate spacing between interchanges. These values vary significantly from country to country and there are also differences between rural and urban motorways. The recommended distances vary between 1,6 to 3km. A frequently referenced document for minimum values for interchange spacing is AASHTO (2018): A Policy on Geometric Design of Highways and Streets - Green Book, according to which "minimum interchange spacing" is 1 mile (1,6km) in urban areas and 2 miles (3,2km) in rural areas".

Instead of interchange density, ramp density is often used for motorways planning, design and assessment. Particularly, the Freeway and Interchange Geometric Design Handbook (ITE Freeway Handbook) published by the Institute of Transportation Engineers (ITE) and TRB's Access Management Manual provide planning and design guidance related to interchange and ramp spacing. In 1975, Jack E. Leisch proposed a table with "Recommended Minimum Ramp Terminal Spacing" for various combinations of ramps; it included "desirable minimum," "adequate minimum," and "absolute minimum" spacing values, and is shown in Figure B.3.



RATING	CRITERIA
GOOD	Spacing is "Desirable" or better according to criteria in below table
FAIR	Spacing is greater than "absolute minimum" but less than "Desirable"
POOR	Spacing is less than "absolute minimum"

MINIMUM VALUES	EN-EN OR EX-EX		EX-EN		TURNING ROADWAYS		EN-EX (WEAVING)			
							SYSTEM TO SERVICE INTERCHANGE		SERVICE TO SERVICE INTERCHANGE	
	FULL FREEWAY	C-D ROAD OR FWY. DIST.	FULL FREEWAY	C-D ROAD OR FWY. DIST.	SYSTEM INTERCHANGE	SERVICE INTERCHANGE	FULL FWY	C-D ROAD OR FWY DIST.	FULL FWY	C-D ROAD OR FWY DIST.
DESIRABLE	1500	1200	750	600	1200	1000	3000	2000	2000	1500
ADEQUATE	1200	1000	600	500	1000	800	2500	1000	1000	1200
ABSOLUTE	1000	800	500	400	800	600	2000	1000	1000	1000

* Based on Operational Experience and Need for Flexibility
NOTE: FOR METRIC EQUIVALENTS DIVIDE ABOVE VALUES BY 3.3

Figure B.3: *Minimum Ramp Terminal Spacing (Leisch, 1975)*

Taking into consideration the potential impact of ramp density on road safety, several studies have investigated its effect and incorporated it in crash prediction models. Table B.11 illustrates the respective findings.

Table B.11: *CMFs for interchange ramps spacing, according to existing literature*

Source	CMF value / function	Comments
Park et al. (2010) *Urban freeways*	$AMF_{OnD(all)} = e^{0{,}0321*(OnD)}$ Where: OnD: on-ramp density in both directions (on ramps/mi)	All crash types
Le & Porter (2012) *All area types*	$CMF_{TOTAL} = e^{(\frac{352.485-133.962*Auxln}{s})}$ Where: Auxln: auxiliary lane (1=yes, 0=no) s: ramp spacing (ft)	All crash types and severities
Bonneson & Pratt (2008) *All area types*	$CMF_{wev,FI,TX} = e^{(\frac{152{,}9}{L_{wev}})}$ for $L_{wev} \geq 800$ft Where: $CMF_{wev,FI,TX}$: CMF for fatal and injury crashes in weaving areas developed by using Texas freeway data L_{wev}: weaving section length (ft)	Fatal and injury crashes

The comparison of available ramp spacing CMFs applicable in motorways is presented in Table B.12 and Figure B.4 below for typical values of ramp spacing. It appears that the trend is similar in all studies with Le & Porter (2012) being the most strict and Bonneson & Pratt (2008) being the most tolerant. With respect to Le & Porter study, it should be noted that CMFunctions for ramp spacing with and without the presence of auxiliary lane have been combined in order to provide a single CMF value. Eventually, an average of all the three mentioned studies has been estimated for user‵s convenience.

Table B.12: *Comparison of CMFs for ramp spacing in motorways*

CMF estimates for ramps spacing on motorways							
L (m)	L (ft)	Le & Porter (2012)	Le & Porter (2012)	Le & Porter (2012) average	Bonneson & Pratt (2008)	Park et al. (2010) (proposed for urban MWs)	Proposed for rural MWs
		rural motorways				urban	
1600	5249,3	1,069	1,043	1,056	1,030	1,032	1,043
1400	4593,2	1,080	1,049	1,064	1,034	1,032	1,049
1200	3937,0	1,094	1,057	1,075	1,040	1,032	1,057
1100	3608,9	1,103	1,062	1,083	1,043	1,032	1,063
1000	3280,8	1,113	1,069	1,091	1,048	1,032	1,069
900	2952,8	1,127	1,077	1,102	1,053	1,032	1,077
800	2624,7	1,144	1,087	1,115	1,060	1,066	1,088
700	2296,6	1,166	1,100	1,133	1,069	1,066	1,101
620	2034,1	1,189	1,113	1,151	1,078	1,066	1,115
560	1837,3	1,211	1,126	1,169	1,087	1,106	1,128
500	1640,4	1,240	1,142	1,191	1,098	1,106	1,144
440	1443,6	1,277	1,163	1,220	1,112	1,151	1,166
380	1246,7	1,327	1,192	1,259	1,130	1,151	1,195
320	1049,9	1,399	1,231	1,315	1,157	1,173	1,236
260	853,0	1,512	1,292	1,402	1,196	1,205	1,299
200	656,2		1,395			1,240	1,395
140	459,3		1,609			1,291	1,609
Comments	*1ft = 0,3048m*	*CMFs for ramp spacing (auxiliary lane not present)*	*CMFs for ramp spacing (auxiliary lane present)*	*Average of CMFs with and without auxiliary lane*	*Fatal and injury crashes*	*modified CMF based on ramps spacing*	*Le&Porter Average + Bonneson & Pratt*

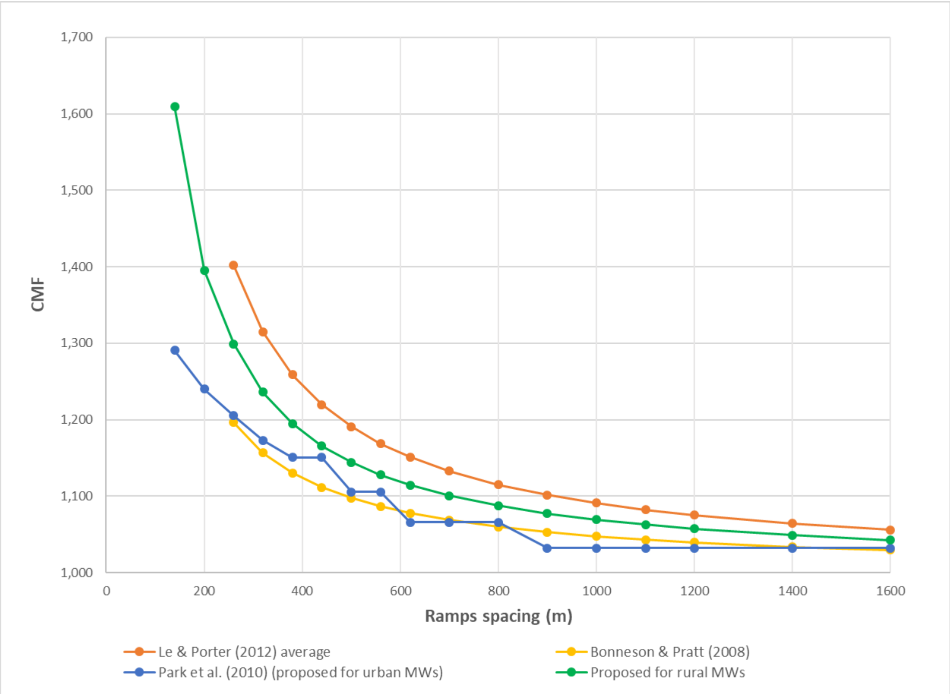


Figure B.4: *Comparison of CMFs for ramp spacing in motorways*

Based on the above research results, an assessment approach is presented in Table B.13, with different values for rural and urban motorways. Specifically, the following assumptions and adjustments are considered:

- The ramp spacing estimation refers to the "gore to gore" section of an interchange, i.e., the distance from the gore of an entrance/exit ramp till the gore of next exit/entrance ramp.
- For ramp spacing longer than 1600m, the Reduction Factor is considered as 1,00 for all sections between these interchanges.
- For ramp spacing of 1600m or lower, Reduction Factors are presented in the following Table, derived from Park et al. (2010) for urban motorways, and from the average CMFs of Le & Porter (2012) and Bonneson & Pratt (2008), for rural motorways.

Table B.13: *CMFs and Reduction Factors for ramp spacing in motorways*

Ramp Spacing (m) (gore to gore length)	PAverage CMF rural MW	RF rural MW	Average CMF urban MW	RF urban MW
1600	1,043	0,959	1,032	0,969
1400	1,049	0,953	1,032	0,969
1200	1,057	0,946	1,032	0,969
1100	1,063	0,941	1,032	0,969
1000	1,069	0,935	1,032	0,969
900	1,077	0,928	1,032	0,969
800	1,088	0,919	1,066	0,938
700	1,101	0,908	1,066	0,938
620	1,115	0,897	1,066	0,938
560	1,128	0,887	1,106	0,904
500	1,144	0,874	1,106	0,904
440	1,166	0,858	1,151	0,869
380	1,195	0,837	1,151	0,869
320	1,236	0,809	1,173	0,853
260	1,299	0,770	1,205	0,830
200	1,395	0,717	1,240	0,807
140	1,609	0,621	1,291	0,775

In case of small length sections, with one or more sections between the two closely located interchanges, the resulting Reduction Factor applies for all sections regardless of whether the gore point(s) is located inside or outside the specific segment.

In case of large sections including an interchange but also spreading well before and after the interchange, the above Reduction Factors are relevant only for the part of the road at the area of influence of each interchange. In order to estimate the average CMF across the examined section, a weighted average CMF needs to be estimated based on the length of each element, also considering segments outside the influence of intersections. For this purpose, an influence length of 1km is considered for each segment between interchange ramps, regardless of the actual gore to gore length. For example, on a section of a rural motorway 4km long, with two interchanges at 800m ramp spacing (and spacing > 1600m to other interchanges, outside the examined section), the resulting average CMF would be:

$$CMF_{section} = (1000 \times 1{,}088 + 3000 \times 1{,}000) / 4000 = 1{,}022$$

In, turn the section-wide RF would be: RF = 1 / 1,022 = 0,978.

B.2.5 Motorways: Conflicts between pedestrians/ bicyclists and motorized traffic

Motorways are designed to accommodate high speed and high-volume of motorized traffic. As such, the presence of pedestrians and bicyclists on the carriageway and shoulders of motorways is incompatible to the predominant function of this type of roads and is an obvious cause of serious road safety concerns.

Crash data, both internationally and in the EU, indicate however that crashes involving bicyclists or pedestrians on motorways do occur, although rarely. According to CARE data from 2015 to 2019 3253 crashes with pedestrians and 1021 crashes with bicyclists were recorded on EU motorways, representing 1,1% and 0,3% respectively of all crashes on motorways.

According to common experience as well as relevant literature there are two main causes for such crashes, justifying the presence of vulnerable non-motorized users on motorways. In certain cases, pedestrians or bicyclists might move alongside a motorway (on unprotected paths) or cross, in order to minimize trip distance or in case of no other alternative route. Wang and Cicchino (2020) found that crossing was the most common (42%) crash type for pedestrian fatalities on U.S. freeways. A second causal factor, concerning pedestrian related crashes is related to the presence of motorist rest areas or incident/ crash scenes. Pedestrians might be moving around or within a rest area and be hit by a moving vehicle. Similarly, after a road incident or a crash, car passengers are moving on or near the motorway carriageway on foot and an increased risk of crash is observed: 18% of pedestrian fatalities on US freeways have been attributed to pedestrians moving around an incident scene (Wang & Cicchino, 2020).

Despite the fact that only a small percentage of crashes on EU motorways concerns pedestrians and bicyclists (collectively 1,4% for years 2015-2019, according to CARE data), it is considered appropriate to incorporate a distinct variable in the proactive assessment methodology to help identify those parts of the motorway network that exhibit such problems and prioritize detailed road safety inspections and remedial treatment. This approach is in line with the provisions of Directive 2008/96/EC (Article 6.b: Protection of vulnerable road users) and aims to account for the very high severity of such crashes, usually resulting in fatalities due to the high vehicle speeds and the vulnerability of pedestrians and bicyclists.

The developed methodology does not aim to assess the quality and safety of infrastructure for non-motorized users alongside or transverse to the motorway. It aims to isolate those sections that, in terms of in-built infrastructure characteristics (e.g., absence of pedestrian/bicycle overpass or underpass if needed, improper design of rest areas environment, etc.), do not adequately prevent the presence of pedestrians and bicyclists in the "danger" zone of the motorway. As such, a practically binary approach for this parameter is decided, with a RF equal to 1,00 (no reduction of the safety score) if no problems are identified and a very low RF equal to 0,05 if such a deficiency is present, in order to ensure that this specific section scores very low and is classified as "unsafe" and of high intervention priority, regardless of its performance in all other parameters.

Based on the above, the **Reduction Factors** for assessing VRU safety on motorways are defined as follows:

- for segments where pedestrians and bicyclists do not approach the motorway carriageway: **RF=1,00**

- for segments where pedestrians and bicyclists near the motorway carriageway are on level-separated or fully protected facilities: **RF=1,00**
- for segments where there are potential conflicts between vehicles and pedestrians / bicyclists: **RF=0,05**

It is noted that in motorways, the parameter "Conflicts between motorized vehicles and pedestrians/bicyclists" is examined along the motorway segments (including any auxiliary/ additional lanes) and along exit or entrance ramp segments at interchange areas. The secondary road at a motorway interchange, including any at-grade intersections with the motorway ramps (if present) are outside the scope of the assessment, unless the secondary road is also within the scope of 2008/96/EC Directive (e.g., being a primary road). In that case, potential conflicts with VRUs will affect the scoring of the secondary (primary) road and not the motorway. Overpasses or underpasses of local roads above or below a motorway, where VRUs might be present are not assessed in relation to the near-by motorway and do not affect the motorway scoring.

B.2.6 Motorways: Traffic Operation Centers and/ or mechanisms to inform users for incidents

Traffic operation centers monitor motorway traffic with the objective to respond timely when any sort of incidents take place. Besides more effective traffic management, traffic operation centers through their warning information system also significantly enhance safety for motorway users. Traffic operation centers inform drivers when crashes or stalled vehicles, queues, or lane closure are ahead of them and they also provide weather related information (e.g., presence of fog or strong wind, risk of fire, etc.). Literature results on the safety effectiveness of traffic operation centers is summarized in Table B.14.

