SAPIENZA UNIVERSITÀ DI ROMA

Faculty of Civil and Industrial Engineering

The Improvement and Transferability of the European Network-wide Road Safety Assessment Methodology

By

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A thesis submitted to the Faculty of Civil and Industrial Engineering in partial fulfillment of the requirements for the degree of:

Doctor of Philosophy in Transportation and Infrastructures

SAPIENZA UNIVERSITÀ DI ROMA

FEBRUARY 2026

Abstract

Speed is a major risk factor in road safety that contributes to the increase in the probability and severity of a crash. However, the safety effects of vehicle operating speed related to the road infrastructure is often given less attention in road safety assessment procedures. In most cases, it is assumed that there is no risk of speeding if the vehicle travels within the speed limit. Nevertheless, several road traffic crashes still occur at below the speed limit. As such, the primary objective of this research is to estimate the safety effects of vehicle operating for two-lane undivided rural highways, and incorporate these effects into the current Network-wide Assessment (NWA) Proactive model. Since statistics have shown that speed contributes to over 30 percent of road fatalities, including speed in the safety assessment would lead to accurate identification of hazardous road locations. The safety effects of speed were obtained by developing a Crash Modification Factor (CMF) for speed using the simplified cross-sectional method. This factor is then converted into reduction factors and incorporated into the new NWA Proactive model. The performance of the proposed model with speed inclusive is then compared to the current model without speed on four different sample of two-lane undivided rural highways within the Lazio Region in Italy. Furthermore, the impact of the proposed model on the overall integration of reactive and proactive assessment results was examined.

The second part of this thesis focused on investigating the transferability of the European NWA procedure to typical highways in Sub-Saharan Africa, particularly the Yaounde – Douala highway in Cameroon, which is a Trans-African Highway (TAH) serving as a major corridor for neighboring landlocked countries such as Chad and Central African Republic. The primary objective is to investigate if the European procedure is capable of identifying potential crash locations in this part of the world.

The results in the first part of this thesis showed that by incorporating the safety effects of operating speeds into the model, the predictions were closer to the observed crashes than when speed was not considered. This means that the safety effects of speed improved the identification of crash locations. Also, the analysis revealed that this affects the integration results by ranking the road sections safer when speed is not considered. The results for the second part of this thesis revealed that there is a high possibility of implementing the European procedure in identifying the safety performance levels of rural highways in Sub-Saharan Africa. Overall, the research provides a significant contribution to the field of road safety assessment procedures by demonstrating the contribution of operating speeds in safety assessments, as well as the possibility of applying these procedures in other parts of the world.

Keywords: *Risk assessment, road safety assessment, road safety inspections, road safety evaluations, network screening, transferability.*

SOMMARIO

La velocità è un importante fattore di rischio per la sicurezza stradale, che contribuisce ad aumentare la probabilità e la gravità di un incidente. Tuttavia, gli effetti sulla sicurezza della velocità di marcia del veicolo in relazione all'infrastruttura stradale sono spesso considerati meno importanti nelle procedure di valutazione della sicurezza stradale. Nella maggior parte dei casi, si presume che non vi sia alcun rischio di eccesso di velocità se il veicolo viaggia entro i limiti di velocità. Ciononostante, diversi incidenti stradali si verificano ancora a velocità inferiori ai limiti. Pertanto, l'obiettivo principale di questa ricerca è stimare gli effetti sulla sicurezza della circolazione di veicoli su autostrade rurali a due corsie non divise e incorporare tali effetti nell'attuale modello proattivo di valutazione dell'intera rete (NWA). Poiché le statistiche hanno dimostrato che la velocità contribuisce a oltre il 30% degli incidenti mortali, l'inclusione della velocità nella valutazione della sicurezza porterebbe a un'identificazione accurata dei punti stradali pericolosi. Gli effetti sulla sicurezza della velocità sono stati ottenuti sviluppando un fattore di modifica dell'impatto (CMF) per la velocità utilizzando il metodo trasversale semplificato. Questo fattore viene quindi convertito in fattori di riduzione e incorporato nel nuovo modello proattivo NWA. Le prestazioni del nuovo modello con velocità inclusiva sono state quindi confrontate con il modello attuale senza velocità su quattro diversi campioni di autostrade rurali a due corsie non divise all'interno della Regione Lazio, in Italia. Inoltre, è stato esaminato l'impatto del nuovo modello sull'integrazione complessiva dei risultati delle valutazioni reattive e proattive. La seconda parte di questa tesi si è concentrata sulla possibilità di trasferibilità della procedura NWA alle autostrade tipiche dell'Africa subsahariana, in particolare all'autostrada Yaoundé-Douala in Camerun, che è un'autostrada transafricana (TAH) che funge da corridoio importante per paesi senza sbocco sul mare come il Ciad e la Repubblica Centrafricana. L'obiettivo principale è verificare se la procedura NWA proattiva sia in grado di identificare i luoghi degli incidenti in questa parte del mondo. I risultati della prima parte di questa tesi hanno mostrato che, incorporando gli effetti sulla sicurezza delle velocità operative nel modello, le previsioni erano più vicine agli incidenti osservati rispetto a quando la velocità non era considerata. Ciò significa che gli effetti sulla sicurezza della velocità hanno migliorato l'identificazione dei luoghi degli incidenti. Inoltre, l'analisi ha rivelato che questo influisce sui risultati dell'integrazione, classificando i tratti stradali più sicuri quando la velocità non viene considerata. I risultati relativi al secondo obiettivo hanno rivelato un'elevata possibilità di implementare questa metodologia per identificare i livelli di sicurezza delle strade nell'Africa subsahariana. Nel complesso, la ricerca fornisce un contributo significativo al campo delle procedure di valutazione della sicurezza stradale, dimostrando il contributo delle velocità operative nelle valutazioni di sicurezza, nonché la possibilità di applicare queste procedure in altre parti del mondo.

Parole chiave: *Valutazione del rischio, valutazione della sicurezza stradale, ispezioni di sicurezza stradale, valutazioni della sicurezza stradale, screening della rete, trasferibilità.*

Résumé

La vitesse est un facteur de risque majeur pour la sécurité routière, contribuant à l'augmentation de la probabilité et de la gravité des accidents. Cependant, les effets de la vitesse de circulation des véhicules sur la sécurité routière sont souvent moins pris en compte dans les procédures d'évaluation de la sécurité routière. Dans la plupart des cas, on suppose qu'il n'y a aucun risque d'excès de vitesse si le véhicule respecte la limite de vitesse. Néanmoins, plusieurs accidents de la route surviennent encore à des vitesses inférieures à la limite. L'objectif principal de cette recherche est donc d'estimer les effets de la circulation des véhicules sur les routes rurales à deux voies à chaussée unique sur la sécurité routière et d'intégrer ces effets au modèle proactif actuel d'évaluation du réseau routier (NWA). Les statistiques montrant que la vitesse contribue à plus de 30 % des décès sur la route, son inclusion dans l'évaluation de la sécurité permettrait d'identifier précisément les zones dangereuses sur la route. Les effets de la vitesse sur la sécurité ont été obtenus en élaborant un facteur de modification des accidents (FMA) pour la vitesse à l'aide de la méthode transversale simplifiée. Ce facteur est ensuite converti en facteurs de réduction et intégré au nouveau modèle proactif NWA. Les performances du nouveau modèle, incluant la vitesse, sont ensuite comparées à celles du modèle actuel, sans vitesse, sur quatre échantillons différents de routes rurales à deux voies non divisées dans la région du Latium, en Italie. De plus, l'impact du nouveau modèle sur l'intégration globale des résultats des évaluations réactives et proactives a été examiné. La deuxième partie de cette thèse s'est concentrée sur l'étude de la transférabilité de la procédure NWA aux autoroutes classiques d'Afrique subsaharienne, notamment l'autoroute Yaoundé-Douala au Cameroun, une route transafricaine (TAH) servant de corridor majeur pour des pays enclavés comme le Tchad et la République centrafricaine. L'objectif principal est de déterminer si la procédure proactive NWA est capable d'identifier les lieux d'accidents dans cette région du monde. Les résultats de la première partie de cette thèse ont montré qu'en intégrant les effets de la vitesse de circulation sur la sécurité dans le modèle, les prédictions étaient plus proches des accidents observés que lorsque la vitesse n'était pas prise en compte. Cela signifie que les effets de la vitesse sur la sécurité ont amélioré l'identification des lieux d'accidents. De plus, l'analyse a révélé que cela influence les résultats d'intégration en classant les tronçons routiers plus sûrs lorsque la vitesse n'est pas prise en compte. Les résultats du deuxième objectif ont révélé une forte probabilité d'application de cette méthodologie pour identifier les niveaux de sécurité des routes en Afrique subsaharienne. Globalement, cette recherche apporte une contribution significative aux procédures d'évaluation de la sécurité routière en démontrant l'importance des vitesses de circulation dans les évaluations de sécurité, ainsi que la possibilité d'appliquer ces procédures à d'autres régions du monde.

Mots-clés : *Évaluation des risques, évaluation de la sécurité routière, inspections de sécurité routière, évaluations de la sécurité routière, analyse du réseau, transférabilité.*

Acknowledgments

I would begin by thanking my supervisors, Prof. Luca Persia, Dr. Davide Usami Shingo, and Dr. Brayan González-Hernández for all their support, inspiration, and guidance that have enabled me to acquire and improve my research skills throughout these years of training.

I am also highly indebted to Prof. Marko Ševrović and his entire team at the Department of Transport Planning at the Faculty of Transport and Traffic Sciences, University of Zagreb, for accepting and supporting me throughout the three-month research training I was privileged to have in their institution.

Special thanks also to Prof. Guido Gentile (the Co-ordinator for the PhD program in Transportation and Infrastructure at Sapienza University of Rome) and his team, especially his assistant Dr. Lory Bresciani, for the administrative support and quality of Researchers invited to deliver guest lectures. Sincerely, I learnt a lot from the lectures and also about future career opportunities available for me.

My sincere gratitude also goes to all the Staff in the Centre of Transport and Logistics (CTLup) including Roberto, Marco, Stephen, Steffel, Kangan, Tejas, Francesca, Iryna, Manuel, Artem, Cansu, Valerio, Leonardo, Laurencio, Ricardo, Sergio, Tevoh, and Isaac for all their support and collaboration during my research.