Table B.14: *CMFs for incident warning systems in motorways, according to existing literature*

Source	CMF value	Comments
Elvik et al. (2009)	CMFs for incident warning systems: (i) Crash warning: CMF=0,560 (ii) Fog warning: CMF=0,160 (iii) Weather-controlled speed limits: CMF=0,920	*(i) Provided that a crash has already occurred* *(ii) all crash types during fog* *(iii) all crash types*
Highway Safety Manual (AASHTO, 2010)	CMF for crash ahead warning signs: CMF=0,560	*Provided that a crash has already occurred. Refers to fatal and injury crashes of all types.*

It is noted that during normal operation (i.e., on usual operating conditions, good weather conditions, etc.) the safety impact of traffic operation centers is very minor, if any. Their impact becomes extremely important, with CMFs significantly lower than 1 (e.g., fog warning CMF=0,160, crash warning CMF=0,56 - for secondary crashes, etc.) when a safety related incident or abnormal condition has occurred. An overall estimation of the safety benefit of traffic control centers cannot however be derived from the above CMFs, as this would require knowing the ratio of exposure (veh.km) of motorway users to abnormal/ incident related conditions, in relation to total exposure. Therefore, it is not feasible through the available literature, to assess the overall effect of all policies and warning systems and estimate a single CMF value.

Overall, for the assessment of traffic operation centers in motorways a **Reduction Factor** equal to one for motorways where these facilities are present, is used. For motorways without these facilities, the Reduction Factor is lower than one, as follows:

- **Reduction Factor = 1,000**, for motorways with traffic operation centers and/ or mechanisms to inform users for incidents.
- **Reduction Factor = 0,950**, for motorways without traffic operation centers or mechanisms to inform users for incidents.

It is noted that the presence of traffic operation centers and/ or mechanisms to inform users of incidents is assessed not at a segment per segment basis, but at a road axis level. For example, the positive safety effect of a VMS that may, if needed, inform users of an incident on the road ahead, is not limited only to the particular segment in which this VMS is located, but it affects several segments ahead. Therefore, if a motorway is equipped with such facilities, in terms of the network-wide assessment all of its segments will be considered with an RF equal to one.

B.2.7 Primary roads: Lane width

As in the case of motorways, lane width affects the safety performance of primary roads, both divided and undivided, with one or more lanes per direction. The trend identified in literature is that overall, narrow lanes provide less space for manoeuvres and drivers have less margin for an error. The impact on safety is greater when traffic increases.

Research conducted for the development of the Highway Safety Manual (AASHTO, 2010, AASHTO, 2014) suggests that wider lanes are overall safer, for both rural roads ("highways") and motorways ("freeways").

The base condition (CMF=1,00) is a 12-ft lane (3,66m); the range of CMFs for various lane widths are presented in Table B.15 below (assuming an AADT of 2000veh/day for both directions). The iRAP Star Rating Protocol also considers a positive relationship between crash risk reduction and the lane width, common for motorways and rural roads, as shown in the Table below, as well as other individual studies identified in literature (Hauer, 2000, Abdel-Rahim & Sonnen, 2012). However, an extensive meta-analysis of previous studies (Elvik et al., 2009) reported a non-conclusive relationship between lane width and road safety, and a study by Abdel-Aty et al. (2014) identified an opposite trend of decreasing crashes as the lane width decreases.

Table B.15: *CMFs for lane width in rural roads, according to existing literature*

Source	CMF value	Comments
Highway Safety Manual (AASHTO, 2010) *two-lane undivided roads (AADT>2000v/day)*	LW ≥ 3,66m: 1,000 LW = 3,50m: 1,026 LW = 3,25m: 1,134 LW = 3,00m: 1,331 LW ≤ 2,75m: 1,500	*CMF values estimated from Table 10-8 of the HSM, for run-off-road, head-on and side-swipe crashes (intermediate width values obtained through extrapolation).*
Highway Safety Manual (AASHTO, 2010) *multilane undivided roads (AADT>2000v/day)*	LW ≥ 3,66m: 1,000 LW = 3,50m: 1,021 LW = 3,25m: 1,104 LW = 3,00m: 1,254 LW ≤ 2,75m: 1,380	*CMF values estimated from Table 11-11 of the HSM, for run-off-road, head-on and side-swipe crashes (intermediate width values obtained through extrapolation).*

Source	CMF value	Comments
Highway Safety Manual (AASHTO, 2010) *multilane divided roads (AADT>2000v/day)*	LW ≥ 3,66m: 1,000 LW = 3,50m: 1,014 LW = 3,25m: 1,070 LW = 3,00m: 1,166 LW ≤ 2,75m: 1,250	*CMF values estimated from Table 11-16 of the HSM, for run-off-road, head-on and side-swipe crashes (intermediate width values obtained through extrapolation).*
iRAP Star Rating Protocol	LW ≥ 3,25m: 1,00 LW ≥ 2,75m and < 3,25: 1,20 LW ≤ 2,75m: 1,50	*Values included in relevant iRAP factsheet, obtained from other previous studies*
Elvik et al. (2009)	Non-conclusive results	*Meta-analysis of previous studies*
Abdel-Aty et al. (2014)	Initial LW=3,658m (12 ft) (i) LW=3,353m: CMF=0,78 (ii) LW=3,048m: CMF=0,58 (iii) LW=2,743: CMF=0,44	*CMF for decreasing LW from 3,658m to:3.353m, 3,048m, 2,743m* *Results are contradictory to other studies!*
Hauer (2000)	Initial LW=3,353m (11 ft) (i) LW = 3,048m: CMF=1,09 (ii) LW = 2,743m: CMF=1,21	*CMF for decreasing LW from 3,353m to:3,048m, 2,743m*
Abdel-Rahim & Sonnen (2012)	Initial LW=3,658m (12 ft) LW=3,048m: CMF=1,05	*CMF for decreasing LW from 3,658 to 3,048m.*

In order to define the Reduction Factors for lane width of primary roads based on the above input from existing literature, the following also need to be considered:

- The adverse safety impact of narrow lanes is **more prominent in two-lane undivided roads compared to multilane undivided roads**, as the presence of additional lanes increases the margin for driver corrective actions in case of lane departure or temporary loss of control. This is evident in the respective HSM CMFs, as shown on the first two rows of Table B.15. For simplicity purposes, an average value is used in the NWA process.
- The CMF values for undivided roads from HSM (Table B.15) correspond to run-off-road, head-on and side-swipe crashes. Therefore, before estimating the average CMF for lane width for the undivided roads, it is needed to **adjust existing CMFs for undivided roads to account for all crashes**. According to US crash statistics, in the case of two-lane roads those crashes are 57,4% of all crashes while for multi-lane roads those crashes account for 27% of all crashes. Therefore, the CMFs for two-lane and multi-lane roads are scaled up to account for all crash types. For this purpose the following formula is used to estimate the final CMF: CMFall crashes = 1 + P×(CMF-1), where P is the percentage of run-off-road, head-on and side-swipe crashes for the respective road type. After adjusting CMFs to account to all crashes, the average CMF is estimated for the lane widths of two-lane and multi-lane undivided roads.
- The adverse safety impact of narrow lanes is **more prominent in undivided roads compared to divided roads** (see CMFs at the second and third row of Table B.15). A reason for this is that lane departure in an undivided road is related to increased possibility of head-on crash. Therefore, there are different CMFs and RFs for the parameter of lane width in divided and undivided primary roads.

- The CMF values from HSM for divided roads (Table B.15) correspond to run-off-road, and side-swipe crashes. According to US crash statistics, those crashes account for 50% of all crashes. Therefore, the **CMFs for divided roads are adjusted to account for all crash types**. For this purpose, the following formula is used to estimate the final CMF: CMFall crashes = 1 + P×(CMF-1), where P is the percentage of run-off-road, and side-swipe crashes.
- A construction and measuring allowance of 5-10cm is considered appropriate for assessment purposes; therefore, Reduction Factor limits are set at 10cm lower than common design thresholds (e.g., at 3,40m for the design threshold of 3,50m).

CMFs and **Reduction Factors** for lane width in primary roads are presented in Tables B.16 and B.17 below:

Table B.16: *CMFs and Reduction Factors (RF) for lane width in undivided primary roads*

Lane width	CMF value	RF value
LW ≥ 3,40m	1,000	1,000
3,15m ≤ LW <3,40m	1,050	0,952
2,70m ≤ LW <3,15m	1,120	0,893
LW ≤ 2,70m	1,190	0,840

Table B.17: *CMFs and Reduction Factors (RF) for lane width in divided primary roads*

Lane width	CMF value	RF value
LW ≥ 3,40m	1,000	1,000
3,15m ≤ LW <3,40m	1,021	0,979
2,70m ≤ LW <3,15m	1,080	0,926
LW ≤ 2,70m	1,120	0,893

Across a section the average lane width may vary. In this case, it is first needed to estimate the weighted average CMF for the section and then, calculate the RF. The steps for this process are described in paragraph B.1.3.

B.2.8 Primary roads: Roadside

Research on the roadside environment of rural roads, both divided and undivided, is conclusive in that the presence of features such as clear zone, recoverable and traversable slopes, and safety barriers improve road safety. With the exemption of Highway Safety Manual (AASHTO, 2010) and the iRAP Star Rating Protocol that consider multiple safety conditions at the same time when assessing the roadside impact, the rest of the studies assess the impact of one individual treatment (or feature or condition) on crash occurrence. The research findings regarding the roadside environment of rural roads are presented in Table B.18.

Table B.18: *CMF values for roadside environment of rural roads, according to existing literature*

Source	CMF	Comments
Highway Safety Manual (2010) *applicable for two-lane undivided rural roads*	$CMF = \frac{e^{(-0,6869+0,0668 \times RHR)}}{e^{-0,4865}}$ Where: RHR is Roadside Hazard Rating	*RHR is a scale from 1-7 corresponding to seven roadside conditions.*
Petegem & Wegman (2014)	1,49	*Rural roads (speed limit=80 km/h)* *Impact of obstacles present at a distance up to 2m from the right lane on run-off-road crashes*
Elvik et al. (2009)	0,78	*Meta-analysis of previous studies:* *Increase clear zone width from 0,91m to 5,094m*
Elvik et al. (2009)	0,56	*Meta-analysis of previous studies:* *Increase clear zone width from 5,09m to 9,14m*
Hovey & Chowdhury (2005)	0,62	*Remove or relocate fixed objects outside of clear zone*
Jurewicz & Pyta (2010)	Initial condition: CZ>8m 4m ≤ CZ ≤ 8m: CMF=1,27 2m ≤ CZ ≤ 4m: CMF=1,60	*Impact of clear zone width reduction on run-off-road crashes*
iRAP Star Rating Protocol	CMF values for different clear zone (CZ) widths: CZ < 1m: CMF=1,00 1m <= CZ < 5m: CMF=0,80 5m <= CZ < 10m: CMF=0,35 CZ >= 10m: CMF=0,10	*Values included in relevant iRAP factsheet, obtained from other previous studies and concern run-off-road crashes*

Source	CMF	Comments
	Risk factors associated with the presence of roadside objects: Safety barrier - wire rope: Risk factor=9 Safety barrier – metal: Risk factor=12 Safety barrier – concrete: Risk factor=15 Downwards slope: Risk factor=45 Upwards steep slope (>75º): Risk factor=40 Upwards slope (15 º to 75º): Risk factor=45 Deep drainage ditch: Risk factor=55 Cliff: Risk factor=90 Aggressive vertical face: Risk factor=55 Frangible structure or building: Risk factor=30 Tree (>=10cm diameter): Risk factor=60 Non-frangible sign/post/pole (≥10cm diameter): Risk factor=60 Non-frangible structure/bridge or building: Risk factor=60 Unprotected barrier end: Risk factor=60 None (or object >20m from road): Risk Factor=35	*Values included in relevant iRAP factsheet, obtained from other previous studies.* *The listed Risk factors are different from CMFs.*
Elvik et al. (2009)	0,58	*Meta-analysis of previous studies: Flatten sideslope from 1V:3H to 1V:4H*
Elvik et al. (2009)	0,78	*Meta-analysis of previous studies: Flatten sideslope from 1V:4H to 1V:6H*
Petegem & Wegman (2014)	0,49	*Rural roads (speed limit=80 km/h)* *Impact of installing side barriers on run-off-road crashes*
Elvik et al. (2009)	0,93	*Meta-analysis of previous studies: Installing side barriers*

Research conducted for the development of the Highway Safety Manual (AASHTO, 2010) suggests that wider clear zones, flatten slopes, as well as the presence of barriers help in reducing crash occurrence in rural roads. For **rural two-lane undivided roads**, the Roadside Hazard Rating (RHR) (Zegeer, 1987) is used for assigning roadside environment in one out of seven categories and then, for each category there is a CMF, as shown in Table B.19. The CMFs are estimated using the CMF function presented in the first row of Table B.18, however, it needs to be highlighted that the assessment of the roadside is qualitative. The HSM includes typical roadside views to guide practitioners in the rating of a roadside environment. The rating is subjective and so, the selected RHR value may differ between different assessors. The Highway Safety Manual advises that RHR for the same segment may vary up to 2 rating levels. An average RHR, or more accurately a weighted average RHR can be estimated, taking into account the section’s length. Overall, clear zone (CZ) width larger than 7,62m and slopes up to 1V:4H, i.e., RHR equal to 1 or 2, significantly reduce crash frequency.

Table B.19: *CMF values for the Roadside Hazard Rating (adopted from the Highway Safety Manual, Exhibit 13-32 (AASHTO,2010))*

RHR	Clear zone	Side slope	Roadside	CMF
1	CZ ≥ 9,14m	Flatter than 1V:4H; recoverable	N/A	0,878
2	6,10m ≤ CZ ≤ 7,62m	About 1V:4H; recoverable	N/A	0,942
3	CZ ~ 3,05m *also applicable for guardrail with offset >1,98m*	About 1V:3H or 1V:4H; marginally recoverable	Rough roadside surface	1,010
4	1,52m ≤ CZ < 3,05m *also applicable for guardrail with offset 1,52m to 1,98m*	About 1V:3H or 1V:4H; marginally forgiving, increased chance of reportable roadside crash	May have guardrail (offset 1,52 to 1,98m) May have exposed trees, poles, other objects (offset is about 3,05m)	1,083
5	1,52m ≤ CZ < 3,05m *also applicable for guardrail with offset <1,52m*	About 1V:3H; virtually non-recoverable	May have guardrail (offset up to 1,52m) May have rigid obstacles or embankment (offset 1,98m to 3,05m)	1,161
6	CZ ≤ 1,52m	About 1V:2H; non-recoverable	No guardrail Exposed rigid obstacles (offset up to 1,98m)	1,246
7	CZ ≤ 1,52m	1V:2H or steeper; non recoverable with high likelihood of severe injuries from roadside crash	No guardrail Cliff or vertical rock out	1,336

The iRAP Star Rating Protocol considers CMFs and Risk factors to model the interaction between clear zone width and the roadside objects. The same values are used for all segment types, i.e., motorways, urban and rural roads. Elvik et al. (2009) found that increasing clear zone width reduces all crash types while Hovey & Chowdhury observed a reduction in crash frequency when removing obstacles from the clear zone. Jurewicz & Pyta (2010) concluded that decreasing clear zone width from an initial value larger than 8m increases run-off-road crashes. The increase is positively related to the final clear zone width. Petegem & Wegman (2014) found that rural roads where obstacles are present up to 2m from the travel lanes experience more run-off-roads crashes compared to roads that obstacles are present at distance larger than 2m. Flattening the slopes of a road is a measure for reducing the negative impacts of run-off-road crashes. Elvik et al. (2009) found that all crashes are reduced when slopes are 1V:4H or flatter. Lastly, the presence of barriers is found effective in reducing crash frequency.

Among the existing literature, the one presented in the Highway Safety Manual (AASHTO, 2010) is considered the most solid and sound for the in-built safety assessment methodology for **undivided primary roads**. Firstly, compared to other existing studies, it provides CMF estimations considering the presence of multiple roadside conditions (e.g., clear zone width and barrier presence combined). Secondly, the HSM approach has been developed specifically for rural roads, in contrast to the iRAP one that is for all road types.

With regards to **divided primary roads** however, no comprehensive research/ literature on the safety impact of roadside characteristics has been identified. It can reasonably be assumed that the impact will be less prominent compared to undivided roads, as the roadside in divided roads affects crashes towards one direction of roadway departure (the other being towards the central median). In absence of more detailed knowledge, the RHR approach of the Highway Safety Manual is also applied for divided roads, with a reduction of 50% to the anticipated safety impact.

Considering also that a Roadside Hazard Rating of 3 is the base condition for the Highway Safety Manual (i.e., RHRs of 1 and 2 are exceptionally convenient/ safe layouts), the rating of 3 is considered as the basic characteristic of the "safe road. Therefore, unlike other parameters of the NWA assessment, no normalization of the Highway Safety Manual CMFs for adjusting to the most safe condition is required.

Based on the above, the CMFs and respective **Reduction Factors** for the in-built safety assessment methodology for primary roads are defined as follows (see also indicative values in Table B.20):

For **primary undivided roads**, the CMF function from the Highway Safety Manual is used, considering the average Roadside Hazard Rating (RHR) for both sides of each examined segment. CMFs lower than one are converted to one:

$$CMF = \max\left\{1{,}00, \qquad \frac{e^{(-0{,}6869+0{,}0668\times RHR)}}{e^{-0{,}4865}}\right\}$$

and the respective Reduction Factor is estimated as:

$$RF = \frac{1}{CMF} = \min\left\{1{,}00, \qquad \frac{e^{-0{,}4865}}{e^{(-0{,}6869+0{,}0668\times RHR)}}\right\}$$

For **primary divided roads**, the safety impact of roadside (as estimated for undivided roads using the above equation), i.e., the difference of the estimated Reduction Factor from 1,00 ("ideally safe road"), is reduced by 50%, as follows:

$$RF = \min\left\{1{,}00, \qquad 1{,}00 - \ 0{,}50 * [1{,}00 - \min(1{,}00, \qquad \frac{e^{-0{,}4865}}{e^{(-0{,}6869+0{,}0668\times RHR)}})]\right\}$$

It is noted that for divided roads the assessment and therefore also the Roadside Hazard Rating and respective RF estimation, is performed separately for each direction of travel. In Table B.20, the estimated Reduction Factor values for different values of the Roadside Hazard Rating are presented, separately for undivided and divided primary roads.

Table B.20: *CMFs and Reduction Factors (RF) for roadside environment in undivided and divided primary roads.*

Roadside Hazard Rating	CMF value for undivided roads (based on HSM)	NWA Reduction Factor for undivided roads	NWA Reduction Factor for divided roads
1	0,875	1,000	1,000
2	0,935	1,000	1,000
3	1,000	1,000	1,000
4	1,069	0,935	0,968
5	1,143	0,875	0,937
6	1,222	0,818	0,909
7	1,306	0,766	0,883

If the examined segment has a varying roadside environment, then a weighted average Roadside Hazard Rating needs to be estimated, using the sub-section lengths as weights. This average RHR will be used in the aforementioned equations.

Following the initial results and feedback from the pilot implementation of the methodology, the potential impact of **sidewalk curbs** (e.g., on primary road bridges) to the roadside parameter and ultimately to the proactive assessment score was also examined. It is recognized that the installation of curbs instead of flush shoulders (i.e., at the same level with the pavement) appears to increase crashes of all types and severities (AASHTO, 2010). On the other hand, existing research has not yet established the magnitude of the effect in crashes. Specifically:

- In the AASHTO Highway Safety Manual (AASHTO, 2010) the trend is recognized but the uncertain magnitude of the effect is mentioned (section 13A.3.2.3) and no CMF is proposed.
- In the iRAP methodology, the presence of sidewalk curbs is not considered for roadside risk factors.
- In the FHWA CMF Clearinghouse, a single study (Lienau, 1996) is mentioned for CMF of barrier curb on the road edge; however the study refers to suburban multilane highways, it has been rated as low quality (1 out of 5 stars), and most importantly the range of estimated CMFs is large (from 0,64 to 3,57) and with large standard error in the statistical analysis. As a result, the estimated CMFs are considered unreliable.

Taking all the above into consideration, while also considering that sidewalks are uncommon in rural primary roads and are found mostly in tunnels (i.e., outside the scope of the present methodology) and on bridges (i.e., limited length compared to the entire network) **the presence of sidewalk curbs is not taken into consideration**. A roadside consisting of a flush shoulder and one also including a curb are therefore receiving the same Reduction Factor, if all other roadside elements are identical).

B.2.9 Primary roads: Curvature

Similar to motorways, in rural roads curves with small radii are also associated with high crash numbers. The effect is in fact more pronounced in rural roads, as radii tend to be smaller. Estimation of CMFs for curvature in rural roads are presented in Table B.21 that follows.

Table B.21: *CMFs for curvature in rural roads, according to existing literature*

Source	CMF value / function	Comments
Highway Safety Manual (AASHTO, 2010) *for two-lane rural roads*	$$CMF_{3r} = \frac{(1.55 \times L_c) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_c)}$$ where: Lc=length of curve (miles) including spiral transitions (minimum (100ft) R=radius (ft) (minimum 100ft) S=presence of spiral (1 on both ends, 0,5 on one end, 0 if no spiral is present	
iRAP Star Rating Protocol *for all road types*	Straight/gentle curve (R>900m): 1,00 Moderate curve (R=500m-900m): 1,80 Sharp curve (R=200m-500m): 3,50 Very sharp curve (R<200m): 6,00	*CMFs for run-off-road and head-on crashes*
Elvik et al. (2009) *for all road types*	R1<200m to R2=200-400m 0,50 R1=200-400m to R2=400-600m to 0,67 R1=400-600m to R2=600-1000m to 0,77 R1=600-1000m to R2=1000-2000m 0,82 R1=1000-2000m to R2>2000m 0,88 R1>2000 to greater 1,00 R1>1000 to straight road 1,10	*Meta-analysis of previous studies for converting curves from R=R1 to R=R2*
Elvik (2013)	CMF = 127,1685*$R^{-0.7099}$ where: R=radius (m)	*CMF compared to curve with radius of 1000m, derived from meta-analysis of 8 previous studies*
Gooch et al. (2018)	CMF=$e^{0,053*HC+0,054*DC}$ where: HC=presence of curve (1 if present, 0 if not) DC=degree of curvature (deg/100ft)	
Fitzpatrick et al. (2010)	CMF=$e^{0,0831(DC)}$ where: DC=degree of curvature =1747/R (R in m)	*Derived from rural two lane highways in Texas*
Pratt et al. (2014)	$$CMF_R = 1 + 1.0077(0.147V)^4 \frac{(1.47V)^2}{32.2R^2}$$	*Rural 4-lane roads, undivided - all severity levels*
	$$CMF_R = 1 + 0.5796(0.147V)^4 \frac{(1.47V)^2}{32.2R^2}$$ where: V=speed limit (mph) (min35mph, max 75mph) R=curve radius (ft)	*Rural 2-lane roads, undivided - all severity levels*
Banihashemi (2015)	$$CMF_{HC} = \begin{cases} 1 & \text{Tangent Segments} \\ Max\left(1, \frac{197.6}{R^{0.688}}\right) & \text{Curve Segments} \end{cases}$$ where: R=curve radius (ft)	*Rural multilane roads - all severity levels*

Source	CMF value / function	Comments
Fitzpatrick et al. (2010)	$\frac{e^{0.1837*\frac{V^2}{Y}*}}{e^{0.1837*\frac{V^2}{X}}}$ where: V = speed limit (mph) (minimum: 55mph) X, Y = existing and proposed curve radius (ft)	*Derived from roads in Texas*
Donell et al. (2019)	$CMF = \frac{e^{\left[\left(\frac{405.32}{R_{proposed}}\right) - 0.496 * NC_{proposed} + \left(\frac{512.07 * NC_{proposed}}{R_{proposed}}\right)\right]}}{e^{\left[\left(\frac{405.32}{R_{existing}}\right) - 0.496 * NC_{existing} + \left(\frac{512.07 * NC_{existing}}{R_{existing}}\right)\right]}}$ $R_{proposed}$ = proposed horizontal curve radius (ft) $NC_{proposed}$= proposed indicator for normal crown (=1 if normal crown; 0 if superelevated) $R_{existing}$ = existing horizontal curve radius (ft) $NC_{existing}$ = existing indicator for normal crown (=1 if normal crown; 0 if superelevated)	*Rural 2-lane roads - fatal & injury crashes*

The comparison of available curvature CMFs applicable in rural roads is presented in Table B.22 and Figure B.5 below for typical values of curve radius. Although the trend is similar in all studies and models, there are considerable differences on the CMF values, especially at smaller radii.

With regards to potential application in the NWA methodology, the following are noted:

- Unlike the motorways model, the CMFunction of the Highway Safety Manual is cumbersome to apply on long road sections, combining tangents and several curves of different radii. A separate CMF must be estimated for each curve and these need to be combined in order to obtain an overall estimate of the effect of curvature on road safety.
- The meta-analysis performed by Elvik (2013) provides a simple, straightforward approach to estimate the overall effect of curvature on crashes, and has a more universal application as it is based on studies from several countries: Canada, Germany, UK, New Zealand, Norway, Portugal, Sweden and USA.
- The approach of Pratt et al. (2014) and of Fitzpatrick et al. (2010) is interesting as it examines the effect of curvature in conjunction to the speed limit. This combination is considered very appropriate for assessment purposes, as it is obvious that a specific curve on a road with higher speeds is more hazardous compared to the same curve on a lower speed road. On the other hand, compliance to speed limits is overall greater in the US than in many EU countries (depending on speed enforcement), and this should be considered in the model.

Table B.22: *Comparison of CMFs for curvature in primary roads*

CMF estimate for primary roads compared to tangent or R>2.000

R (m)	R (ft)	HSM (AASHTO, 2010)	iRAP	Elvik et al. (2009)	Elvik (2013)	Gooch et al. (2018)	Fitzpatrick et al. (2010)	Pratt et al. (2014) V=55mph	Pratt et al. (2014) V=35mph	Fitzpatrick et al. (2010) V=55mph	Banihashemi (2015)	Donell et al. (2019)
2000	6.561,68	1,001	1,000	1,000	1,000	1,105	1,075	1,016	1,001	1,000	1,000	0,940
1500	4.921,26	1,018	1,000	1,136	1,000	1,123	1,102	1,028	1,002	1,000	1,000	0,960
1000	3.280,84	1,054	1,000	1,136	1,000	1,159	1,156	1,064	1,004	1,000	1,175	1,000
900	2.952,76	1,065	1,800	1,386	1,017	1,171	1,175	1,079	1,005	1,019	1,256	1,014
800	2.624,67	1,080	1,800	1,386	1,105	1,186	1,199	1,100	1,007	1,043	1,354	1,031
700	2.296,59	1,099	1,800	1,386	1,215	1,207	1,230	1,131	1,009	1,075	1,473	1,054
600	1.968,50	1,124	1,800	1,386	1,356	1,234	1,274	1,178	1,012	1,120	1,624	1,086
500	1.640,42	1,159	3,500	1,800	1,543	1,273	1,337	1,256	1,017	1,185	1,823	1,131
400	1.312,34	1,211	3,500	1,800	1,808	1,335	1,438	1,400	1,027	1,289	2,099	1,204
350	1.148,29	1,249	3,500	2,686	1,988	1,381	1,514	1,522	1,035	1,370	2,284	1,258
300	984,25	1,299	3,500	2,686	2,218	1,444	1,622	1,711	1,047	1,485	2,519	1,334
250	820,21	1,369	3,500	2,686	2,524	1,538	1,787	2,023	1,068	1,662	2,827	1,449
200	656,17	1,474	6,000	2,686	2,957	1,690	2,067	2,599	1,106	1,969	3,255	1,639
150	492,13	1,649	6,000	5,372	3,627	1,978	2,632	3,843	1,189	2,611	3,906	2,014
100	328,08	2,000	6,000	5,372	4,837	2,708	4,271	7,396	1,425	4,592	5,049	3,040
75	246,06	2,350	6,000	5,372	5,933	3,709	6,929	12,370	1,755	8,077	6,057	4,589
50	164,04	3,051	6,000	5,372		6,957					7,829	
Comments	*1ft = 0,3048m*	*with superelavation, assuming Lc=0,15miles*	*for run-off-road and head-on crashes*	*all accidents*				*average for four and two lane roads - speed limit 55mph*	*average for four and two lane roads - speed limit 35mph*			*with superelavation, compared to R=1000m*