A special appreciation to my father and uncle, Senator Wanlo John Chiamua, and my mother, Mrs. Chiamua Grace Fuen, for all their sacrifices to see me ascend the educational ladder. I have finally reached the apex, and I am very grateful.

Finally, I would like to thank my wife, Mrs. Kezia Chiangwah, and my children, Jemima, Awesome, Marvellous, and Elvis Chiangwah Jnr, for their co-operation and prayers through all the happy and hard times I had throughout my training.

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List of Abbreviations and Acronyms

WHO	World Health Organization
PAIRC	Permanent International Association of Road Congresses
ANFISA	Agenzia Nazionale per la Sicurezza delle Ferrovie e delle Infrastrutture Stradali e Autostradali
UN	United Nations
PS	Proactive Score
EC	European Commission
AADT	Annual Average Daily Traffic
FCD	Floating Car Data
GDP	Gross Domestic Product
GIS	Geographical Information System
RTM	Regression to Mean
VRU	Vulnerable Road Users
CMF	Crash Modification Factors
RF	Reduction Factors
MS	Member States
NWA	Network-wide Assessment
NWRSA	Network-wide Road Safety Assessment Assessment
IRAP	International Road Assessment Programme
RAP	Road Assessment Programme
ANRAM	Australian National Risk Assessment Model
HSM	Highway Safety Manual
FHWA	Federal Highway Administration
AASHTO	American Association of State Highway and Transportation Organization
PRACT	Predicting Road Accidents Transferability

SPF	Safety Performance Functions
CPM	Crash Prediction Models
RSI	Road Safety Inspection
CURE	Cumulative Residuals
GOF	Goodness-Of-Fit
MAD	Mean Absolute Deviation
RMSE	Root Mean Square Error
SP	Strada Provinciale
ASTRAL	Azienda Strada Lazio
QGIS	Quantum Geographical Information System
B-A	Before - After
EB	Empirical Bayes
TEN	Trans-European Network
TAH	Trans-African Highway
SSA	Sub-Saharan Africa

CHAPTER 1. INTRODUCTION

1.1. Background

The most recent global status report on road safety indicated that over 1.19 million fatalities are continuously being recorded on the world's roads annually (WHO, 2023). This shows a five percent decrease compared to 1.25 million fatalities in 2010 (WHO, 2010). Generally, road traffic crashes are a result of three contributory factors: human behaviors, vehicles, and the road infrastructure. Statistics have shown that over 30 – 40% of these crashes are due to the state of the road infrastructure (Elvik 2009). In Europe, 20,653 deaths were recorded in 2022 in which 56% of the crashes are related to the road infrastructure (European Commission, 2022). Therefore, there's a need to improve the road infrastructure as a major step towards crash reduction. In this regard, global efforts have been taken towards improving the world's road infrastructure, for instance, in accelerating efforts towards meeting the UN Second Decade of Action Plan for the period 2020 - 2030 (United Nations, 2020b), Member States adopted 12 Global Road Safety Performance Targets (United Nations, 2020a), in which targets 3 and 4 focus on the improvement of the road infrastructure. The two targets are defined as such: target 3; "all new roads are built to a 3-star or better standard for all road users", while target 4 states that, "at least, 75% of travel on existing roads is on roads that meet technical standards for all road users". At the European level, several efforts have been made over the last decade in which two main legislatures/directives have been developed aimed at fostering the safety management of road infrastructures within Europe. The first legislature is directive 2008/96/EC (European Commission, 2008) with the overall objective of improving the safety of road infrastructures at each phase of the life cycle of the road using safety management tools such as road safety audits, road safety impact assessment, road safety inspection, and network safety ranking. After a decade of implementation, the directive was amended by directive (EC) 2019/1936 (European Commission, 2019) which widens the scope of the first directive and introduced an additional safety management tool, known as the "Network-wide Road Safety Assessment " (NWRSA) methodology (European Commission, 2023). This tool is made up of two Network-wide Assessment (NWA) components: the NWA Reactive component, which is based on statistically analyzing the historical crashes that occurred on an existing road, and the second component, known as the NWA Proactive component, which evaluates the risks on the road based on the in-built characteristics of the road infrastructure.

1.2. Problem statement

Following the publication of the NWA methodology by the European Commission in 2023, Member States were mandated to implement the methodology on the roads defined by the 2019 directive and report back to the Commission by December 2024. In Italy, ANSFISA, which is the Italian National Agency for Safety of Railway, Road, and Motorway Infrastructures, found several technical issues with the NWA model. These challenges resulted in the creation of an Italian NWA procedure (Conticini et al., 2025). Nevertheless, the poor performance of the European NWA, maybe due to the absence of speed as a risk factor in the model (Van et al., 2021). This is because statistics have shown that speed is a major risk factor that contributes to over 30% of road fatalities within Europe (ETCS, 2018). For instance, in Italy, 172,183 road crashes were reported in 2019, and speed was responsible for over 12.2% of the total fatal crashes on rural roads (ACI, 2019). Thus, speed is an important risk factor and also the leading contributor to death and serious injury on the world's roads (GRSF, 2020). Since the risk factors in the NWA Proactive model are quantified based on Crash Modification Factors (CMF), this means that to incorporate the safety effects of speed, the CMF of speed is required. CMFs are multiplicative factors that represent the proportion of crashes that would be expected after implementing a countermeasure (FHWA-2023). A CMF value quantifies the risk of each risk factor and varies depending on the availability and/or condition of the risk factor. These CMF values are obtained from different databases such as the iRAP methodology factsheets (iRAP 2009), CMF ClearingHouse (FHWA 2020), Road Safety Effect Handbook (Elvik 2009), and some relevant studies. Due to the unavailability of CMF for speed in these databases, the optimum solution would be to develop the CMF for speed to facilitate its incorporation into the model.

Another problem examined is the possibility of implementing the NWA methodology in Africa. Though this doesn't fall within the scope of directive (EC) 2019/1936, it is important to investigate if the methodology can be expanded to roads funded outside Europe by the European Commission. For instance, the European Commission currently funds roads in Africa through the 'Global Gateway Initiative', focusing on transport corridors (Kavalov, 2025). The NWA Proactive methodology assesses risks based on the in-built design characteristic of the road infrastructure. In

Europe, such procedures have demonstrated that they are complementary with crash history (Montella, 2005), (Cafiso et al., 2007), (González-Hernández et al., 2025). However, limited research has been conducted towards investigating whether these types of procedures are effective in identifying hazardous road sections in Africa. In 2024, the Italian procedure, IASP (Identification of Hazard Location) was tested in Egypt, a country in North Africa, and the results were highly significant to crash occurrences (Erieba et al., 2024). Nevertheless, the positive result may be because Egypt and Italy are both Mediterranean countries and share similarities in climatic conditions, weather, and driving behavior. It is also important to remark that the NWA Proactive model has not yet been tested in Africa.

1.3. Objectives

The main objective of this thesis is to improve the predictive performance of the current European network-wide road assessment methodology and also investigate its applicability on roads outside Europe. To achieve this aim, the following specific objectives are considered:

- To identify and critically examine the current road safety assessment procedures. This provides a foundation for understanding the concept behind the development of NWA methodology, which is an integration of results from different methodologies.
- To investigate if speed is a significant risk factor on two-lane undivided rural highways in Italy, and if yes, quantify speed-crash risks by developing a CMF function for vehicle operating speed.
- To improve the predictive performance of the NWA Proactive model by incorporating the safety effects of vehicle operating speed within the model, and investigating the impact of different operating speeds on the model.
- To test the applicability of the NWA methodology on non-European roads. Specific focus is on typical highways in Sub-Saharan Africa, which is the worst-performing subregion in terms of road safety.

1.4. Contributions of this Thesis

The most significant contributions of this thesis include:

•A novel CMF function for speed was developed for two-lane, two-way rural highways in Italy, which captured the safety effects of vehicle operating speeds related to this type of road infrastructure.

•An advanced NWA Proactive model that incorporates the safety effects of operating speed was proposed and successfully applied.

•There is no linear correlation between the NWA Proactive scores and historical crashes on Sub-Saharan African highways, nevertheless, there is enormous potentials in using this model for ranking safety levels of road sections.

1.5. Organization of Thesis

The remaining part of the thesis is structured as follows:

- Chapter 2, the state of practice for road safety assessment, which provides an overall picture of the existing methodologies, analyzing and examining the strengths and weaknesses of each.
- In chapter 3, the CMF function for vehicle operating speed on two-lane, rural highways in Italy was developed.
- Next, in chapter 4, a modified NWA Proactive model is proposed by incorporating the safety effects of vehicle operating speed, comparing the results with the existing proactive model without speed, and examining how this affects the overall prioritization results. The modified model was applied in four different road networks selected in Italy.
- Chapter 5 consists of investigating the applicability of the NWA methodology on a typical Sub-Saharan African highway, specifically the Yaounde – Douala highway in Cameroon, a country in West Africa.
- Finally, chapter 6 ends with the conclusion of the thesis.

CHAPTER 2. STATE OF PRACTICE: ROAD SAFETY ASSESSMENTS

2.1. Introduction

State-of-practice reviews examine existing procedures and approaches within a specific field to identify best practices and make recommendations for improvements. In this study, this type of review aims at identifying and analyzing the existing road safety assessment procedures, providing a practical understanding of their strengths and weaknesses. Generally, road safety assessment procedures are applied to investigate the level of safety of road sections within a road network. It is the first step in road infrastructure safety management and assists decision makers in the proper allocation of budgets meant to improve the road infrastructure. Several procedures have been developed and implemented all over the world, all with the end goal being to improve the safety performance of the road infrastructure. As such, it is important to concretize the concepts embedded in these procedures to provide a better understanding of the current state of practice. In the section that follows, a systematic review was carried out to identify the existing road safety assessment procedures; they are then classified into three main groups based on the approach used; within each group critical analysis of the procedures aimed at identifying the strengths and limitations of each approach is provided.

2.2. Method

2.2.1. Systematic review

To identify the existing road safety assessment procedures, this study adopted the systematic review process. A systematic review is a structured process of answering a well-defined primary question with the main goal of minimizing bias and producing more reliable outcomes (Gough et al., 2017). In this study, the systematic review was conducted following the principles and guidelines provided by the Joanna Briggs Institute (JBI) (McArthur et al., 2015) and the Preferred

Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA-P) (Page et al., 2021) checklist 2020. The main research question guiding this review was: “What are the existing road safety evaluation procedures currently applied for the safety assessments of road infrastructures?” This question sought to clarify the following questions:

- What are the different approaches or methods available for the safety assessment of the roads?
- What road elements are currently being assessed?
- What relationships exist amongst the current procedures?
- How have safety assessment procedures evolved over the years, and what is the future direction?

2.2.2. Search strategy

A search strategy is an important component of a systematic literature review process that ensures the comprehensive identification of relevant studies. A key element in the search is the identification of keywords that would be used to develop the search terms. In this study, the keywords were identified based on the main objective of the review. Based on the keywords, the search terms were developed, and Boolean operators such as “OR” and “AND” were used to broaden or narrow down the search (Higgins et al., 2020). The following search terms were used:

(“Reactive assessment” OR “Network screening” OR “Safety Ranking” OR “Road Assessment Programs” OR “Risk Assessment” OR “Road Safety Inspection” OR “Road Safety Assessment” OR “Road Infrastructure Assessment” OR “Road Infrastructure Safety Assessment” OR “Road Risk Index” OR “Safety Index”) AND “road safety”.

Also, the snowballing technique based on the relevant studies obtained was applied to identify other procedures from individual references.

2.2.3. Databases

After identifying the search terms, bibliographic databases were searched systematically for relevant studies. The search was conducted on the 25th July 2025, in the following databases:

“Scopus”, “Science Direct”, “TRID”, and “Taylor and Francis Online”. All these databases are academic sources, and since this study is focused on the state-of-the-practice, the websites of road agencies or international organizations such as the International Road Assessment Program (IRAP), World Health Organization (WHO), World Bank (WB), Federal Highway Administration (FHWA), and European Commission (EC) were manually searched.

2.2.4. Inclusion and exclusion criteria

The following inclusion and exclusion criteria were considered: Only published papers or reports written in English were considered. This eliminated well-known safety assessment procedures available in other languages. No geographical restriction was defined, and as such, studies from all countries were included. Also, only studies that clearly showed the methodological assessment process involving the data inputs, data collection, evaluation method, and identification of safety levels of road elements were considered. Duplicate studies, as well as those with no full-text files available, were excluded.

2.2.5. Screening

In total, 1100 papers were identified. They were compiled by the Mendeley bibliographic software tool, which made it possible to sort through the references and remove 247 duplicates. In this way, the title and abstract screening of 853 papers was performed, considering methodologies that calculated a risk index based on the physical characteristics of the road. Of these, 773 papers were excluded. Subsequently, the full text screening of 80 papers was performed, considering methodologies that met the previously mentioned IRSA methodology definition. Of these, 54 full-text papers were excluded. Thus, finally, 23 papers were included in the review. Figure 1, provides the summary of the entire process.

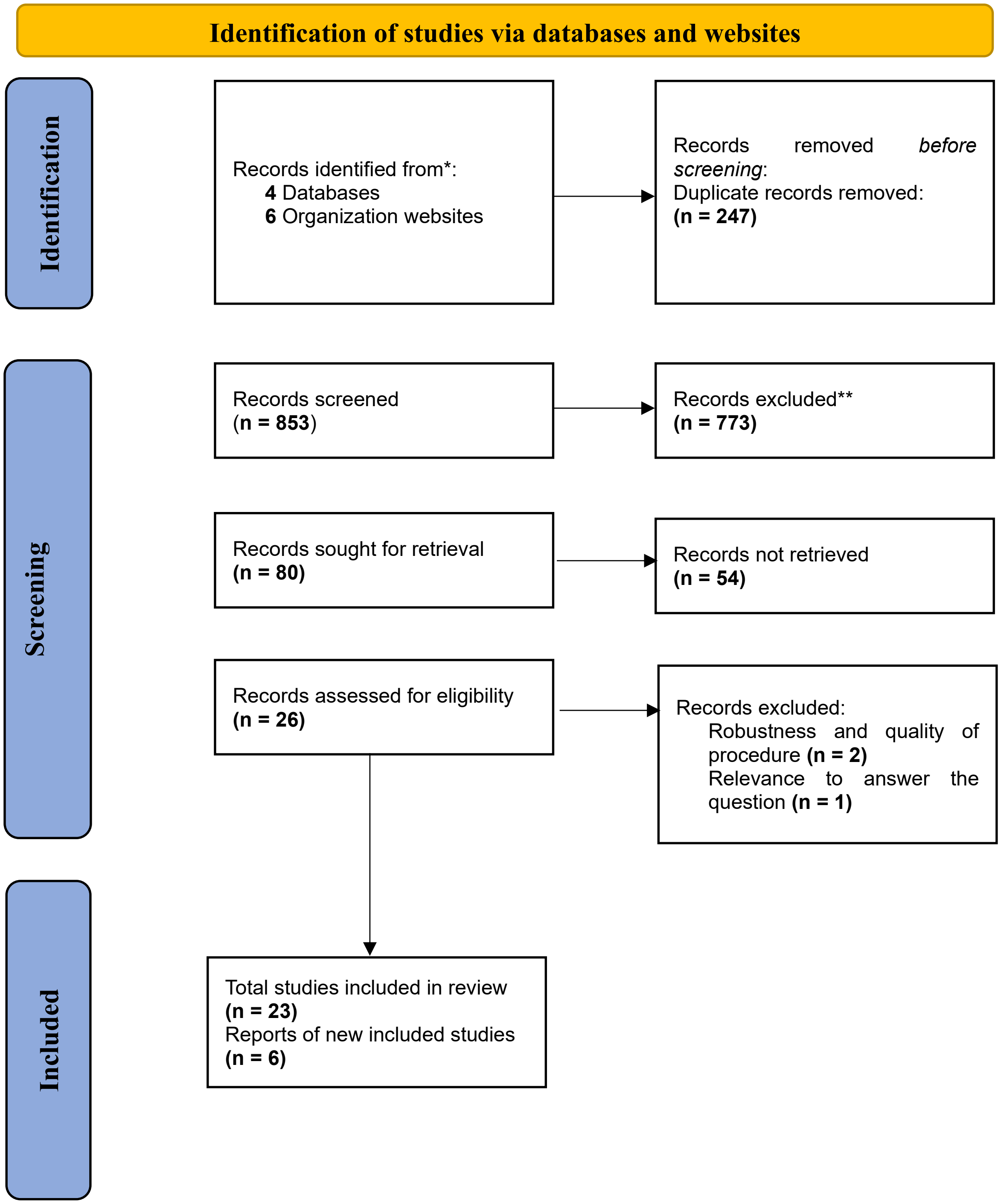


Figure 2-1. PRISMA Flow Chart

2.3. Findings

The road safety assessment procedures identified were classified into three groups: the reactive, proactive, and integrated procedures. The reactive procedures are those that rely mainly on crashes that occurred on an existing road, while the proactive procedures are non-crash related methods that are based on other factors not involving crashes, for instance, road design characteristics, vehicle operating speed, human factors, etc. The integrated assessment procedures are those that combine the results from two different procedures to improve the prioritization of interventions. In the first main group, 13 reactive assessment procedures were identified and further subdivided into crash-based procedures and those based on Crash Prediction Models. Within these two sub-groups, 10 were crash-based procedures, and 3 were procedures based on CPMs. In the second main group, 26 proactive procedures were identified, in which 21 are procedures based on the safety inspection of in-built characteristics of the road infrastructure, 3 are based on vehicle operating speed data, and 2 are based on Human Factors (HFs). Lastly, for the third main group, 3 integrated assessment procedures were identified. **Figure 2.2** presents an overall framework of the different groups of road safety assessment procedures currently applied by safety Practitioners all over the world.

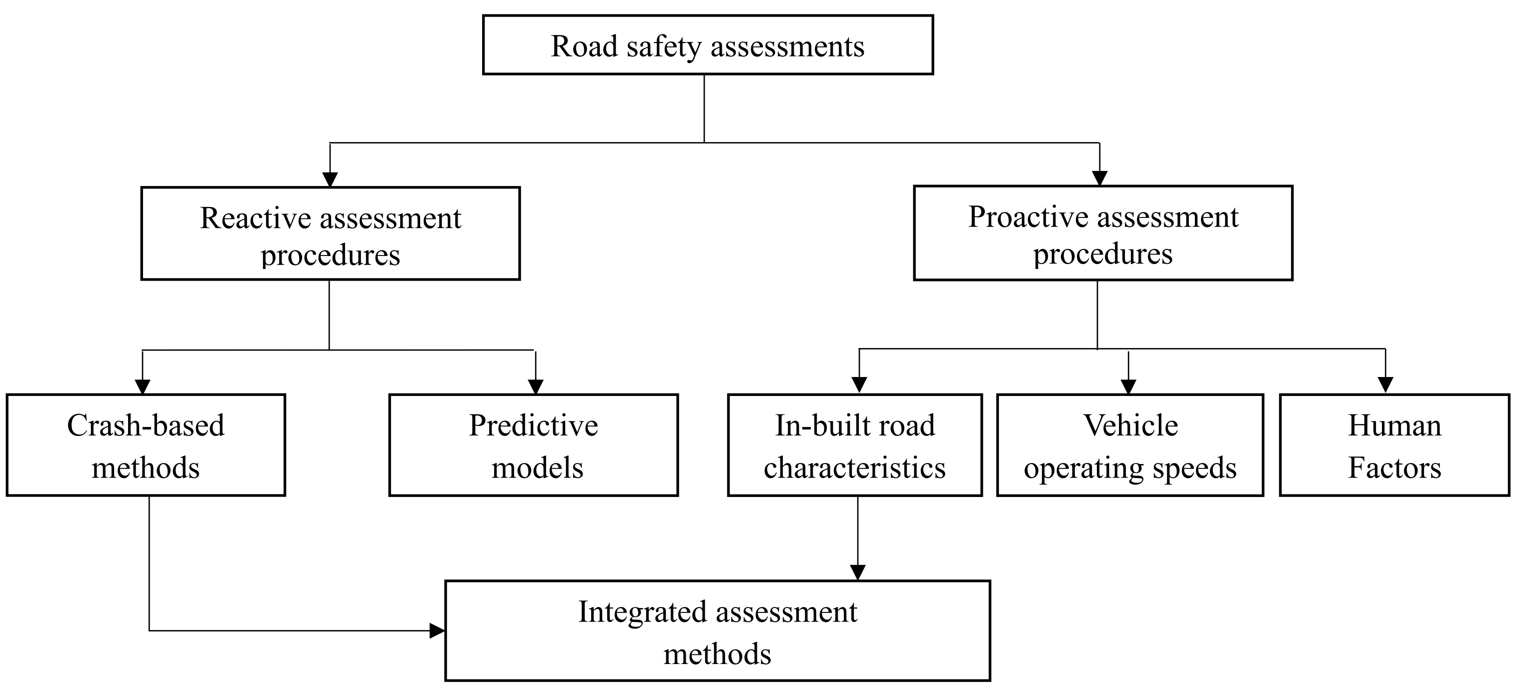


Figure 2-2. Framework for different groups of road safety assessment procedures

The next section briefly describes the different specific procedures and critically compares the procedures within each group, examining the relationships that exist within them in terms of specific thematic areas.