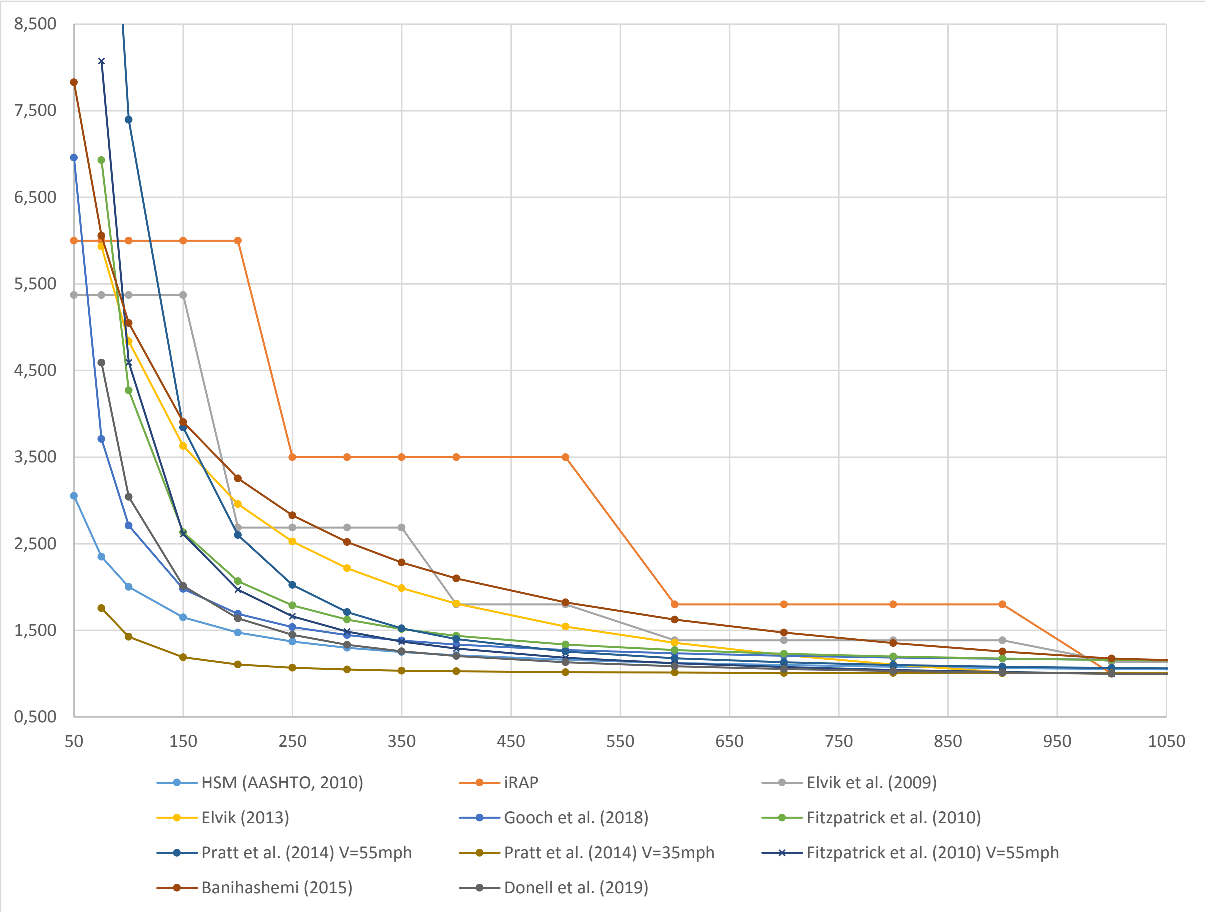


Figure B.5: *Comparison of CMFs for curvature in rural roads*

Based on the above, the CMFs and respective **Reduction Factors** for the in-built safety assessment methodology for primary roads are:

- for segments with tangents and curves with R≥1000m: CMF=1,00 => **RF=1,00**
- if at least one curve with R<1000m exists in the segment:

  Average 2-lane and 4-lane CMFunction from Pratt et al. (2014), converted from feet to meters and from mph to km/h:

$$CMF = 1{,}00 + 0{,}7937 \times (0{,}147\, V/1{,}6093)^4 \times \frac{(1{,}47\, V/1{,}6093)^2}{32{,}2 \times (R/0{,}3048)^2}$$

and finally:

$$CMF = 1{,}00 + 0{,}7937 \times (0{,}09134\, V)^4 \times \frac{(0{,}9134\, V)^2}{32{,}2 \times (R/0{,}3048)^2}$$

where: R (m) = 1,5 x radius of the **sharpest curve** within the segment
V (km/h)= <speed limit>, if automated speed enforcement is present,
<speed limit + 20km/h> if automated speed enforcement is not present
or
<operation speed V_{85}) if data is available

and the respective RF = 1/CMF =>

$$\text{RF} = {}^{1}\Big/_{1{,}00 + 0{,}7937 \times (0{,}09134\,V)^4 \times \frac{(0{,}9134\,V)^2}{32{,}2 \times (R/0{,}3048)^2}}$$

B.2.10 Primary roads: Density of property access points

Property access points refer to sites where access is provided from a public road to a private property, also known as "driveways" in the U.S. Overall, roads with high density of property access points (no. of access points per km) exhibit higher crash rates. The Highway Safety Manual (AASHTO, 2010), the iRAP Star Rating Protocol as well as several stand-alone studies have developed CMFs to quantify the impact of the density of property access points on crash frequency in rural roads. The following table summarizes the available CMFs that are relevant to high volume rural roads (Table B.23):

Table B.23: *CMFs for density of property access points in primary roads, according to the existing literature*

Source	CMF	Comment
Highway Safety Manual (AASHTO, 2010)	$CMF = \frac{0.322 + DD \times (0{,}05 - 0{,}005 \times ln(AADT))}{0.322 + 5 \times (0{,}05 - 0{,}005 \times ln(AADT))}$ Where: DD: access point density measured in driveways per mile (1 mile = 1,60934) AADT: average annual daily traffic measured in vehicles per day	*CMF for rural two-lane roads developed based on U.S. data.*
Fitzpatrick et al. (2008)	(i) $CMF = exp(0{,}0232 \times (DD - 3))$ (ii) $CMF = exp(0{,}0206 \times (DD - 3))$	*CMFs for rural two-lane roads developed based on Texas (U.S.) data:* *(i) All ADT ranges* *(ii) ADT > 2000 veh/day* *Where ADT: Average Daily Traffic*
Cafiso et al. (2010)	$CMF = exp(0{,}0646 \times DD)$ $CMF = exp(0{,}0670 \times DD)$ DD: access point density measured in driveways per mile (1 mile = 1,60934)	*CMFs for rural two-lane roads developed based on Italy data.*
iRAP Star Rating Protocol	Per 100m No access points: CMF=1,0 Commercial access 1 or more points: CMF=2,0 Residential access 1 or 2 points: CMF=1,1 Residential access 3 or more points: CMF=1,3	*CMFs based on existing literature for urban and rural roads.*

In Table B.24 and the graph of Figure B.6 the above CMFs as a function of the number of property access points per kilometer are comparatively presented. The values used for the graph can be seen in Table B.24. As the estimated CMFs from the aforementioned studies may results in values lower than one (i.e., have a positive safety effect), they have been normalized so that all have as base scenario (CMF=1,00) the absence of property access points. For this conversion, all initially estimated CMF values were divided by the minimum CMF (from the same function). The HSM manual is the only resource that includes traffic volume as one of the variables and so, the provided CMF formula was originally estimated assuming different AADT values. However, after the normalization process the resulting CMF is not dependent on the AADT.

With regards to the estimation of iRAP values for Table B.24, it was assumed that the property access points are equally divided between commercial and residential driveways, and that these are uniformly distributed throughout a 1km length segment. The individual iRAP risk factors for each 100m sub-segment were estimated and the average risk factor value was included in the table. In order to avoid double consideration of some studies, only original studies are included in the averaging process, i.e., iRAP values are not included in the last column of Table B.24.

Table B.24: *Comparison of CMFs for property access point density in rural roads*

Points/ mile	Points/ km	iRAP	Fitzpatrick et al. (2008) Model1	Fitzpatrick et al. (2008) Model2	Cafiso et al. (2010) Model1	Cafiso et al. (2010) Model2	HSM (2010)	Average CMF *(excluding iRAP)*
0,000	0	1,000	1,000	1,000	1,000	1,000	1,000	1,000
1,609	1	1,010	1,038	1,034	1,067	1,069	1,020	1,045
3,219	2	1,110	1,077	1,069	1,138	1,143	1,039	1,093
4,828	3	1,120	1,118	1,105	1,214	1,223	1,059	1,144
6,437	4	1,220	1,161	1,142	1,295	1,307	1,079	1,197
8,047	5	1,230	1,205	1,180	1,381	1,398	1,099	1,253
9,656	6	1,330	1,251	1,220	1,473	1,495	1,118	1,312
11,265	7	1,340	1,299	1,261	1,572	1,598	1,138	1,374
12,875	8	1,440	1,348	1,304	1,677	1,709	1,158	1,439
14,484	9	1,450	1,399	1,348	1,789	1,828	1,178	1,508
16,093	10	1,550	1,453	1,393	1,908	1,954	1,197	1,581
17,703	11	1,550	1,508	1,440	2,035	2,090	1,217	1,658
19,312	12	1,640	1,565	1,489	2,171	2,234	1,237	1,739
20,921	13	1,640	1,625	1,539	2,316	2,389	1,257	1,825
22,531	14	1,730	1,687	1,591	2,470	2,555	1,276	1,916
24,140	15	1,730	1,751	1,644	2,635	2,732	1,296	2,012
25,750	16	1,820	1,817	1,700	2,811	2,921	1,316	2,113
27,359	17	1,820	1,886	1,757	2,999	3,124	1,335	2,220
28,968	18	1,910	1,958	1,816	3,199	3,340	1,355	2,334
30,578	19	1,910	2,033	1,877	3,412	3,572	1,375	2,454
32,187	20	2,000	2,110	1,941	3,640	3,819	1,395	2,581
33,796	21	2,000	2,190	2,006	3,883	4,084	1,414	2,715
35,406	22	2,000	2,274	2,074	4,142	4,367	1,434	2,858
37,015	23	2,000	2,360	2,144	4,418	4,669	1,454	3,009
38,624	24	2,000	2,450	2,216	4,713	4,993	1,474	3,169
40,234	25	2,000	2,543	2,291	5,028	5,339	1,493	3,339
41,843	26	2,000	2,640	2,368	5,363	5,709	1,513	3,519
43,452	27	2,000	2,740	2,448	5,721	6,104	1,533	3,709
45,062	28	2,000	2,845	2,530	6,103	6,527	1,553	3,912
46,671	29	2,000	2,953	2,615	6,510	6,980	1,572	4,126
48,280	30	2,000	3,065	2,704	6,945	7,463	1,592	4,354

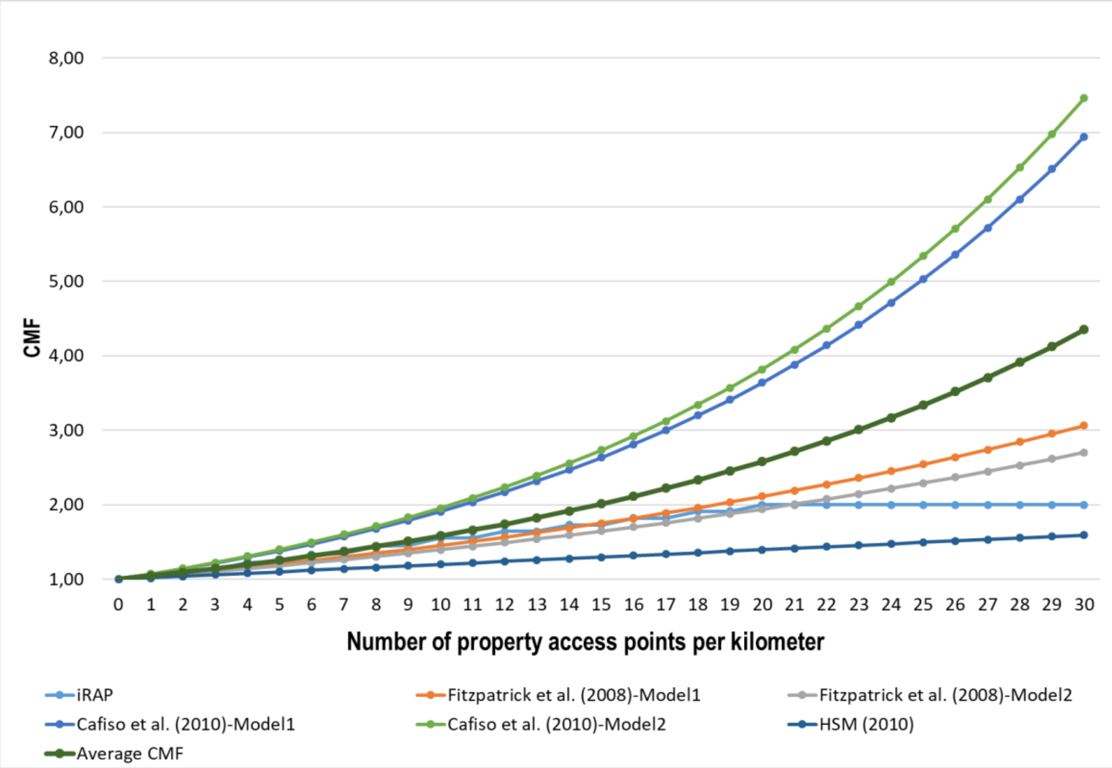


Figure B.6: *Comparison of CMFs for property access point density in rural roads*

Based on the above, it is decided that the **CMFs and Reduction Factors for the density of property access points on primary roads** are based on the average values of the above studies (last column of Table B.24). Furthermore, in order to better reflect the two most generalizable models, i.e., the iRAP approach (with a maximum CMF of 2,00), as well as the HSM predictive method, with lower CMFs, especially for high number of access points per km, a maximum CMF equal to 2,00 is set.

The final CMFs and Reduction Factors for the NWA methodology are presented in Table B.25 below.

Table B.25: *CMFs and Reduction Factors (RF) for property access points density in primary roads*

Density of property access points (Points per km)	Average CMF	Reduction Factor
0	1,000	1,000
1	1,045	0,957
2	1,093	0,915
3	1,144	0,874
4	1,197	0,835
5	1,253	0,798
6	1,312	0,762
7	1,374	0,728
8	1,439	0,695
9	1,508	0,663
10	1,581	0,633
11	1,658	0,603
12	1,739	0,575
13	1,825	0,548
14	1,916	0,522
15 or more	2,000	0,500

It is finally noted that in case of undivided primary roads, the number of access points per km is measured on both sides of the road, whereas for divided primary roads it is measured separately on each side of the road, as the assessment is performed separately for each direction of travel. In that sense, the parameter "density of access points" considered as treated differently for divided and undivided primary roads.