2.3.1. Reactive Assessment Procedures

The reactive assessment procedures have been subdivided into two groups: crash-based procedures and Crash Prediction Models (CPM).

2.3.1.1. Crash-based Assessment Procedures

These are procedures that rely on statistically analyzing crash data recorded on existing road networks over a specific period of time. It involves analyzing crashes based on statistical metrics such as crash frequency, crash rates, crash densities, etc. A summary of the crash-based assessment procedures identified are presented in Table 2-1.

Table 2-1. Summary of crash-based reactive assessment procedures

Author	**Data required**	**Road segmentation**	**Safety Performance Metrics (SPM)**	**Time Period**
AASHTO (2010)	Number of crashes, accident cost data, road geometric data, AADT.	Minimum 0.1 mile (160 meters)	Accident frequency, accident rate, accident cost, PDO equivalent values, accident frequency from APMs.	3 years
Nguyen et al. (2015)	Crash data by severity and location, crash unit cost by severity, basic crash cost, road geometric data, AADT.	Sections and spots on basis of accident occurrence	Crash frequency, Safety Potential (SAPO)	3-5 years
AUSTROADS (2015)	Number of accidents per collision type, number of vehicles involve, cost per collision type, segment length and AADT.	Sections in which fatal crash occur of 200 meters, intersections.	Accident cost, accident density, accident rate	3 years
Transport Infrastructure Ireland (2017)	Crash locations, number of crashes and severity levels, AADT, road geometric data.	Homogeneous sections of 1km	High collision frequency, high collision rate.	3 years

Author	Data required	Road segmentation	Safety Performance Metrics (SPM)	Time Period
iRAP (2020)	Number of crashes and severity levels, crash locations, road geometric data.	Typically around 12 miles (20km)	Crash density (crashes per km), crash rate (crashes per km travelled), crash frequency (crashes per road user, crash cost density (crash cost per distance travelled)	3-5 years
Šarić et al. (2020)	Number of crashes, AADT, segment length.	300 meters	Crash rates, critical crash rate, critical crash rate average.	3 years
Treeranurat & Suanmali (2021)	Number of crashes, and four severity levels (fatalities, serious injuries, minor injuries, and PDO), road geometric data.	100 meters	Equivalent accident number, Upper Control Limit (UCL), Weighted Accident Number (WAN)	3-5 years
Borghetti et al. (2021)	Number of crashes and severity (fatalities, injuries), crash locations, crash social cost, AADT, road geometric data,	Fixed segments of 1 km	Crash frequency, crash rate, social cost index, mortality index, severity index.	3-5 years
Gurung et al. (2023)	Number of crashes and severity levels (fatal, grievous injuries, and minor injuries), road geometric data.	Sections and intersections	Weighted Severity Index (WSI), Prioritization Index (PI)	3 years
Deliali et al. (2023a)	Number of crashes at sections and intersections, AADT, road characteristic data.	Homogeneous sections of maximum length	Crash density, crash rate, average crash rate, average crash density.	3 – 5 years

The next section provides a brief description of all the procedures identified in the summary above.

2.3.1.1.1. Highway Safety Manual (HSM) Accident Analysis Method - AASHTO (2010)

This procedure is found in the HSM Part B and is divided into five steps. The first two steps consist of stating the purpose of the network screening and then specifying the type of sites or facilities to screen. The third step involves the estimation of safety performance metrics such as accident frequency, accident rate, accident-cost frequency, depending on the data available. In the fourth step, the hazardous sections are identified based on any of the following types of screening methods: sliding window, peak window, and simple ranking. Lastly, in the fifth step, a list of the sites identified is ordered according to the selected safety performance metric. The main data inputs in this procedure include: accident data for at least three years with their locations, accident severity types, accident cost data, basic road design data, and traffic volume data.

2.3.1.1.2. Nguyen et al. (2015)

The procedure consists of identifying blackspots based on the 'Potential Saving' in accident costs. The data employed include accident data by severity and location, considering an average crash period between 3-5 years, traffic volume data, and basic accident cost rates. The road network is divided into spots and sections, and blackspots are identified based on the threshold value of the observed number of injury accidents at every road section. A black section in this procedure is any section with the observed number of accidents higher than the threshold value. The method also applied the Poisson statistical test to determine whether the sections identified as hazardous are not merely influenced by random variation in accident counts. Then, the safety potential of the blackspots evaluated is determined based on the annual average accident cost, accident cost density, accident rate, accident cost rate, and basic accident cost rate. Finally, the spots or road sections are ranked according to the magnitude of the safety potential. The higher the safety potential, the more societal benefits can be expected from the improvements.

2.3.1.1.3. AUSTROADS (2015)

This procedure presents a multifaceted approach primarily based on the crash cost metric. This metric is estimated by assigning a crash cost to each crash type. Crash types include single and two-vehicle crashes. The crash costs by crash type are assigned to each crash at every location where there has been a crash. This allows the locations to be ranked and those with the highest total crash costs to be identified. Road sections are ranked with respect to decreasing crash cost. The crash cost method is also used in road safety economic appraisal. Other metrics used include the frequency of crashes within the adopted period, crash rates, and the rate of crashes exceeding a critical value. The metrics are then compared against a predefined threshold, and road sections that experience higher values than the threshold are classified as hotspots. Crash data for a period of 3 to 5 years is typically used as this time frame provides statistical reliability.

2.3.1.1.4. Transport Infrastructure Ireland (2017)

This procedure was developed by Transport Infrastructure Ireland (TII), a state agency in charge of providing sustainable transport infrastructures in Ireland. It consists of statistically analyzing crashes based on two metrics: accident frequency and accident rates. In this procedure, a hazardous road section is the section that exceeds two thresholds; that is the accident frequency and accident rates threshold. Hazardous sections are identified considering accidents with fatalities and injuries, and a crash period of at least three years. This procedure is applied to motorways and other primary divided rural roads and primary undivided rural roads. Sections that are prone to accidents are visually inspected, and all the accident data estimated.

2.3.1.1.5. iRAP Crash Risk Mapping – iRAP (2020)

Crash risk maps are colored-coded maps that show how crash risks vary on different routes. The maps are developed based on historical crash data collected for a minimum period of three years and include fatal and injury crashes. The process begins by breaking down the road network into smaller sections. Typical section length recommended is 12 miles (20km). Then, the safety metrics are determined, including crash densities, crash rates, crash costs depending on the data inputted. Based on the estimated value of the safety metric, the road section is then classified into different risk bands defined with their corresponding chromatic scale as presented in Table 2.2

Table 2-2. Crash density and crash rate risk bands

Risk band	**Crash density**	**Crash rate**
Low	0 to < 0.08	0 to < 1.2
Low-medium	0.08 to < 0.16	1.2 to < 4.9
Medium	0.16 to < 0.24	4.9 to < 8.4
Medium-high	0.24 to < 0.32	8.4 to < 14.2
High	>= 0.32	>= 14.2

2.3.1.1.6. Šarić et al. (2020)

The procedure is divided into five steps. The first step identifies the locations where traffic accidents occurred on the road network in the last three years. In the second step, segmentation is performed at fixed segments of 300 meters. All crashes belonging to each segment are analyzed in terms of the safety performance metrics considered. The third step is the statistical examination of the hazards of each location where traffic accidents have occurred. Metrics estimated include crash rate, average traffic volume for segment and intersection elements. In the fourth step, the critical level of traffic accident for each location is calculated as shown in Equation (2-1).

$$C_{CR} = CR_A + K \times \sqrt{\frac{CRA}{M}} + \frac{1}{2.M} \quad \textbf{(2-1)}$$

Where; C_{CR} is the critical crash rate, CR_A is the critical crash rate average, and K is the coefficient of confidence level. Sections with rate of traffic accidents exceeding the critical crash rate are identified as hazardous sections. In the fifth step, the identified potential hazardous sites are ranked according to the ratio between traffic accident rates and the critical level of traffic accidents.

2.3.1.1.7. Treeranurat & Suanmali (2021)

The procedure is applied to identify black spots and use several data inputs such as accident data of at least three years classified according to severity levels: Death (D), Serious or severe Injury (SI), Minor Injury (MI) and Property Damage Only (PDO) crashes. The method is based on estimating the Equivalent Accident Number (EAN) and the Upper Control Limit (UCL). The accident numbers in each severity level are multiplied by the EAN value to obtain the Weighted Accident Number (WAN), as shown in Equation (2-2)

$$WAN = EAN_D \, x \, D + EAN_{SI} \, x \, SI + EAN_{MI} \, x \, MI + EAN_{PDO} \, x \, PDO \quad (2-2)$$

Where; WAN is the weighted accident number, D is the number of deaths, SI is the number of serious injuries, MI is the number of minor injuries, PDO is the number of property damage only. The UCL is a statistical control chart that is used to compare with the EAN, and the road section that contains the WAN higher than the value of the UCL is defined as a blackspot. The advantage of this procedure is that it does not only rely on total crashes to identify a hazardous location, but employed different severity levels such as death and serious injuries. The limitation of this procedure is that the weight is based on the decision of experts in Thailand.