B.2.11 Primary roads: Junctions

Junctions in primary rural roads may be either level separated (interchanges) as in motorways, or at-grade (level) intersections of various types. Research findings indicate that level separated junctions are safer, as the crossing directions of travel are physically separated. At-grade intersections on the other hand tend to exhibit higher number of crashes compared to other parts of the road network, and this can be partially attributed to the large number of conflict points between vehicles and between vehicles and pedestrians / bicyclists. Three basic types of at-grade junctions with regards to their layout are usually considered in existing safety related research: four-leg-, three-leg, and roundabouts. Four-leg junctions have 32 conflicts points more than three times higher compared to three-leg junctions (9 points) and both have more conflict points compared to roundabouts. Therefore, roundabouts are generally expected to be safer compared to three- and four-leg junctions, however, other impacts such as the control type and the presence of channelization and turning-lanes impact the safety performance of the three- and four-leg junctions.

Available literature on the type and layout of junctions mostly focuses on the four following aspects:

1. Visibility and sight conditions
2. Control type (e.g., signals, STOP or yielding signs)
3. Geometric layout (e.g., 4-leg intersection, roundabout)
4. Presence of channelization

5. Presence of turning lanes
6. Cross-section characteristics (e.g., lane width)

According to Elvik et al. (2009) improvement in junction's visibility does not result in statistically significant reduction of injury and fatal crashes, possibly because users are already cautious in poor-visibility junctions. On the other hand, other research (FHWA, 2000) has identified significant impact of intersection sight distance restrictions, with suggested CMFs for intersections with STOP control on the minor leg(s) at 1,05 if sight distance is limited in one quadrant of the intersection, 1,10 if sight distance is limited in two quadrants of the intersection, 1,15 if sight distance is limited in three quadrants of the intersection and 1,20 if sight distance is limited in four quadrants of the intersection. Considering however that visibility assessment requires very detailed on-site inspections and measurements that cannot be practically applied within the scope of a network-wide methodology, intersection visibility is not further investigated. The same also applies for cross-section characteristics; Table B.26 summarizes research findings and available CMFs on control type, geometric layout, presence of channelization and turning lanes at junctions.

Table B.26: *CMFs for type and layout of junctions in primary roads, according to the existing literature*

Source	CMF	Comment
Grade-separated junctions		
Elvik et al. (2009)	Convert 3-leg at-grade intersection to grade-separated: CMF=0,76 Convert 4-leg at-grade intersection to grade-separated: CMF= CMF=0,43 Convert at-grade intersection to grade-separated: CMF= CMF=0,85	*Meta-analysis of existing studies.*
Wallis et al. (2018)	Convert at-grade intersections to Diverging Diamond Interchanges: CMF=0,42	*All crash types.*
Zlatkovic et al. (2015)	Convert at-grade intersections to Diverging Diamond Interchanges: CMF=0,76	*All crash types.*

Source	CMF	Comment
At-grade junctions		
Highway Safety Manual (AASHTO, 2010)	SPF for 3-leg intersections: $N = epx\left(-9{,}86 + 0{,}79 \times \ln(AADT_{MAJOR}) + 0{,}49 \times ln(AADT_{MINOR})\right)$ SPF for 4-leg intersections: $N = epx\left(-8{,}56 + 0{,}60 \times \ln(AADT_{MAJOR}) + 0{,}61 \times ln(AADT_{MINOR})\right)$ SPF for 4-leg signalized intersections: $N = epx\left(-5{,}13 + 0{,}60 \times \ln(AADT_{MAJOR}) + 0{,}20 \times ln(AADT_{MINOR})\right)$ Where: $AADT_{MAJOR}$ = AADT for the major road $AADT_{MINOR}$ = AADT for the minor road	*SPFs developed for junctions in rural roads.*
	Convert a signalized intersection to roundabout: CMF=0,220 Convert STOP-controlled intersection to roundabout: CMF=0,130 Convert STOP-controlled intersection to signalized: CMF=0,560 Left-lane presence: 3-leg intersection: CMF=0.85 4-leg intersection: CMF=0.82 Channelized left-turn presence: 3-leg intersection: CMF=0.91 4-leg intersection: CMF=0.73 Right-lane presence: Signalized intersection: CMF=0.77 STOP-controlled intersection: CMF=0.91	*CMFs developed for junctions in rural road. The CMFs are intended to be used with the above SPFs.*
Elvik et al., 2009	Convert any intersection to roundabout: CMF=0,310 Convert 3-leg intersection to roundabout: CMF=0,92 Convert 4-leg intersection to roundabout: CMF=0,66 Convert signalized intersection to roundabout: CMF=0,86 Convert unsignalized intersection to roundabout: CMF=0,60	*Fatal and injury crashes. Results based on meta-analysis of existing studies.*

Source	CMF	Comment
iRAP Star Rating Protocol	Junction type and Risk Factor - Roundabout: 15 - 3-leg unsignalized with protected turn lane: 13 - 3-leg unsignalized without protected turn lane: 16 - 3-leg signalized with protected turn lane: 9 - 3-leg signalized without protected turn lane: 12 - 4-leg unsignalized with protected turn lane: 16 - 4-leg unsignalized without protected turn lane: 23 - 4-leg signalized with protected turn lane: 10 - 4-leg signalized without protected turn lane: 15	*Risk factor corresponds to the likelihood of a crash. The adopted scale (9-23) has been adjusted to the Star Rating formula and the values are based on existing studies.*
	Junction type and Severity Score - Roundabout: 15 - 3-leg unsignalized with protected turn lane: 45 - 3-leg unsignalized without protected turn lane: 45 - 3-leg signalized with protected turn lane: 45 - 3-leg signalized without protected turn lane: 45 - 4-leg unsignalized with protected turn lane: 50 - 4-leg unsignalized without protected turn lane: 50 - 4-leg signalized with protected turn lane: 50 - 4-leg signalized without protected turn lane: 50	*Severity score indicates the injury severity level in the case of a crash. The adopted scale (15-50) has been adjusted to the Star Rating formula and the values are based on existing studies.*
Brabander et al., 2005	Convert intersection to roundabout CMF=0,660 CMF=0,610 CMF=0,580	*Fatal and injury crashes* *Major/minor road: Speed limit=50-90km/h* *Major/minor road: Speed limit=50km/h* *Major/minor road: Speed limit=70km/h*

Based on the research results summarized in Table B.26, the following observations can be drawn:

- Grade-separated junctions are safer compared to at-grade intersections. It is however noted that the iRAP Star Rating Protocol does not consider CMFs for grade-separated junctions.
- Regarding the at-grade junction types, the majority of available studies concluded that roundabouts are the safest junction type. Converting any intersection type to a roundabout usually results in a reduction in crash frequency. The iRAP methodology is also in line with this trend, and this is reflected in the Risk Factors and Severity Scores, with roundabouts having the lowest score.
- When not accounting for the number of legs, signalized intersections outperform unsignalized ones. Considering the Highway Safety Manual CMFs as well as the iRAP Risk Factors, the presence of channelization and turning lanes improve intersection safety.
- Regarding the number of legs, it is reasonable to consider three-leg intersections safer than four-leg ones, based on the number of conflict points at each case.

Considering the above research results, an **assessment approach based jointly on iRAP and on Elvik et al (2009) is formulated**; CMFs for basic intersection types are derived from Elvik et al, whereas the differences between signalized/ unsignalized as well as the presence of turn lanes are estimated based on iRAP risk factors. Specifically, the following assumptions and adjustments are considered:

- If the examined section has **no junctions, grade-separated junctions** or **roundabouts**, no reduction factor is applied (RF=1,00). Although there is a higher number of conflicts and increased collision risk in roundabouts compared to grade-separated junctions or no junctions, it has been assumed this is counterbalanced by the safety benefits originating from the overall reduction in vehicle speeds imposed by the presence of roundabouts.
- For **3-leg** and **4-leg intersections**, the average crash reductions estimated by Elvik et al (2009) are utilized:
  - Convert 3-leg intersection to roundabout: CMF=0,92
  - Convert 4-leg intersection to roundabout: CMF=0,66

  After normalization for roundabout as the base scenario (CMF=1,00), the respective CMFs are estimated at CMF=1,087 for 3-leg and CMF=1,515 for 4-leg intersections as an average.
- This estimation is further detailed for the **presence of signalization and of turn lanes** based on the iRAP risk factor estimations.
  Considering an average iRAP risk factor for all four cases for 3-leg intersections of (13+16+9+12)/4 = 12,5 (see also Table B.27), and assuming that this is relevant to the average CMF=1,087, one can assume that the 3-leg unsignalized with protected turn lane will exhibit a CMF of 13/12,5 x 1,087 = 1,130 and so on. In case of estimated CMFs less than 1,00 (base value), the CMF for this category was assumed as 1,00.
- The resulting, more detailed CMFs and Reduction Factors are presented in the following Table.

Table B.27: *NWA CMFs and Reduction Factors for the different junction types*

Junction type	Average CMF *(Elvik et al, 2009)*	iRAP Risk Factor	NWA CMF	NWA RF
No junction			1,000	1,000
Grade-separated			1,000	1,000
Roundabout	1,000		1,000	1,000
3-leg signalized with turn lane	1,087	9	1,000	1,000
3-leg signalized without turn lane		12	1,044	0,958
3-leg unsignalized with turn lane		13	1,130	0,885
3-leg unsignalized without turn lane		16	1,391	0,719
4-leg signalized with turn lane	1,515	10	1,000	1,000
4-leg signalized without turn lane		15	1,420	0,704
4-leg unsignalized with turn lane		16	1,515	0,660
4-leg unsignalized without turn lane		23	2,178	0,459

The above Crash Modification Factors are relevant only for the part of the road within each junction; in order to estimate the **average Crash Modification Factor** across all the examined segment, a weighted average CMF needs to be estimated based on the length of each element.

For example, on a section 3km long, with a 0,5km 4-leg unsignalized with turn lane intersection and a 0,2km roundabout, the resulting average Reduction Factor would be:

CMF_{final} = [0,5 x 1,515 + 0,2 x 1,000 + (3-0,5-0,2) x 1,000] / 3 =>

CMF_{final} =1,219

The final Reduction Factor will be: RF_{final} = 1/1,219 = 0,820 .

With regards to the considered length for junctions, if detailed data are available for their actual length, they should be used. Otherwise, the predetermined default lengths for junctions, as defined for the application of the reactive, crash-based methodology can be used instead.

B.2.12 Primary roads: Conflicts between pedestrians/ bicyclists and motorized traffic

The main function of primary rural roads is to connect cities or other major traffic generators, predominantly at high speeds. As such, pedestrian and bicyclists presence either along the road, on the carriageway and shoulders without adequate separation / protection, or crossing the road in unprotected facilities is an obvious cause of serious road safety concerns.

Unlike motorways, CARE crash statistics cannot provide a fully comprehensive image of actual situation, as primary roads have not yet been defined by Member States and related crashes cannot be reliably isolated. Nevertheless, an indicative trend can be estimated by observing CARE data for all EU rural roads excluding motorways from 2015 to 2019. Overall, 35732 crashes with pedestrians and 101214 crashes with bicyclists were recorded, representing 3,1% and 8,8% respectively of all crashes on EU rural non-motorway roads.

Most pedestrian injuries (of whatever severity) are sustained in urban areas. In European countries, 73% of all pedestrian fatalities occur in urban areas where also most pedestrian traffic takes place. However, in rural areas, crash severity is higher (OECD, 2010). Higher vehicle speed in such areas is a key factor. Other contributing factors are the absence of pedestrian footpaths and street lighting (ECMT, 2000). Regarding cyclists, it is found that most cycling injuries does also occur in urban areas; around 80% of fatal or serious cyclist crashes occur in urban areas (Elvik, 2009). However, around half of cyclist fatalities occur on rural roads.

Based on the above, although most injuries to pedestrians and bicyclists occur in urban areas, crash severity is found to be higher in rural areas, highlighting the importance of incorporating a distinct variable in the proactive assessment methodology to help identify those parts of the rural network that exhibit such problems and prioritize detailed road safety inspections and remedial treatment. This approach is in line with the provisions of Directive 2008/96/EC (Article 6.b: Protection of vulnerable road users) and aims to account for the very high severity of such crashes, usually resulting in fatalities due to the high vehicle speeds and the vulnerability of pedestrians and bicyclists.

Unfortunately, existing literature does not include reliable indications regarding the safety impact of pedestrian and bicycle related features of rural roads, at a macroscopic level. The vast majority of related studies examines urban roads and streets and focuses on the safety impact of specific detailed features, e.g., the presence of refuges on crossings, of signalization or signage (e.g., pelican vs. puffin crossing), or of pedestrian fencing. These features are either not applicable to rural primary roads or are too detailed to examine at a network-wide level. Similar difficulties are also encountered for bicycle facilities, and obstacles are faced by other, even more detailed approaches: in CycleRAP documentation for example it is mentioned that "*more robust research would be required to provide the conclusive evidence necessary to substantiate the risk factors in the CycleRAP model*".

The only available methodology that seems to partially tackle the potential safety impact of pedestrian and bicycle related facilities is iRAP, with a selection of risk factors identified in the fact sheets "*Facilities for Bicycles*", "*Pedestrian Crossing Facilities*", "*Pedestrian Crossing Quality*" and "*Pedestrian Fencing*". Although the relevant original literature sources and the methodology to derive those risk factors is not clearly presented in the iRAP fact sheets, they seem to be the only feasible input for estimating a network-wide applicable Crash Modification Factor and subsequently Reduction Factor.

It is therefore suggested to estimate, based on iRAP risk factors, one network-wide applicable CMF for pedestrians one for bicyclists, and combine them in a single Crash Modification Factor and subsequently Reduction Factor for pedestrian/ bicyclists using weights derived from the respective crash numbers from CARE database (3,1% and 8,8% respectively of all crashes on EU rural non-motorway roads). Regarding pedestrians, the focus is placed equally on crossing facilities and pathways along the road, whereas regarding cyclists, the focus is mostly on facilities along the road, considering that safe crossing facilities for pedestrians can also be used by cyclists. Specifically, the iRAP Risk factors considered relevant for primary rural roads, as well as their transformation to NWA Reduction Factors are presented in Table B.28 that follows.

Values in the Table also incorporate feedback from EGRIS, which indicated that level pedestrian crossings are acceptable on roads with a speed limit of 70km/h or less, as experience shows that even “protected” crossings are unsafe at higher speeds. Therefore, there is a differentiation on CMF scoring according to the speed limit, with the impact for lower speed roads slightly reduced, as shown in Table B.28.