2.3.1.1.8. Borghetti et al. (2021)

The procedure seeks to analyze road accidents to identify the most critical road segments and then prioritize the allocation of economic resources accordingly. The procedure is divided into five steps. The first step is concerned with gathering road crash data that consists of crash location and type, the number of people involved and their consequences, and site characteristics. A minimum crash period of 3 years is required. The second step consists of identifying the segments with the highest road accident frequency. The road network is divided into fixed segments of 1 km each, and crash frequency is computed over the study period. The segments identified with the highest crash frequency are then computed. The third step identifies the 'black segment' that is the segment showing the worst safety performances among the segments with the highest crash frequency. This safety performance is evaluated based on a set of Key Performance Indicators (KPIs), which include crash rate, social cost index, mortality index, severity index, and injury index. They are assessed chronologically. Step 4 is applied after identifying the black segments and provides a focused evaluation of the road infrastructure and operational characteristics of such segments. The final step consists of on-field inspections considering detailed data such as pavement state, weather conditions, visibility, driver behaviors, and vehicle features.

2.3.1.1.9. Gurung et al. (2023)

The procedure consists of estimating two safety performance metrics: Weighted Severity Index (WSI) and Prioritization index (PI). The accident data are analyzed based on the WSI, while the PI is estimated by assigning a suitable weight to the factors contributing to an accident. The WSI is calculated based on the classification of accidents as fatal (K), grievious injuries (GI), and Minor Injuries (MI) as shown in Equation (2-3).

$$WSI = 41K + 4GI + MI \qquad (2-3)$$

Where; WSI is the weighted severity index, K is the fatal injuries, GI is the Grievious Injuries and MI is the Minor injuries. The location having the highest WSI value is ranked first, followed by the rest. On the other hand, the Prioritization Index (PI) is based on assessing the road attributes and geometric parameters, and it is estimated per road section by adding all the individual weights and normalizing the value using the maximum weight as shown in Equation (2-4).

$$\text{PI} = \frac{\Sigma\, Individual\ Weight}{Total\ Weight\ assigned} \tag{2-4}$$

Based on the WSI and PI values, the most critical section of the road can be categorized.

2.3.1.1.10. Deliali et al. (2023)

The procedure classifies road sections into three categories: high risk, low risk, and unsure. The methodology applies the Poisson method to determine the upper and lower confidence intervals estimated for the observed number of crashes of each site. Based on the intervals, two safety performance metrics can be calculated per section or junction: crash rate and crash density. The data required are the crash data and locations, traffic data, and basic road design/geometric data for road segmentation. The identification of hazardous locations is obtained by comparing the safety performance metric with that obtained for a set of roads with similar characteristics, known as reference populations.

2.3.1.2. Reactive assessments based on Crash Prediction Models

Crash Prediction Models (CPM) are statistical models developed based on historical crash data and geometric characteristics of the road. These models linked road safety performance and crash risk factors. The first models were developed using Poisson regression models, and due to the inability of these models to handle overdispersion, Lord and Mannering (2010) recommended the use of Negative Binomial (NB) models. In road safety assessment, CPMs are used to identify hazardous sites in the road network. This study shall review three internationally applied CPMs, which include: HSM Predictive models, PRACT Predictive models, and ANRAM models.

2.3.1.2.1. HSM Predictive Models – AASHTO (2010)

The HSM Predictive method is a procedure used for estimating the expected average crash frequency of a road network, facility, or site. In this method, the roadway is divided into individual sites that are either homogenous roadway segments or intersections. This method used regression models developed from historical crash data for several number of individual sites. Several regression models have been developed for different road types, such as for rural two-lane roads, multilane rural highways, urban/suburban arterials (AASHTO 2010). Later, more regression models were developed for freeway segments, interchange ramp segments, ramp terminals (AASHTO 2014). SPFs are developed considering some base conditions. So, adjustments are required when it is applied on conditions different from the base conditions. CMFs are used to account for these differences, and the HSM Part D provides over 200 CMFs. Also, since the SPFs were developed with observed data from five different states in the USA, to apply these SPFs in another country or region, calibration is required. Thus, the general form of predictive models in the HSM, for a given type of site, is given as:

$$N_{predicted} = N_{spf} \text{ x } (CMF_1 \text{ x } CMF_2 \text{ x } \ldots\ldots\text{x}CMF_x) \text{ x C} \quad \textbf{(2-5)}$$

Where: $N_{predicted}$: Predicted average crash frequency for a specific year, N_{spf} : Predicted average crash frequency determined for the base conditions of the SPF, CMF: Crash Modification Factors, C: Calibration factor to adjust the SPF for local conditions related to the network where the model is to be applied.

2.3.1.2.2. PRACT Accident Prediction Models (Yannis et al., 2016) (La Torre et al., 2016) (Torre et al., 2018)

These are European accident prediction models developed based on the HSM predictive methods, which can be applied across Europe after proper calibration. PRACT models were developed using data from five European countries including Germany, Italy, UK, Greece, and the Netherlands. PRACT base SPFs were developed using Generalized Linear Models (GLM) with negative binomial distributions. A set of CMFs were also developed which can be used for adjusting the model to local conditions. PRACT models are available for two road types: rural freeway segments, and rural two-lane two-way road segments. The SPFs and base CMFs have been implemented into a computer-based tool, facilitating the model calibration task. The functional form of the SPF for rural freeway segments in “base conditions” is given as:

$$\boldsymbol{N_{SPF}} = L\ x\ e^{[a+b\ x\ In\ (C\ x\ AADT)]} \quad \textbf{(2-6)}$$

Where**;** $\boldsymbol{N_{SPF}}$ is the predicted average crash frequency in one direction of travel, $\boldsymbol{L}$ is the segment length (km), AADT is the average annual daily traffic in one direction of travel (vehicles/day), a,b,c are the SPF coefficients.

2.3.1.2.3. **The Australian National Risk Model (ANRAM) Predictive Models -**(Jurewicz & Excel, 2016)

ANRAM Predictive models are currently used by road safety practitioners and road agencies across Australia and New Zealand to identify road sections with the highest risk of FSI accidents. ANRAM is made up of three main parts: the Risk Assessment Module, Crash Prediction Module, and the Crash Validation Module. In this part of the review, the focus is on the crash prediction module. The crash prediction module is the prediction of the fatal and severe injury accidents for various road network types by considering the traffic volume, and the speed limit in addition to geometric characteristics. This output is referred to as total Predicted FSI accidents and is made up of the Predicted FSI accidents for the five crash types used in ANRAM: run-off-road, head-on, intersection, pedestrian and other. The module works by using each of the five ANRAM Weighting Factors from RAM to adjust the relevant Mean FSI crash value predicted from the model based on the road stereotype, section length and AADT. This way, five Predicted FSI values are produced for each road section. Aggregated, they form the Total Predicted FSI accidents for a given road section. This module contains have over 30 SPFs developed based on data from the jurisdiction of Victoria. The SPFs have been calibrated for use in the entire continent. The Mean FSI accidents is determined as shown in Equation (2-7).

$$\text{M}ean\ FSIij = L \times Aij \times Bij \times AAD\text{T} \qquad \textbf{(2-7)}$$

Where; FSIij is the mean average crash frequency for crash type i, and road type j; L is the length of the road section; Aij is the model constant from the SPF for crash type i and road stereotype j; AADTis the annual average daily traffic for the respective road section; and Bij is the power model exponent from the SPF for crash type i and road stereotype j constant.

Generally, the predictive methods in road safety assessment are applied through the EB technique. The EB method accounts for the overdispersion bias. The predictive models are used to estimate the predicted crash frequency for each road element while the EB technique is applied to estimate the expected crash frequency using predicted crash frequency, observed crash frequency and length dependent overdispersion parameter (Hauer, 2021). At the end, safety quantity determined is known as the "Potential for Safety Improvement" (PSI) which is obtained as a difference between EB estimate and predicted crash frequency (Persaud et al. 1999). The PSI values obtained are used for network screening and ranking the road sections in a descending order.

2.3.1.3. Comparative analysis of the reactive assessment procedures

2.3.1.3.1. Crash data and time period

Crash data is the primary data source used in reactive assessment procedures. It is usually obtained from Police records and is compounded with challenges such as underreporting, missing information, and sometimes not adequate for statistical analysis. The main limitation of the procedure is the fact that it can only be implemented after road users are killed or injured after using the road over some number of years. The review showed that the minimum time period required for the historical crash data varies between 3 – 5 years, which aligns with the recommendations by Elvik et al. (2008). This period is chosen because it is enough to provides a sufficient number of crashes for statistical analysis. The longer period of 5 years is often applied when few crashes are recorded per year, and smaller periods less than 3 years do not ensure a large enough sample size for a robust statistical analysis, and such results would be too susceptible to the Regression-To-Mean (RTM). From the review, only two crash-based procedures accounted for the RTM effect using the Poisson statistical test (Nguyen et al., 2015)and (Deliali et al., 2023b) . On the other hand, the predictive methods account for the RTM effects using the EB technique.

2.3.1.3.2. Road network segmentation

The process of segmentation involves dividing the road into quantifiable units. Homogeneous segments are preferred and is carried out based on certain variables obtained from geometric and operational characteristics such as road category, number of lanes, paved shoulder, traffic volume, speed limit etc. Crash-based methods most often do not require segmentation at the beginning of the analysis, instead segmentation is applied based on the screening methods selected. There are three categories of screening methods most commonly applied namely: sliding window, peak searching window, and simple ranking. The sliding window method is widely implemented for finding segments that meet the criteria of accident's threshold. The sliding window moves across the entire road section to identify segments that meet the threshold value and when the criterion is met, a black spot is identified (Ghadi and Torak, 2017).

2.3.1.3.3. Road element screened

Crash-based procedures are mainly used for the safety assessment of road segments, nevertheless, they can also be applied to other road elements such as intersections, roundabouts, interchanges etc, considering crash data specific to this element is available enough for statistical analysis. This is often difficult to have, making this procedure rarely used for the assessment of other road elements outside of road segments. However, reactive predictive models are applicable for the safety assessment of road elements for instance, ANRAM and HSM have predictive models that can be used for the safety assessment of road segments, different intersection types, and interchanges, while PRACT models are available solely for road segments. Also, the predictive models are available for different road types such as rural and urban roads, thus, this procedure can be applied in urban roads. This is not very feasible for crash-based methods because crash data is rarely available for urban roads.