Table B.28: *iRAP risk factors and Reduction Factors for pedestrian- and bicyclist-related features*

Feature	iRAP Risk Factor	NWA CMF	NWA RF
Pedestrians - crossing			
No pedestrian traffic	-	1,000	1,000
Grade separated facility *(used as CMF estimation basis)*	0,40	1,000	1,000
Signalized crossing with refuge - *speed limit > 70km/h*	1,00	2,500	0,400
Signalized crossing without refuge - *speed limit > 70km/h*	1,25	3,100	0,323
Unsignalized marked crossing with refuge - *speed limit > 70km/h*	3,80	9,500	0,105
Unsignalized marked crossing without refuge - *speed limit > 70km/h*	4,80	12,000	0,083
No facility for pedestrians crossing- *speed limit > 70km/h*	6,70	16,750	0,060
Signalized crossing with refuge - *speed limit ≤ 70km/h*	1,00	2,000	0,500
Signalized crossing without refuge - *speed limit ≤ 70km/h*	1,25	2,500	0,400

Feature	iRAP Risk Factor	NWA CMF	NWA RF
Unsignalized marked crossing with refuge - *speed limit ≤ 70km/h*	3,80	8,000	0,125
Unsignalized marked crossing without refuge - *speed limit ≤ 70km/h*	4,80	10,000	0,100
No facility for pedestrians crossing- *speed limit ≤ 70km/h*	6,70	12,000	0,083
Pedestrians - along			
No pedestrian traffic	-	1,000	1,000
Segregated - protected pedestrian path (e.g. on shoulder, behind safety barriers)	0,00	1,000	1,000
No facility for pedestrians walking along	1,25	20,000	0,050
Bicyclists - along			
No bicycle traffic	-	1,000	1,000
Segregated bicyclist path *(used as CMF estimation basis)*	1	1,000	1,000
Dedicated bicyclist lane on roadway	12	12,000	0,083
Wide paved shoulder (width > 1m)	17	17,000	0,059
No facility for bicyclists	20	20,000	0,050

Since CMFs for pedestrian/ bicycle crossings are mostly derived from iRAP methodology that assumes 100m increments for scoring, they are relevant only for part of the examined segment that is 100m in length, at the crossing location. In order to estimate the average pedestrian crossing CMF across all the examined segment, a weighted average of CMFs needs to be estimated based on the length of each element. With regards to CMFs for pedestrians and bicyclists moving along the road, these characterize the whole length for which the specific pedestrian/ bicyclist traffic and/ or facility exits, with weighted average applied only if differences exist within the examined road section.

B.2.13 Primary Roads: Shoulder type and width

Research findings indicate that shoulder type (i.e., paved, gravel, turf) and width affect road safety performance, as they may potentially offer the opportunity to the driver of an errant vehicle to regain control or stop and thus prevent a run-off-road crash. Overall, wide, paved shoulders have been found to improve road safety. In Table B.29, relevant literature findings are concisely presented.

Table B.29: *CMFs for the type and width of shoulders in rural roads, according to existing literature*

Source	CMF value	Comments
Shoulder Width (SW)		
Highway Safety Manual (AASHTO, 2010)	CMFs for AADT>2000 veh/day: (i) SW=0,00m: CMF=1,50 (ii) SW=0,61m: CMF=1,30 (iii) SW=1,23m: CMF=1,15 (iv) SW=1,83m: CMF=1,00 (v) SW=2,44m: CMF=0,87	*CMFs apply to single-vehicle run-off the road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes on undivided rural roads (two-lane and multi-lane).*
	CMFs for reducing SW from 2,44m to: (i) SW=0,00m: CMF=1,18	*CMFs apply to all crashes in divided rural, multi-lane roads.*

Source	CMF value	Comments
	(ii) SW=0,61m: CMF=1,13 (iii) SW=1,23m: CMF=1,09 (iv) SW=1,83m: CMF=1,04 (v) SW = 2,44: CMF=1,00	
iRAP Star Rating Protocol	CMFs for paved shoulders: (i) SW ≥2,40m: CMF=0,77 (ii) 1,00m≤SW<2,40: CMF=0,83 (iii) 0,00m<SW<1,00: CMF=0,95 (iv) None: CMF=1,00	*For run-off-road crashes of all types. The values are based on existing literature.*
Abdel-Rahim and Sonnen, (2012)	(i) SW=0,00m: CMF=1,13 (ii) SW=0,30m: CMF=1,11 (iii) SW=0,61m: CMF=1,03 (iv) SW=0,91m: CMF=1,00 (v) SW=1,23: CMF=0,97 (vi) SW=1,52: CMF=0,95 (vii) SW=1,83: CMF=0,93 (viii) SW=2,13: CMF=0,91 (ix) SW=2,44: CMF=0,87	*The CMFs are for all crash types. Data is from Idaho State.*
Stamatiadis et al. (2009)	(i) SW=0,00m: CMF=1,17 (ii) SW=0,91m: CMF=1,00 (iii) SW=1,23: CMF=0,95 (iv) SW=1,52: CMF=0,90 (v) SW=1,83: CMF=0,85 (vi) SW=2,13: CMF=0,81 (vii) SW=2,44: CMF=0,77	*The CMFs are for all crash types in divided rural four-lane roads. The shoulder width corresponds to average shoulder width of left and right side.* *Data from the states of Kentucky, Minnesota, and California.*
	(i) SW=0,00m: CMF=1,22 (ii) SW=0,91m: CMF=1,00 (iii) SW=1,23: CMF=0,94 (iv) SW=1,52: CMF=0,87 (v) SW=1,83: CMF=0,82 (vi) SW=2,13: CMF=0,76 (vii) SW=2,44: CMF=0,71	*The CMFs are for all crash types in undivided rural four-lane roads. The shoulder width corresponds to average right-side shoulder width.* *Data from the states of Kentucky, Minnesota, and California.*
Shoulder Type		
Highway Safety Manual (AASHTO, 2010)	<u>Gravel</u> (i) SW=0,00m: CMF=1,00 (ii) SW=0,30m: CMF=1,00 (iii) SW=0,61m: CMF=1,01 (iv) SW=0,91m: CMF=1,01 (v) SW=1,23: CMF=1,01 (vi) SW=1,83: CMF=1,02 (vii) SW=2,44: CMF=1,02	*Undivided rural two-lane roads and multi-lane rural roads.* *CMFs are for all single-vehicle run-off the-road and multiple-vehicle head-on, opposite direction sideswipe, and same-direction sideswipe crashes of all severity levels.*
	<u>Turf</u> (i) SW=0,00m: CMF=1,00 (ii) SW=0,30m: CMF=1,01 (iii) SW=0,61m: CMF=1,03 (iv) SW=0,91m: CMF=1,04 (v) SW=1,23: CMF=1,05 (vi) SW=1,83: CMF=1,08 (vii) SW=2,44: CMF=1,11	

Source	CMF value	Comments
	Composite (50% paved, 50% turf) (i) SW=0,00m: CMF=1,00 (ii) SW=0,30m: CMF=1,01 (iii) SW=0,61m: CMF=1,02 (iv) SW=0,91m: CMF=1,02 (v) SW=1,23: CMF=1,03 (vi) SW=1,83: CMF=1,04 (vii) SW=2,44: CMF=1,06	

Regardless the road type (i.e., divided or undivided) and the number of lanes, there is a consensus in the literature that larger shoulder widths are associated with lower CMF values. There is also a consensus that shoulder widths of approximately 2,40m (or higher) achieve the higher reduction in crashes.

From the above studies, iRAP Star Rating Protocol provide general values for all road types (i.e., urban, rural, motorways, etc.), based on other previous (not explicitly defined) studies and are thus considered less reliable. Abdel-Rahim and Sonnen (2012) CMFs refer only to roads in the State of Idaho, while Stamatiadis et al. (2009) have analyzed data for four-lane rural roads only, and are also not further considered.

For these reasons, it was decided to use the HSM-based CMFs for shoulder width. HSM provides CMFs that have been obtained using data from multiple States, and so there is a greater transferability of the resulting CMFs. The HSM provides CMFs for different road types, i.e., for divided roads, undivided two-lane roads, and undivided multi-lane roads. It is decided to take the average CMF values for divided and undivided (rural) roads, after scaling up the CMFs for undivided roads so that they account for all crash types.

Furthermore, the HSM provides CMFs to account for the shoulder type; this is another reason for using this methodology from the available literature on the assessment of shoulders in rural roads. According to the manual, the combined effect of shoulder type and width in rural roads can be estimated by multiplying the CMF for the width (CMF_w) and the CMF for the type (CMF_t), as shown in the following formula:

$$CMF_{final} = CMF_w \times CMF_t$$

For the assessment of primary rural roads, one set of Reduction Factors is provided for paved shoulders and one for unpaved shoulders. Based on the HSM, the CMF_t for paved shoulders is equal to one.

Table B.30 presents the CMFs for the shoulder width (CMF_w). The values in the second column of the table (CMF_{w_und}*) have been adopted from the HSM and correspond to head-on, run-off-road and side-swipe crashes in undivided roads; these need to be scaled up to account for all crashes. The total percentages of these crash types in rural two-lane roads in the US are 57,4% and in rural multi-lane roads 27,0% (AASHTO, 2010). It is noted that the CARE database does not include usable crash type information that could potentially be used instead of US-based crash statistics. For scaling-up the CMF_{w_und}*, the average percentage (42,2%) for two-lane and multi-lane roads is used:

$$CMF_{w\_und} = (CMF_{w\_und}^* - 1) \times 0{,}422 + 1$$

In addition to CMFs for undivided roads, the HSM also provides CMFs for divided roads (CMF_{w_div}), as shown in Table B.30.

Table B.30: *CMFs for shoulder width in primary undivided and divided roads, based on the Highway Safety Manual (AASHTO, 2010)*

Shoulder width (m)	CMF_{w_und}*	$CMF_{w\_undivided}$	$CMF_{w\_divided}$
0,00 ≤ SW < 0,60	1,50	1,211	1,180
0,61 ≤ SW < 0,91	1,30	1,127	1,130
0,91 ≤ SW < 1,23	1,23	1,097	1,110
1,23 ≤ SW < 1,83	1,15	1,063	1,090
1,83 ≤ SW < 2,44	1,00	1,000	1,040
SW ≥ 2,44	0,87	0,945	1,000

In Table B.31 the CMF values for unpaved shoulders are presented, considering that when a shoulder is unpaved it can either be made of gravel or turf. For each width category, the average CMF value for turf and gravel shoulders has been estimated; this value is noted as CMF_t*. CMF_t* needs to be scaled up to account for all crashes, as it only accounts for head-on, run-off-road, and side-swipe crashes. An average of these percentages (p = 42,2%) is used to scale up the CMF for the unpaved shoulders, i.e., CMF_t*, based on the following formula:

$$CMF_t = (CMF_t^* - 1) \times 0{,}422 + 1$$

Table B.31: *CMFs for type of unpaved shoulders in rural roads based on the Highway Safety Manual (AASHTO, 2010)*

Shoulder width (m)	CMF^*_t *(two-lane and multi-lane roads)*	CMF_t
0,00 ≤ SW < 0,61	1,00	1,000
0,61 ≤ SW < 0,91	1,02	1,008
0,91 ≤ SW < 1,23	1,02	1,008
1,23 ≤ SW < 1,83	1,03	1,013
1,83 ≤ SW < 2,44	1,04	1,017
SW ≥ 2,44	1,06	1,025
Comments	*CMFs for head-on, run-off-road and side-swipe crashes*	*All crashes*

Combining all above input distinctively for undivided and divided roads, Tables B.32 - B.34 present the final CMF values and Reduction Factors for paved shoulders, and Tables B.33 - B.35 the final CMF values and Reduction Factors for unpaved shoulders. For the different widths, the final CMF is the product of the CMFs for width and type (CMF_{final} = CMF_w x CMF_t).

Table B.32: *CMFs and Reduction Factors for the assessment of paved shoulders in primary undivided roads*

Shoulder width (m)	CMF_w	CMF_t	CMF_{final}	Reduction Factor
SW ≥ 1,83	1,000	1,000	1,000	1,000
1,23 ≤ SW < 1,83	1,063	1,000	1,063	0,941
0,91 ≤ SW < 1,23	1,097	1,000	1,097	0,912
0,61 ≤ SW < 0,91	1,127	1,000	1,127	0,887
0,00 ≤ SW < 0,61	1,211	1,000	1,211	0,826

Table B.33: *CMFs and Reduction Factors for the assessment of unpaved shoulders in primary undivided roads*

Shoulder width (m)	CMF_w	CMF_t	CMF_{final}	Reduction Factor
SW ≥ 1,83	1,000	1,017	1,017	0,983
1,23 ≤ SW < 1,83	1,063	1,013	1,077	0,929
0,91 ≤ SW < 1,23	1,097	1,008	1,106	0,904
0,61 ≤ SW < 0,91	1,127	1,008	1,136	0,880
0,00 ≤ SW < 0,61	1,211	1,000	1,211	0,826

Table B.34: *CMFs and Reduction Factors for the assessment of paved shoulders in primary divided roads*

Shoulder width (m)	CMF_w	CMF_t	CMF_{final}	Reduction Factor
SW ≥ 2,44	1,000	1,000	1,000	1,000
1,83 ≤ SW < 2,44	1,040	1,000	1,040	0,962
1,23 ≤ SW < 1,83	1,090	1,000	1,090	0,917
0,91 ≤ SW < 1,23	1,110	1,000	1,110	0,901
0,61 ≤ SW < 0,91	1,130	1,000	1,130	0,885
0,00 ≤ SW < 0,61	1,180	1,000	1,180	0,847

Table B.35: *CMFs and Reduction Factors for the assessment of unpaved shoulders in primary divided roads*

Shoulder width (m)	CMF_w	CMF_t	CMF_{final}	Reduction Factor
SW ≥ 2,44	1,000	1,025	1,025	0,976
1,83 ≤ SW < 2,44	1,040	1,017	1,058	0,945
1,23 ≤ SW < 1,83	1,090	1,013	1,104	0,906
0,91 ≤ SW < 1,23	1,110	1,008	1,119	0,894
0,61 ≤ SW < 0,91	1,130	1,008	1,139	0,878
0,00 ≤ SW < 0,61	1,180	1,000	1,180	0,847

The following also should be noted:

- In case of divided roads, the assessment is performed separately for each direction of travel. In case of undivided roads, it is first needed to estimate the weighted average CMF for each direction of traffic and then, get the average of those values.
- In case of varying shoulder characteristics and/ or width inside the examined segment, a length weighted average CMF will be estimated, and then converted to Reduction Factor (see also paragraph B.1.3).

B.2.14 Primary Roads: Passing lanes

The presence of passing lanes enables safe overtaking maneuvers in undivided roads, especially in hilly or mountainous terrain, with long sections of increased longitudinal slope (e.g., over 4%) and high percentage of slow moving traffic (e.g., heavy vehicles). Existing literature on the safety benefits of passing lanes indicates CMFs ranging from 0,52 to 0,87, as presented in Table B.36:

Table B.36: *CMFs for the presence of passing lanes in undivided rural roads, according to existing literature*

Source	CMF value	Comments
Schumaker et al. (2016)	(i) CMF=0,68 (ii) CMF=0,58	*The CMFs are for all crash types and show the effect of passing lanes: (i) across the entire length of the road (ii) at the parts where passing lanes were added.*
D'agostino Et al. (2019)	(i) CMF=0,52 (ii) CMF=0,53	*The CMFs are for all crash types, using (i) Empirical and (ii) Full Bayes.*
Wu et al. (2008)	(i) CMF=0,84 (ii) CMF=0,69	*The CMFs are for all crash types. The study developed two different models with different predictors.*
Park et al. (2012)	CMF=0,65	*All crash types.*
Persaud et al. (2008)	CMF=0,67	*All crash types.*
Bagdade et al. (2012)	CMF=0,67	*All crash types.*
Elvik et al. (2009)	(i) CMF=0,87 (ii) CMF=0,60	*The CMFs are for all crash types and show the effect of passing lanes: (i) in one direction only (ii) at both directions of traffic.*

When implemented in appropriate conditions, literature suggests that passing lanes cause a relatively large reduction in all crashes. With the exemption of the study by Schumaker et al. (2016) that (also) evaluated road segments affected by passing lanes, the rest of the studies provided CMFs for the entire studied road. Moreover, the majority of the studies assessed roads where passing lanes were placed in both directions of traffic, with the exception of Elvik et al. (2009).

Safety assessment of passing lanes for the NWA methodology is based on the above CMF-values combined with the assumption that passing lanes are required in cases of two-lane roads with high longitudinal slopes for long sections. Slope of 4% or higher, over a length of 500m or longer has been considered as criterion. For passing lanes in both directions of travel, the average CMF=0,66 of relevant studies of Table B.36 is used, whereas for passing lane only in the climbing direction of travel, the CMF=0,87 estimated by Elvik et al. (2009) is used.

Therefore, assumed CMFs and **Reduction Factors** for the presence of passing lanes in primary rural roads are presented in Table B.37:

Table B.37: *CMFs and Reduction Factors for the presence of passing lanes in primary roads*

Condition	CMF from literature	Normalized CMF	NWA Reduction Factor
Divided road	n/a	n/a	1,000
Undivided multi-lane road	n/a	n/a	1,000
Undivided 2-lane road with slope <4%, or slope >4% for length<500m	n/a	n/a	1,000
Undivided 2-lane road with slope >4% for more than 500m - passing lane in both directions	0,666	1,000	1,000
Undivided 2-lane road with slope >4% for more than 500m - passing lane in one direction	0,870	1,149	0,870
Undivided 2-lane road with slope >4% for more than 500m - No passing lanes	1,000	1,502	0,666

B.2.15 Primary Roads: Signs and markings

The quality of markings and signs in rural roads has been found to improve road safety. Existing research on markings and signs in the case of rural roads examines not only their quality (e.g., retroreflectivity of markings) but also their presence. The existing literature results are summarized in Table B.38:

Table B.38: *CMFs for the quality of markings and signs in rural roads, according to existing literature*

Source	CMF value	Comments
Road markings		
Potts et al. (2011)	Installation of wider markings: CMF=0,780	*Fatal and injury crashes of all types.*
Lyons et al. (2015)	Installation of wet retro-reflective markings: CMF=0,595	*Fatal and injury crashes of all types.*
iRAP Star Rating Protocol	Adequate delineation: CMF=1,00 Poor delineation: CMF=1,20	*Synthesis of existing studies for all road types. The provided CMFs correspond to head-on and run-off-road crashes.*
Highway Safety Manual (AASHTO, 2010)	Placement of edgeline and centerline markings: CMF=0,760	
Signs		
Highway Safety Manual (AASHTO, 2010)	Presence of signs according to guidelines: CMF=0,870	*All crash types.*
Highway Safety Manual (AASHTO, 2010)	Install combination horizontal alignment/ advisory speed signs: CMF=0,870	*All injury crash types.*
Elvik et al. (2009)	Install signs to conform to guidelines: CMF=0,850	*Fatal and injury crashes of all types.*

The literature on markings and signs consists of studies that assess the effectiveness of specific treatments (e.g., installation of wet retro-reflective markings and installation of signs that conform to national guidelines), however, it is hard to group all treatments in a meaningful way to estimate new CMFs based on the existing ones. Despite the inability, it appears that:

- poor delineation has a negative impact on safety,
- the presence of road markings to determine traffic lanes improves safety,
- the presence of wider markings or of better reflectivity improves safety, and
- signs are more effective when conforming to national guidelines.

For the assessment of markings and signs in the context of network-wide road safety assessment, a few more aspects should be considered. Markings usually exist or not exist along a section. Also, assessing whether they are clear and well-maintained can take only be facilitated in qualitative manner for long road sections. Regarding signs, they are point-level treatments and so their assessment is more challenging at the network-level. It is more meaningful to evaluate whether signs are placed at most critical points of the road (e.g., upstream of intersections, curves, etc.) and are readable.

Based on the above, the following assessment approach and **Reduction Factors (RF)** are presented for the in-built safety assessment methodology for primary roads:

- **Reduction Factor = 1,00**, when required markings and signs are in place, are of high quality and in good condition.
- **Reduction Factor = 0,95** when required markings and signs are in place but are of medium or poor quality and/ or require maintenance.
- **Reduction Factor = 0,90** when critical required markings and signs are missing.

In case that road markings and signs are of different quality along a section, a weighted average CMF should be estimated first and then, calculate the RF as described in paragraph B.1.3.

ANNEX C: NWA-REACTIVE EXCEL TOOL

This section explains step by step the use of the excel "NWA-reactive_Tool" developed for the application of the reactive methodology; the most updated version is the file "NWA-reactive_Tool_v5 (202211).xlsx". For more details on the structure of the crash-based methodology, the different steps to be followed and how to apply it, see Chapter 2 of this Handbook.

Only the cells in **light blue are editable**. The cells in grey are auto. Data whose description is written in blue are used for calculations.

The file consists of three worksheets, the contents of which are explained in detail below. The three worksheets are:

- Preliminary info.
- Methodology (S).
- Methodology (J).

The worksheets should be filled in the **order in which they appear** in the Excel file. So, first the data concerning preliminary information must be entered and then the next two worksheets regarding the analysis of road sections and junctions are used.

The three worksheets are protected by a **password** to prevent crashal changes to the file setting. To remove the protection, click on "Unprotect Sheet" in the "Review" tab of excel and enter the following password: **NWA**. All cells that must not be modified for the correct operation of the file are locked, so it is strongly recommended not to unprotect the worksheets.

C.1 Worksheet "Preliminary info"

This first worksheet collects all general data about the road and the reference population to which the road belongs. Most of the data contained in this worksheet are used in the following worksheets for the crash-based assessment of road sections and junctions.

C.1.1 Box "General information"

In the first box "**General information**" enter (optional) the details of the road under assessment (Figure C.1).

General information	
Location:	
Road name:	
Road category:	Rural motorway
Suggested road section length:	**10 ± 5 km**

Figure C.1: *General information box*

These data can be useful to have a reference of the road to which the file applies, but their filling in is left to the user's discretion. Specifically, the data are:

Location: country/region/city/locality or other indication of the area in which the assessed road is located.

Road name: name used to indicate the road within the national network.

Road category: category to which the road belongs to be chosen from those to which the Directive 2008/96/EC applies (i.e., rural motorway, urban motorway, divided primary road, undivided primary road).

Suggested road section length: automatic value linked to the road category chosen that gives approximate road section lengths to give an order of magnitude, but they are not mandatory for segmentation. These lengths refer only to road sections and not to junctions.

C.1.2 Box "Reference data – Road sections"

This box must be filled in whichever of the three approaches[5] is chosen.

The box in Figure C.2 contains the input data for the reactive assessment only for road sections. The data contained therein are linked to the "**1. Methodology (S)**".

Reference data - Road sections	
Data on the road under assessment:	
Time period of accident data (years)	
Total n. accidents	
Total length of all road sections (km)	
Data on the Reference Population to which the road sections belong:	
Total km of roads	
Total n. accidents	
Average AADT	
Average accident density - calculated *(acc./km)*	-
Average accident density - input *(acc./km)*	
Average accident rate - calculated *(acc./veh.*km)*	-
Average accident rate - input *(acc./veh.*km)*	
Average AADT - calculated	-

Figure C.2: *"Reference data – Road sections" box*

The first data to be entered are those relating to the road under assessment. In particular, the following data must be entered:

- **Time period of crash data (years):** the number of years considered for the crash data. Three years is the minimum time period suggested. A longer period of time (e.g., 5 years) could be used when few crashes by year are recorded.

[5] *1. Road sections*, *2. Road sections + junctions (predefined dimension)*, *3. Road sections + junctions (measured dimension)*.

- **Total n. crashes:** total number of fatal and injury (severe and slight) crashes on the road under assessment during the considered time period.
- **Total length of all road sections (km):** total length of all road sections to be assessed.

In the part related to the reference population, the specific data of the group of roads to which the road under assessment belongs shall be entered. If, for example, a rural motorway is being assessed, the data for the group of rural motorways at national level should be entered in this section.

Specifically, the following data must be entered:

- **Total km of roads:** total length of roads belonging to the same reference population (in the example above, the length of all road sections of rural motorways in the country).
- **Total n. crashes:** total number of fatal and injury (severe and slight) crashes occurring along all road sections belonging to the reference population.
- **Average AADT:** average AADT of all road sections belonging to the reference population.

With these data, the worksheet automatically calculates the average crash density and the average crash rate in the cells ***Average crash density - calculated (acc./km)*** and ***Average crash rate - calculated (acc./veh.*km)***. If the data listed above are not available, but only the value of the metric in aggregate form is known, the average crash density and the average crash rate of the reference population can be entered directly as input in the cells:

- Average crash density - input (acc./km).
- Average crash rate - input (acc./veh.*km).

With these input data entered, the average AADT is calculated automatically in the cell ***Average AADT – calculated***.

C.1.3 Box "Reference data – Road junctions"

This box only must be filled in if the 2nd approach or 3rd approach[6] is chosen.

The box in Figure C.3 contains the input data for the reactive assessment only for junctions. The data contained therein are linked to the "**2. Methodology (J)**".

[6] *1. Road sections*, *2. Road sections + junctions (predefined dimension)*, *3. Road sections + junctions (measured dimension)*.

Reference data - Road junctions	
Data on the road under assessment:	
Time period of accident data (years)	
Total n. accidents (occurring only at junctions)	
Total length of all junctions (km)	
Data on the Reference Population to which the road junctions belong:	
Total km of road junctions	
Total n. accidents	
Average AADT of road junctions	
Average accident density - calculated *(acc./km)*	-
Average accident density - input *(acc./km)*	
Average accident rate - calculated *(acc./veh.*km)*	-
Average accident rate - input *(acc./veh.*km)*	
Average AADT - calculated	-

Figure C.3: *"Reference data – Road junctions" box*

The first data to be entered are those relating to the road under assessment. In particular, the following data must be entered:

- **Time period of crash data (years):** the number of years considered for the crash data. Three years is the minimum time period suggested. A longer period of time (e.g. 5 years) could be used when few crashes by year are recorded.
- **Total n. crashes (occurring only at junctions):** total number of fatal and injury (severe and slight) crashes occurred only at junctions on the road under assessment during the considered time period.
- **Total length of all junctions (km):** total length of all junctions to be assessed.

In the part related to the reference population, the specific data of the group of roads to which the road under assessment belongs shall be entered. If, for example, a rural motorway is being assessed, the data for the group of rural motorways at national level should be entered in this section.

Specifically, the following data must be entered:

- **Total km of road junctions:** total length of road junctions belonging to the same reference population (in the example above, the length of all road junctions of rural motorways in the country).
- **Total n. crashes:** total number of fatal and injury (severe and slight) crashes occurring along all road junctions belonging to the reference population.
- **Average AADT:** average AADT of all road junctions belonging to the reference population.

With these data, the worksheet automatically calculates the average crash density and the average crash rate in the cells ***Average crash density - calculated (acc./km)*** and ***Average crash rate - calculated (acc./veh.*km)***. If the data listed above are not available, but only the value of the metric in aggregate form is known, the average crash density and the average crash rate of the reference population can be entered directly as input in the cells:

- **Average crash density - input (acc./km).**
- **Average crash rate - input (acc./veh.*km).**

With these input data entered, the average AADT is calculated automatically in the cell ***Average AADT – calculated***.

C.2 Worksheet "1. Methodology (S)"

Enter the "*Section code*" (number in ascending order), the chainage of the start and end point of the section; if this information is not available, only add the length of each section.

Enter the number of crashes that occurred on the road section in the column "*n. crashes*" and the AADT traffic related to the road section, if the latter is available.

Automatic calculations will be performed in all other cells of the worksheet. In particular, the upper and lower confidence intervals, crash density and crash rate are calculated for each road section.

The "*Crash density info box*" (Figure C.4) collects data on thresholds obtained through the Poisson method that allow road sections to be classified according to the crash density. It also shows the number of sections which, based on the assessment, are in each of the three classes, high risk, unsure and low risk.

Accident density summary box	
Average acc. Density (Ref. population)	*0.00*
High risk sections	*0*
Unsure risk sections	*0*
Low risk sections	*0*

Figure C.4: *Crash density info box*

The "*Crash rate info box*" (Figure C.5) collects data on the crash rate thresholds obtained from the crash density thresholds, including average AADT of the reference population in the calculations. These thresholds allow road sections to be classified according to the crash rate. In the box, it is also shown the number of sections which, based on the assessment, are in each of the three classes, high risk, unsure and low risk.

Accident rate summary box	
Average accident rate (Ref. population)	*0.00*
High risk sections	*0*
Unsure risk sections	*0*
Low risk sections	*0*

Figure C.5 – *Crash rate info box*

The final section ranking is based on crash rate "*Ranking by crash rate*", if AADT data are available. Otherwise, the ranking is based on crash density ("*Ranking by crash density*".

The "*Useful information*" box contains some additional information to check that the entire length of the road has been considered and that all crashes indicated in the reference box have been assigned to the sections under assessment.

C.3 Worksheet "2. Methodology (J)"

This worksheet is structured and works in the same way as "1. Methodology (S)", with the only difference that "2. Methodology (J)" refers to junctions and therefore the data useful for its operation are those contained in the "Reference data – Road junctions" box (paragraph C.1.3).