2.3.1.3.4. Safety Performance Metrics (SPMs)

Safety performance metrics are the statistical quantities estimated for each road segment and used to compare with defined thresholds to establish the safety performance level of a road entity. The following SPMs, which are most commonly applied in reactive assessment procedures include: crash frequency, crash density, crash rates, crash costs, safety potential, predicted crash frequency, and expected crash frequency. The definition of each of the SPMs is provided as shown in Table 2-3.

Table 2-3.. Safety Performance Metrics Commonly Applied

Safety Performance Metrics	Definition	Procedure applied
Crash frequency	*Average number of crashes per year*	
Crash rate	*Average number of crashes per year in relation to the amount of exposure (typically traffic volume).*	Crash-based procedures
Crash density	*Average number of crashes per year over a unit length of a roadway.*	
Crash cost	*Total economic value of all the negative consequences resulting from a crash.*	

Safety Potential (SAPO)	*The difference between the actual accident cost and the expected accident cost.*	
Predicted crash frequency	*Estimated long-term average number of crashes at a specific site (segment, intersection, etc.)*	Predictive procedures
Expected crash frequency	*Estimated long-term average number of crashes expected at a specific site (segment, intersection, etc.)*	

2.3.1.3.5. Identification of hazardous locations

Hazardous locations or safety performance levels of road sections are identified by combining the estimated SPMs with different criteria for comparisons and ranking. Several procedures depend on criteria such as average crash frequency, average crash rate, average crash densities etc. These average metrics are estimated for several road sites that share similar characteristics in terms of geometric and/or operational characteristics. This type of metric is known as Reference Population (RP) and is applied by the following procedures such as AASHTO 2010 (crash frequency method), (AUSTROADS, 2015; Deliali et al., 2023b; Transport Infrastructure Ireland, 2017). The other procedures for instance, Treeranurat & Suanmali (2021) identified hazardous road sections based on Equivalent Accident Number (EAN) and Upper Control Limit (UCL). The EAN is a numeric economic scale used to weigh the degree of accidents. The accident numbers in each severity level is multiplied by the EAN value to obtain the Weighted Accident Number (WAN). On the other hand, UCL is used to determine blackspot location using statistically quality control chart. When the WAN value exceeds the UCL, a hazardous location is identified. Hazardous locations can also be identified based on the safety potential metric type (Hug et al. 2015). One procedure begins by identifying the segments with the highest crash frequency. Then, the following Key Performance Indicators (KPI) are calculated for these segments: crash rate, social cost index, mortality index, severity index, and injury index. The hazardous segment identified is the one with the highest KPI for these segments (Fabio et al. (2021). Lastly, hazardous locations can be identified depending on the estimated Weighted Severity Index (WSI) Prioritization Index (PI) (Gurung et al., 2023).

2.3.2. Review of Proactive Assessment Procedures

Proactive assessments are safety assessment methodologies based on other characteristics except crash data. They are called proactive, because they can be assessed before crash occurrence. These are the most reliable and recommended method for safety assessments, since there is no need to wait for road users to die before the assessment is conducted as it is the case with reactive assessments. Another advantage is that these methodologies are applicable during the preliminary and post-design stage of the road. Several terminologies have been used to identify this type of road assessment methods including, road safety inspection procedures (Cafiso et al., 2007b; Montella, 2005b), Road Assessment Programs (IRAP, 2009; Persia et al., 2016), Proactive method (European Commission, 2023b), and In-built Road Safety Assessments (González-Hernández et al., 2025b). In this review, they are referred to as "Road Safety Inspection (RSI) Procedures".

2.3.2.1. RSI Procedures Based on Road Infrastructure Characteristics

These are procedures assessed through the safety inspection of the design and/or operational characteristics of the road infrastructure, by allocating scores or weights to each feature based on its availability, standard, and condition. For each road section or junction, the total scores are obtained and used to define its safety level. The RSI procedures selected have been divided into two groups: RSI procedures for the safety assessment of road segments, and RSI procedures for the safety assessment of junctions.

Road Safety Inspection Procedures Based on Infrastructure – For Road Segments

A summary of the procedures for the safety assessment of road segments is presented in **Table 2-4.**

Table 2-4: Road safety inspection procedures for road segments

No.	Author	Data required	Road type	Road safety index
1	De Leur & Sayed (2002)	17 road attributes, AADT, posted speed	Rural & urban road	Road Safety Risk Index (RSRI)
2	Montella (2005b)	31 road attributes	Rural highways	Potential for Safety Improvement (PFI)
3	Cafiso et al. (2007b)	18 general road attributes		Safety Index (SI)
4	IRAP (2009)	54 road attributes, AADT, operating & posted speed	Rural & urban road	Star Rating Score (SRS)

5	Appleton (2009)	8 road attributes for segments & 6 attributes for intersection	Rural highway	Road Infrastructure Safety Assessment (RISA)
6	Li et al. (2010)	27 road attributes	Rural highway	Safety Index (SI)
7	Mahgoub et al. (2011)	5 categories of road attributes	Rural highway	Rural Road Safety Index (RRSI)
8	Habibian et al. (2011)	5 main road attributes for segment & 8 attributes for intersection	Rural highway	Safety Index (SI)
9	Agarwal et al. (2013)	8 main road attributes for straight sections, curve sections & intersections	Rural highway	Safety Hazardous Index (SHI)
10	Rosolino et al. (2014)	5 main road attributes	Rural highway	Risk Index (RI)
11	Jurewicz et al. (2014)	44 road attributes	Rural & urban highways	Star Rating Score (SRS)
12	Ambros et al. (2016)	9 road attributes	Regional road	Risk Index (RI)
13	Mohamed Eltayeb Zumrawi (2016)	14 road attributes	Highways	Risk Factor Index (RFI)
14	Demasi et al. (2018)	55 road attributes, AADT.	Urban road	Branch Index Risk (BIR) & Section Index Risk (SIR)
15	Zia et al. (2019)	10 main road attributes	Rural & urban	Infrastructure Risk Rating (IRR)
16	Tripodi et al. (2020)	20 road attributes, AADT, operating speed.	Primary rural road	Global Risk Score (GRS)
17	Cantisani et al. (2023)	5 main road attributes	State highway	Normalized Total Score (TS_{norm})
18	Dragomanovits et al. (2023)	9 general in-built road attributes	Primary divided & un-divided, urban & rural motorways	Proactive Score (PS)

2.3.2.1.1. De Leur & Sayed (2002)

This procedure pioneered the safety assessment of roads based on the inspection of road characteristics away from the traditional method based on crashes. It's a driver-based risk assessment procedure, which depends on a set of road characteristics examined during inspection. The road attributes are assessed and scored during the drive-through inspection by the participants at fixed sections of 5 km. The scores are combined to produce a risk index known as "Road Safety Risk Index" (RSRI) which is a combination of the three components of risks: exposure, probability, and consequence. The road attributes assessed are different for both rural and urban roadways. After testing the RSRI on a 370 km Trans-Canada Highway (TCH), the results showed that it is an acceptable indicator for identifying crash locations and ranking safety levels of road sections.

2.3.2.1.2. Montella (2005)

This procedure consists of a Potential For safety Improvement (PFI) index that is based on risk attributes known to have an impact on road safety. The attributes considered include alignment, cross-section, markings, longitudinal rumble strips, pedestrian crosswalks, delineation, signs, pavement, roadside, and accesses. These attributes are examined and scored during inspection for fixed sections of 200 meters excluding junctions. The score values allocated are 0.0 if the attribute is not present, and 1.0 if the attribute is present. The scores are multiplied by the safety effect of the respective attribute and summed for each section, to obtained the PFI index which is used to rank the risk on the network. The procedure was applied on a 406 km of rural two-lane highways in Italy and the results showed that the PFI index is an acceptable indicator for identifying high risk segments.

2.3.2.1.3. Cafiso et al. (2007)

This is a RSI procedure that was an output from the EU funded IASP Project. It involves the use of both road inspections and well-established design consistency estimation to define a risk index known as "Safety Index" (SI). The SI is developed by combining risk attributes related to the three components of risks: exposure, probability, and consequence. Assessment involves the safety inspections of risk attributes for fixed segments of 200 meters each excluding intersections. The attributes assessed include accesses, cross-section, delineation, markings, pavement, roadside, sight distance, and signs. Each of these attributes are allocated scores depending on the characteristic and condition of the attribute. The scores used are 0.0, 0.50, and 1.0 which represents three conditions- no problem, low-level problem, and high-level problem, respectively. The procedure successfully identified high crash locations on a sample of 100 km two-lane rural highways in Italy. Also, the procedure was recognized by the UK Transport Research Laboratory (TRL) as one of the six promising safety assessment models for testing in the UK (Fletcher et al. 2016).

2.3.2.1.4. IRAP (2009)

This RSI procedure is primarily based on the inspection of road design characteristics. The road data is accompanied by support data such as traffic flow and speed data. The road attribute data is collected using a specialized equipped vehicle and later coded using the VIDA software. Over 60 road infrastructure attributes are assessed and are available in the IRAP Methodology Factsheet 3-

Road Attributes. The safety performance index estimated for each road section is known as "Star Rating Score" (SRS). The SRS is estimated for fixed sections of 100 meters each, and for four road users: vehicle occupants and motorcyclists, bicyclists, and pedestrians. Based on the SRS, the road sections can be ranked into five classes as shown in **Table 2-5.**

Table 2-5: SRS for different road user types

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

2.3.2.1.5. Appleton (2009)

This RSI procedure is known as "Road Infrastructure Safety Assessment" (RISA), developed by the New Zealand Transport Agency. The RISA estimates two risk types: Personal Risk which is the risk related to the individual driver; and Collective Risk, which is the risk related to all road users. Before risk scores are evaluated, a benchmark road is first identified, so that each feature is assigned a risk relative to the benchmark road features. The model is a simple additive model and results in a risk score relative to the benchmark road. The risk score is evaluated for every km of road enabling roads of unequal lengths to be compared. Personal risks are determined relative to the benchmark road, for instance, a risk of 1.3 indicates that a road user traveling on this road has a 30% probability of being involved in a crash than when traveling on a benchmark road. Next, collective risks are evaluated by combining traffic volume to the risk scores. Typical road lengths of 5km are chosen.