ANNEX D: NWA-PROACTIVE EXCEL TOOL

In order to enable experimentation and testing of the considered NWA proactive score estimation algorithms for validation purposes, and to assist in the pilot implementation of the methodology for the in-built safety assessment of roads, the parameters and relationships presented in Chapter 3 have been incorporated into an estimator tool in Excel format. The tool is open and editable, with visible algorithms and functions to assist in the validation process and is submitted as an excel file together with the present Handbook.

The excel file includes six sheets, namely:

1. **NWA proactive - Rural Motorway**: This sheet serves the estimation of NWA proactive score for rural motorways. It includes cells for user input per parameter, the respective relations and the resulting Crash Modification Factors (CMFs) and Reduction Factors (RFs) per parameter, as well as the overall score of the examined segment.

2. **NWA proactive - Urban Motorway**: This sheet serves the estimation of NWA proactive score for urban motorways. It includes cells for user input per parameter, the respective relations and the resulting Crash Modification Factors (CMFs) and Reduction Factors (RFs) per parameter, as well as the overall score of the examined segment.

3. **NWA proactive - Primary Undivided Road**: This sheet serves the estimation of NWA proactive score for primary undivided roads. It includes cells for user input per parameter, the respective relations and the resulting Crash Modification Factors (CMFs) and Reduction Factors (RFs) per parameter, as well as the overall score of the examined segment.

4. **NWA proactive - Primary Divided Road**: This sheet serves the estimation of NWA proactive score for primary divided roads. It includes cells for user input per parameter, the respective relations and the resulting Crash Modification Factors (CMFs) and Reduction Factors (RFs) per parameter, as well as the overall score of the examined segment.

5. **Lookup Tables**: This sheet includes tables with CMF values for some of the parameters, used by the formulas in the calculator sheets.

6. **Data Validation**: This sheet is used for imposing validation restrictions on user input, to prevent from entering not acceptable values that would lead to false results.

The use of the excel tool is simple and mostly self-explaining, and the following principles apply:

1. **Users need to interact only with the calculator sheet for the specific road type examined**: rural motorway, urban motorway, primary undivided road or primary divided road.

2. Data are entered by the user per parameter, in the cells with light brown colour. Depending on data input, additional data requests may appear in the worksheet.

3. Based on user input, Crash Modification Factors and Reduction Factors are automatically estimated in the right column of the sheet and the overall score is shown at the end of the excel worksheet (red circle in Figures D.1 to D.4).

NWA-proactive assessment: RURAL MOTORWAY

Separate assessment for each direction of travel

no.	Parameter Name	Code	Variable 1	Value 1	Variable 2	Value 2	Variable 3	Value 3	CMF	RF
1	Lane width	LW	Average width of all basic lanes:	3,45 m					1,000	**1,000**
2	Roadside	RS							1,120	**0,893**
			Clear zone width:	4,50 m	Type of obstacle:	barrier steel	% of seg. length:	85 %	1,041	0,960
			Clear zone width:	6,00 m	Type of obstacle:	deep drainage ditch	% of seg. length:	5 %	1,667	0,600
			Clear zone width:	6,00 m	Type of obstacle:	fill/cut slope	% of seg. length:	10 %	1,516	0,660
			Clear zone width:	m	Type of obstacle:		% of seg. length:	%	0,000	n/a
			Clear zone width:	m	Type of obstacle:		% of seg. length:	%	0,000	n/a
3	Curvature	CU	Are there curves with radius less than R=1.500m in the segment?	yes					1,022	**0,978**
			Radius of curve n.1 (R<1.500m):	1.450 m	% of segment length within curve n.1:	20 %			0,290	
			Radius of curve n.2 (R<1.500m):	1.100 m	% of segment length within curve n.2:	15 %			0,378	
			Radius of curve n.3 (R<1.500m):	m	% of segment length within curve n.3:	%			0,000	
			Radius of curve n.4 (R<1.500m):	m	% of segment length within curve n.4:	%			0,000	
			Radius of curve n.5 (R<1.500m):	m	% of segment length within curve n.5:	%			0,000	
			Radius of curve n.6 (R<1.500m):	m	% of segment length within curve n.6:	%			0,000	
			Radius of curve n.7 (R<1.500m):	m	% of segment length within curve n.7:	%			0,000	
			Radius of curve n.8 (R<1.500m):	m	% of segment length within curve n.8:	%			0,000	
			Radius of curve n.9 (R<1.500m):	m	% of segment length within curve n.9:	%			0,000	
			Radius of curve n.10 (R<1.500m):	m	% of segment length within curve	%			0,000	
4	Interchanges	IC	Are there interchanges with ramp spacing ≤1.600m in the segment, or is the segment between interchanges with ramp spacing ≤1.600m?	yes	Length of segment:	2800 m			1,018	**0,983**
			Ramp spacing n.1 (≤1.600m):	1.500 m					1,049	
			Ramp spacing n.2 (≤1.600m):	m						
			Ramp spacing n.3 (≤1.600m):	m						
5	Conflicts between pedestrians/bicyclists and motorized traffic	PB	Do pedestrians or bicyclists move on or approach the motorway carriegeway?	yes	Are all pedestrians and bicyclists near the motorway on level-separated or properly protected facilities?	yes			-	**1,000**
6	Incident monitoring & user information systems	OC	Is there a traffic operation center or incident monitoring/information system in operation?	yes					-	**1,000**

NWA-proactive Segment Score Estimation: 85,9 / 100

Figure D.1: *Screenshot of NWA proactive assessment excel tool for rural motorways.*

NWA-proactive assessment: URBAN MOTORWAY

Separate assessment for each direction of travel

no.	Parameter Name	Code	Variable 1	Value 1	Variable 2	Value 2	Variable 3	Value 3	CMF	RF
1	Lane width	LW	Average width of all basic lanes:	3,30 m					1,000	**1,000**
2	Roadside	RS							1,120	**0,893**
			Clear zone width:	4,50 m	Type of obstacle:	barrier steel	% of seg. length:	85 %	1,041	0,960
			Clear zone width:	6,00 m	Type of obstacle:	deep drainage ditch	% of seg. length:	5 %	1,667	0,600
			Clear zone width:	6,00 m	Type of obstacle:	fill/cut slope	% of seg. length:	10 %	1,516	0,660
			Clear zone width:	m	Type of obstacle:		% of seg. length:	%	0,000	n/a
			Clear zone width:	m	Type of obstacle:		% of seg. length:	%	0,000	n/a
3	Curvature	CU	Are there curves with radius less than R=750m in the segment?	yes					1,050	**0,953**
			Radius of curve n.1 (R<750m):	740 m	% of segment length within curve n.1:	20 %			1,114	
			Radius of curve n.2 (R<750m):	600 m	% of segment length within curve n.2:	15 %			1,271	
			Radius of curve n.3 (R<750m):	500 m	% of segment length within curve n.3:	5 %			0,610	
			Radius of curve n.4 (R<750m):	m	% of segment length within curve n.4:	%			0,000	
			Radius of curve n.5 (R<750m):	m	% of segment length within curve n.5:	%			0,000	
			Radius of curve n.6 (R<750m):	m	% of segment length within curve n.6:	%			0,000	
			Radius of curve n.7 (R<750m):	m	% of segment length within curve n.7:	%			0,000	
			Radius of curve n.8 (R<750m):	m	% of segment length within curve n.8:	%			0,000	
			Radius of curve n.9 (R<750m):	m	% of segment length within curve n.9:	%			0,000	
			Radius of curve n.10 (R<750m):	m	% of segment length within curve	%			0,000	
4	Interchanges	IC	Are there interchanges with ramp spacing ≤1.600m in the segment, or is the segment between interchanges with ramp spacing ≤1.600m?	yes	Length of segment:	3500 m			1,035	**0,966**
			Ramp spacing n.1 (≤1.600m):	800 m					1,066	
			Ramp spacing n.2 (≤1.600m):	1.200 m					1,057	
			Ramp spacing n.3 (≤1.600m):	m						
5	Conflicts between pedestrians/bicyclists and motorized traffic	PB	Do pedestrians or bicyclists move on or approach the motorway carriegeway?	yes	Are all pedestrians and bicyclists near the motorway on level-separated or properly protected facilities?	yes			-	**1,000**
6	Incident monitoring & user information systems	OC	Is there a traffic operation center or incident monitoring/information system in operation?	yes					-	**1,000**

NWA-proactive Segment Score Estimation 82,2 / 100

Figure D.2: *Screenshot of NWA proactive assessment excel tool for urban motorways.*

NWA-proactive assessment: PRIMARY UNDIVIDED ROAD

Common assessment for both directions of travel

Segment Length (m)	2.000	Operation speed (V85) for segment: (cell value equal to zero if unknown)	0 km/h	Posted speed limit:	60 km/h	Is automated speed enforcement present in the segment?	no

no.	Parameter Name	Code	Variable 1	Value 1	Variable 2	Value 2	Variable 3	Value 3	CMF	RF
1	Lane width	LW	Average width of all basic lanes:	3,50 m					1,000	**1,000**
2	Roadside	RS	Roadside Hazard Rating - left side:	2	Roadside Hazard Rating - right side:	3,7			1,024	**0,977**
3	Curvature	CU	Are there curves with radius less than R=1.000m in the segment?	yes	Radius of sharpest curve in segment (R<1.000m):	500 m			1,062	**0,942**
4	Density of property access points	PA	Density of property access points - both sides of the road added	2 p/km					1,093	**0,915**
5	Junctions	JU	Presence of junctions in segment:	yes	Length of segment:	2.000 m			1,000	**1,000**
			Junction no.1 type:	4-leg signalized - turn lanes	Junction no.1 length within segment:	300 m		*CMF 1 =*	*1,000*	
			Junction no.2 type:		Junction no.2 length within segment:	m		*CMF 2 =*	*1,000*	
			Junction no.3 type:		Junction no.3 length within segment:	m		*CMF 3 =*	*1,000*	
			Junction no.4 type:		Junction no.4 length within segment:	m		*CMF 4 =*	*1,000*	
6	Conflicts between pedestrians/bicyclists and motorized traffic	PB	Facilities for bicyclists - along left side:	segregated bicyclist path	Presence of crossing pedestrian traffic:	yes	Facilities for pedestrians - along left side:	segregated - protected pedestrian	1,007	**0,994**
			Facilities for bicyclists - along right side:	no bicycle traffic	No. of grade separated pedestrian crossings in segment:	0	Facilities for pedestrians - along right side:	no pedestrian		
					No. of signalized at-grade pedestrian crossings with refuge:	1				
					No. of signalized at-grade pedestrian crossings without refuge:	0		*CMF bic =*	*1,000*	
			For changing types of pedestrian/ bicyclist facilities along the segment, manual CMF calculation is required		No. of unsignalized marked pedestrian crossings with refuge:	0		*CMF ped =*	*1,025*	
					No. of unsignalized marked pedestrian crossings without refuge:	0		*CMF ped.cr =*	*1,050*	
					No. of pedestrian crossing locations without any arrangement:	0		*CMF ped.al =*	*1,000*	
7	Shoulder type & width	SW	Shoulder type - left side:	unpaved	Shoulder width - left side:	1,30 m			1,077	**0,929**
			Shoulder type - right side:	unpaved	Shoulder width - right side:	1,30 m				
8	Passing lanes	PL	Does the road have more than one basic lane per direction?	no	Length within segment with longitudinal slope >4%?	700 m	Are there passing lanes present?	yes, in one direction	1,052	**0,950**
9	Signs and markings	SM	Signs/ markings rating:	in place, high quality, good condition					-	**1,000**

NWA-proactive Segment Score Estimation: 73,8 / 100

Figure D.3: *Screenshot of NWA proactive excel tool for primary undivided roads*

NWA-proactive assessment: PRIMARY DIVIDED ROAD

Separate assessment for each direction of travel

Segment Length (m)	2.300	Operation speed (V85) for segment: (cell value equal to zero if unknown)	0 km/h	Posted speed limit:	80 km/h
Is automated speed enforcement present in the segment?	yes				

no.	Parameter Name	Code	Variable 1	Value 1	Variable 2	Value 2	Variable 3	Value 3	CMF	RF
1	Lane width	LW	Average width of all basic lanes:	3,25 m					1,021	**0,979**
2	Roadside	RS	Roadside Hazard Rating (outer side):	3					1,000	**1,000**
3	Curvature	CU	Are there curves with radius less than R=1.000m in the segment?	yes	Radius of sharpest curve in segment (R<1.000m):	600 m			1,043	**0,959**
4	Density of property access points	PA	Density of property access points (on the examined direction of travel):	2 p/km					1,093	**0,915**
5	Junctions	JU	Presence of junctions in segment:	yes	Length of segment:	2.300 m			1,000	**1,000**
			Junction no.1 type:	4-leg signalized - turn lanes	Junction no.1 length within segment:	300 m		*CMF 1 =*	*1,000*	
			Junction no.2 type:		Junction no.2 length within segment:	m		*CMF 2 =*	*1,000*	
			Junction no.3 type:		Junction no.3 length within segment:	m		*CMF 3 =*	*1,000*	
			Junction no.4 type:		Junction no.4 length within segment:	m		*CMF 4 =*	*1,000*	
6	Conflicts between pedestrians/bicyclists and motorized traffic	PB	Facilities for bicyclists - along outer side:	segregated bicyclist path	Presence of crossing pedestrian traffic:	yes	Facilities for pedestrians - along outer side:	segregated - protected pedestrian	1,154	**0,866**
			For changing types of pedestrian/ bicyclist facilities along the segment, manual CMF calculation is required		No. of grade separated pedestrian crossings in segment:	0				
					No. of signalized at-grade pedestrian crossings with refuge:	2				
					No. of signalized at-grade pedestrian crossings without refuge:	0		*CMF bic =*	*1,000*	
					No. of unsignalized marked pedestrian crossings with refuge:	1		*CMF ped =*	*1,592*	
					No. of unsignalized marked pedestrian crossings without refuge:	0		*CMF ped.cr =*	*2,185*	
					No. of pedestrian crossing locations without any arrangement:	1		*CMF ped.al =*	*1,000*	
7	Shoulder type & width	SW	Shoulder type - outer side:	unpaved	Shoulder width - outer side:	1,85 m			1,058	**0,945**
8	Passing lanes	PL	*Not applicable in divided roads*						1,000	**1,000**
9	Signs and markings	SM	Signs/ markings rating:	in place, high quality, good condition					-	**1,000**

NWA-proactive Segment Score Estimation: 70,3 / 100

Figure D.4: *Screenshot of NWA proactive excel tool for primary divided roads.*

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