2.3.2.1.6. Li et al. (2010)

This RSI procedure proposed a risk index known as Safety Index (SI) to assess risks of vehicle crashes on highway segments. The SI is estimated separately for fatal, injury, and PDO crashes by combining traffic exposure, crash probability, and crash severity. Nevertheless, the SI in this procedure is also used as a decision-making tool to calculate the benefits of highway improvement projects. Risk attributes are assessed for highway segments of average lengths generally less than 1 mile. The attributes include segment length, traffic volume, geometric design, pavement surface condition, safety hardware condition, and roadside features. The procedure was applied for 193 urban and rural highway segments in Wisconsin, and the SI was compared with the crash history on this road. The results showed that the rankings of SI were consistent at a 99% confidence level with those of crash history thus, SI is a good indicator for identifying high crash locations.

2.3.2.1.7. Mahgoub et al. (2011)

This RSI procedure was developed in South Dakota, in the United States. This procedure is based on the inspection of the following in-built characteristics of the road infrastructures: roadside obstacles, signs and delineation, cross-section, alignment and accesses, road surface and maintenance. Each road section is assigned a priority score subjectively based on the probability, consequence, and relative exposure of the road users to hazards. The road safety index assessed is known as "Rural Road Safety Index" (RRSI) and is estimated as shown in Equation (2-8).

$$\text{RRSI} = 100 - \sum DP \qquad \textbf{(2-8)}$$

Where; DP stands for deduct points.

The RRSI assumes that a road section with no safety issues has 100 points. Then, the safety issue of any road parameter caused the deduction of points. The RRSI ranked the road sections according to the safety features and identifies the deficiencies. The procedure considers five categories of parameters, in which each one of them has four levels, ranging from rank 1 to rank 4. Each of the levels is associated with a number representing the "deducting points". The total points per category are different. Points are allocated depending on the impact of the parameters on safety. For each rank, the first rank receives the maximum number of points, while the fourth rank receives the minimum number of points, which is 0. Taking into consideration that the RRSI is estimated by deducting points from 100, it means that the first rank describes the worst condition (i.e., the most unsafe) and the fourth rank corresponds to safe conditions.

2.3.2.1.8. Habibian et al. (2011)

This is an auditing-based RSI procedure, which consists of decomposing the road into six elements and then into safety factors corresponding to each element. These elements include: straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use. The Analytical Hierarchy Process (AHP) is applied to determine the relative contribution of the elements to the safety of a road segment. AHP determines the weight of the elements, and the weighted sum is used to calculate a Safety Index (SI) for a road segment. The SI is given by Equation (2-9) as:

$$SI = \sum_{i=1}^{6} w_i \sum_{j=1}^{ni} u_j \ P_j \quad \textbf{(2-9)}$$

Where; wi is the weight of element i from the six elements, uj is the weight of factor j, pj is the respective score, and nj represents the number of factors in an element. This index is then used to rank the road segments in a network, producing a priority list for further actions.

2.3.2.1.9. Agarwal et al. (2013)

This procedure also used the AHP method to develop its risk index, known as "Safety Hazardous Index" (SHI). The procedure consists of four stages. Stage one begins with the identification of safety factors affecting road safety. The factors identified are hazardous geometrical conditions, hazardous road surface conditions, hazardous shoulder conditions, hazardous drainage conditions, hazardous street light conditions, hazardous road marking conditions, hazardous island conditions, and hazardous traffic sign and signal conditions. In the second stage, the relative importance of safety factors is determined using the AHP. AHP uses pair-wise comparisons to systematically scale the items. Stage three determines the rating of the safety factor condition. The condition rating is assigned between 0 to 1, as presented in Table 2-6.

Table 2-6: Condition rating of road safety factors

S.No.	State of condition	Value
1	Excellent condition	0
2	Good condition	0.1 – 0.24
3	Average condition	0.25 – 0.49
4	Poor condition	0.5 – 0.75
5	Very poor condition	0.75 - 1

At stage four, the road safety hazardous locations are ranked based on the SHI evaluated separately at the straight section, curve section, and at the intersection. The SHI was applied on the Jaipur and Kiashangarh road section, and then compared with the number of accident reports. The results were statistically significant, indicating SHI can be used to identify accident locations on this highway.

2.3.2.1.10. Rosolino et al. (2014)

The procedure consists of identifying risks on a road segment based on road infrastructure characteristics and using the inputs in a multiplatform mobile application to inform drivers about the risks associated with a particular road segment. The risks for each road section are quantified based on the road safety performance index estimated, known as "Risk Index" (RI). The RI is formulated as:

$$\mathrm{RI} = \sum_{i=1}^{n} x_i \ . \alpha_i \qquad \textbf{(2-10)}$$

Where; α_i represents the weight to be assigned to each risk factor (events), x_i is the number of times each of the risk factors occurred within that road section. The risk attributes evaluated include: number of previously occurred accidents, density of intersections/lateral accesses on the road section, road surface abnormalities and irregularities, problems related to horizontal road signs, problems related to vertical road signs, deficiencies of the roadside and safety barriers.

Three levels of risk are defined based on the RI value: Low ($0<\mathrm{RI}\leq0.3$), Medium ($0.3<\mathrm{RI}\leq0.6$), High ($0.6<\mathrm{RI}\leq1$). The index is equal to zero if there are no occurrences related to the risk factors.

2.3.2.1.11. Jurewicz et al. (2014)

The procedure is the first step in the process of estimating severe crash risk in ANRAM methodology and is calculated according to the iRAP Star Rating methodology. However, the procedure uses fewer parameters compared to iRAP, that is, 44 road attributes. The road attributes are surveyed using specialized vehicles to record digital videos of the road that are later coded for each 100-meter road segment using the iRAP VIDA software. The risk score, that is Star Rating Score (SRS), is first calculated for every 100-meter segment, and then aggregated to a road section level at 1-3 km sections, before comparison to the national average for the given road stereotype. The comparison leads to the ranking of road sections as low, average, or high risk. At the end, ANRAM transformed each of the SRSs at the section level into a weighting factor that indicates if the road's individual risk levels are above or below average for each of the five severe crash types considered in the analysis.

2.3.2.1.12. Ambros et al. (2016)

The procedure was implemented as part of the comparative study by Ambros et al. (2016). Road attribute data is collected through drive-through inspection using instrumented vehicles. During driving through the road network concerned, the safety auditor identifies and records the risk attributes assumed to increase crash occurrence and severity. The attributes assessed include horizontal curves, vertical curves, road signs, markings, shoulder, access points, roadside, pavement, and vegetation. Scores are assigned to each risk attribute using a three-point scale risk severity grade. The roadside attribute is scored differently using a seven-point scale, based on roadside hazard rating by Harwood et al. (2000). The risk index is determined for each road segment by summing the risk severity factors and multiplying by the traffic volume. Based on the value of the risk index, the road segment is then classified into any of the proposed three risk severity categories: Low, Medium, and High. Finally, based on the segment risk level, three different RSI recommendations can be made. For the low-risk segments, no RSI action is needed; medium-risk segments, the risk should be eliminated; and for high-risk segments, the risk must be eliminated.

2.3.2.1.13. Mohamed Eltayeb Zumrawi (2016)

This is a numerical rating RSI procedure. The risk index developed is known as "Risk Factor Index" (RFI), which measures the safety hazards condition of highway sections. The risk attributes assessed through visual inspection include: surface distresses and undulations, surface skid resistance, road width and median absence, shoulder drop-off >75mm and edge wear, superelevation at horizontal curves, street lighting, markings and signs, intersection without islands and traffic signals. A rating score is assigned to each attribute according to its availability, standard, and condition. The RFI is a numerical indicator for rating the road hazard condition of an existing road. The numerical rating of the RFI ranges from (0) to (10), where (0) represents the lowest possible condition, and (10) represents the highest and worst possible condition. Based on the RFI score, the road section is classified from "Very low" to "Extreme" as shown in Figure 2-4.

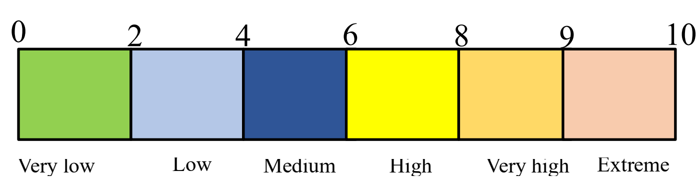


Figure 2-3: The Risk Factor Index scale

2.3.2.1.14. Demasi et al. (2018)

This procedure is designed for the safety assessment of vulnerable road users in urban areas based on the safety inspections of road design and functional characteristics. Risks are assessed at the section and branch levels. The assessment evaluates two main safety indexes, that is, the Branch Index Risk (BIR), and the Section Index Risk (SIR) for urban branch roads. The 9 categories of elements/defects are examined: geometry, cross-section, private access, pavement, lighting, road signs, intersection, urban furniture, and stopping. These categories are subdivided into 56 detailed attributes assessed at fixed segment lengths of 100 meters. These risk attributes are scored subjectively through interviews with technicians and academic experts. Table 2-7 provides the six classes used to classify the road sections with respect to the risk scores.

Table 2-7: Classes of risks

Class	Risk level	Criterion	BIR (%)		Chromatic categorization
			Minimum	Maximum	
I	Not relevant	$1 < \mu - 2\sigma$	0	14.5	White
II	Low	$\mu - 2\sigma<1<\mu - \sigma$	>14.5	21.2	Green
III	Moderate	$\mu - \sigma<1<\mu$	>21.2	28.0	Yellow
IV	High	$\mu<1< \mu+2\sigma$	>28.0	34.8	Orange
V	Very high	$\mu + 2\sigma<1<\mu +2\sigma$	>34.8	41.5	Red
VI	Critical	$1 > \mu + 2\sigma$	>41.5	100	Burgundy

2.3.2.1.15. Zia et al. (2019)

The procedure was first developed in New Zealand before being tested and expanded to Australia. The procedure is designed for the safety assessment of urban and rural roads. The risk index used is known as “Infrastructure Risk Rating” (IRR). The IRR relies on the assessment of a few category road attributes such as land use, road stereotype, horizontal alignment, lane and shoulder width, roadside hazards, intersection density, access density, traffic volume, and speed limit. The last two attributes are considered for rural roads assessment only. The detailed attributes are over 40 and are assessed for each homogeneous road section. The assessment is performed by assigning a value to each variable depending on its condition to calculate the IRR score. Based on the IRR score, the risk level for each homogeneous road section is then classified into one of the following five risk classes in **Table 2-8.**

Table 2-8: Infrastructure Risk Rating Classes

Risk class	IRR Score	
	Urban	**Rural**
High	> 2.22	> 1.64
Medium-high	2.02 – 2.22	1.46 – 1.64
Medium	1.76 – 2.02	1.07 – 1.46
Low-medium	1.49 – 1.76	0.92 – 1.07
Low	< 1.49	< 0.92

2.3.2.1.16. Tripodi et al. (2020)

This is an automated video image RSI procedure, developed based on a few road attributes. The attributes are assessed from videos, OpenStreetMap, and some are manually inputted. The attributes assessed directly from videos include the number of lanes, lane width, curvature, grade, delineation, pedestrian crossing, roadside severity-distance, operating speed, pedestrian observed flow, and bicycle observed flow. The attributes assessed from OpenStreetMap are: intersection type, area type, and property access points. The attribute for road surface condition is obtained using a digital app known as the RoadLab App, which is installed in a Smart Phone during the inspection. Then, six other risk attributes that are inputted manually include: sidewalk, paved shoulder width, median type, traffic calming, facilities for bicycling, and motorcycle dedicated lane. The road safety index applied in this procedure is known as the Global Risk Score (GRS), which is formulated by combining the three components of risks, that is, exposure, probability, and consequence. Depending on the GRS calculated values, the road sections can be classified into one of the five classes presented in Table 2-9.

Table 2-9 ***GRS ranking criteria***

GRS Value	*Risk category*	*Risk color*
GRS < 1.80	*Very low risk*	*Green*
1.8 < GRS < 3.4	*Low risk*	*Yellow*
3.4 < GRS < 6.8	*Medium risk*	*Dark orange*

6.8 < GRS < 17.5	*High risk*	*Red*
GRS >17.5	*Very high risk*	*Black*

2.3.2.1.17. Cantisani et al. (2023)

This RSI procedure was developed based on a weighting system in which weights and scores are assigned to road infrastructure characteristics. The weights are obtained from the European project "Safety Cube" (31), deliverable 5.1, "Identification of infrastructure -related risk factors" (32). Each risk attribute is assigned a color code, which indicates its safety impact on road safety as regarding increasing crash risk, frequency or severity. The color "red" signifies high risk, the color "yellow" signifies probably risk, and the color "grey" signifies unclear risk. The risk attributes are classified as red, yellow, and grey, and are assigned corresponding weights of 1.0, 0.67, and 0.33, respectively. The risk index quantify known as Normalized Total Score, is calculated for a fixed road section of 500 meters, and a chromatic scale is used to classify the section into any of the three classes shown in Table 2-9.

Table 2-10: ...

TS_{normj}	ACC_{normj}	**Normalized Parameters**
Low	Low	< 0.40
Medium	Medium	0.40 – 0.60
High	High	0.60 – 1.00

The RSIs are conducted first during the day to examine the road section and acquire images at specific problematic points, and during the evening to assess the conditions of artificial lighting and the presence of problems that aren't visible with natural light. The procedure was validated by comparing the risk index, TS_{normj}, with the historical crash data on some state highways in Italy, and the results were statistically significant.

2.3.2.1.18. Dragomanovits et al. (2023)

This procedure assesses risks based solely on the in-built design characteristics of the road infrastructure. Ten general road characteristics are assessed for each road section. The risk index is obtained as a multiplicative score of all the road parameters known as "Proactive score". Scores are assigned to each road design characteristic depending on the availability, standard, and condition of the attribute. The CMF values obtained from already established studies are used to score the road attributes. In scoring each road attribute, it is the inverse CMF values known as "reduction factors" that are used. The risks per road segment is quantified by first considering that a safe road section has a score of 100, then this value is then multiplied by the reduction factors of each road attribute. A road section in this procedure can be fixed, with segment length of 500 meters or variable sections can be used, which depends on the homogeneity characteristics of the road infrastructure.

- **Road Safety Inspection Procedures Based on Infrastructure – For Road Junctions**

A summary of the procedures for the safety assessment of road junctions such as intersections, roundabouts, and interchanges, is presented in **Table 2-11.**

Table 2-11: Road safety inspection procedures for road Junctions

No.	Author	Type of junction	Area type	Road safety index
1	Madanu et al. (2010)	Intersection	Rural	Safety Index (SI)
2	Montella & Mauriello (2012)	Unsignalized intersection	Rural	Safety Index (SI)
3	Montella et al. (2020)	Unsignalized intersection	Urban	Safety Index (SI)
4	Riccardi et al. (2022)	Roundabouts	Urban	Safety Index (SI)
5	Zampino (2023)	Interchange	Rural	Road Safety Inspection Score (RSI Score)

2.3.2.1.19. Madanu et al. (2010)

The procedure was designed specifically for intersection safety hardware project evaluation and investment decision-making. It consists of computing the Safety Index (SI) of an intersection based on intersection risk attributes. The SI is formulated by combining the three risk components: traffic exposure factor, crash frequency factor, and crash severity factor. SI is computed separately for fatal, injury, and property damage crashes. The risk attributes assessed include: i) Geometric characteristics such as intersection angle, approached shoulder width, number of through lanes, median width, right and left turn channelization, terrain type, and number of driveways, (ii) Traffic operation characteristics including turning traffic and truck traffic, (iii) safety hardware conditions such as signs, signals, lighting, and pavement markings, and (iv) roadside features such as, embankments, guardrails and barriers, ditches, trees, utility poles, obstacles, and roadside hazard rating. The advantage of the SI is that it can be used for the assessment of the safety benefits of improvement projects related to intersection countermeasures such as intersection signs, signals, lighting, pavement markings, guardrails and barriers, which is different when safety assessments are performed using crash prediction models. The SI was validated using 5-year crash data on 226 highway intersections in Ozaukee County, Wis in the USA.

2.3.2.1.20. Montella & Mauriello (2012)

In this procedure, RSIs of the intersections are carried out by a team of at least two people who are independent of the design and construction team, and who possess deep knowledge on road safety principles. The procedure consists of evaluating a Safety Index (SI) and based on the value obtained, the intersection is ranked for further investigation. The SI was formulated by combining two components of risks: exposure of road users to road hazards, and the probability of being involved in a crash. The risk attributes evaluated consists of ten general issues including: intersection type, sight distance, horizontal alignment, vertical alignment, left and right turn lanes, channelization, markings and signs, pavement and drivers' behaviors. These general issues are further divided into detailed issues. Scores are assigned to each safety issue depending on its condition that is, scores of 1.0, 0.5, and 0.0 are assigned to high-level problem, low-level problem, and no problem respectively. The inspections of the intersections are performed both during the day and night to investigate road user's perceptions with and in the absence of natural lighting. The SI procedure was validated on a sample of 22 rural 3-leg intersections in Italy, with results indicating 84% of the variation in the estimated number of crashes explained by the SI value. The rankings of SI and EB estimate agreed at the 99.9% significance level.

2.3.2.1.21. Montella et al. (2020)

The procedure is similar to the one for rural unsignalized intersections by Montella and Mauriello (2012), except that it is developed for the safety assessment of urban unsignalized intersections, therefore are different to a certain degree. In this procedure, the Safety Index (SI) is also formulated by combining two components of risk: the exposure of road users to road hazards, and the probability of involvement in crashes represented by the risk index. Nevertheless, the SI for urban intersections is made of two elements, one related to vehicles and one to pedestrians. Also, ten general safety issues are assessed: nine to compute the vehicle risk index such as, traffic control, intersection type, sight distance, left and right-turn lanes, channelization, markings and signs, lighting, pavement, and one to compute the pedestrian risk index. Twenty-three detailed issues are assessed from these general issues. The safety issues are ranked with scores equal to 1.0, 0.5, and 0.0 for high-level problem, low-level problem, and no problem respectively. The SI procedure was validated with on a sample of 89 urban intersections in Orange County, Florida in the us. The results were highly significant both for vehicles and pedestrians, with correlation coefficients of 0.66 and 0.58 respectively. Also, further evaluation from Spearman's rank-correlation showed that the SI scores and EB estimate agree at 99.9% with coefficients of 0.78 and 0.93 for vehicles and pedestrians.

2.3.2.1.22. Riccardi et al. (2022)

The procedure assesses the safety of both roundabouts and roundabout approaches and rank them. The Safety Index (SI) is also formulated by combining two risk components: the exposure of road users to road hazards, and the probability of being involved in a crash. The procedure considers 33 detailed safety issues and 5 general issues to compute the risk index. The general safety issues are: (i) Geometric design elements that is, radius of deflection, entry path radius, deviation angle, entry angle, entry width, circulating roadway width, exit radius, exit width, splitter island, and central island; (ii) Markings, such as missing or faded yield line, yield symbol, longitudinal lines, pedestrian crossings, and off-cycle paths; (iii) Signs such as missing or faded or poorly located central island curb, splitter island curb, parking, yield, direction signs, advertisement, and sight distance; (iv) roadway environment issues such as accesses, commercial activities, illegal parking, street furniture, and lighting; (v) Pavement issues such as friction, and unevenness. The SI was validated on a sample of 50 urban roundabouts in Rome, Italy. The correlation between the SI scores and the EB estimate was highly significant both at the roundabout and roundabout level, with coefficients of 0.85 and 0.56 respectively. Spearman's correlation also showed the rankings agree at 99.9% confidence level both at the roundabout level and the roundabout approach level with coefficients of 0.80 and 0.70 respectively.

2.3.2.1.23. Zampino (2023)

The procedure was developed for the safety rating of road interchanges. The safety performance of the interchange is assessed based not only on geometric features and maintenance status, but also on factors which affects the driving behavior as follows:

$$R_p = R_p\,(G, M, HF) \qquad \textbf{(2-11)}$$

Where, Rp is the safety performance of the interchange, which depends on: G is geometric features, M is the maintenance status, and HF is the human factors. The geometric features are assessed using the Interchange Safety Analysis Tool (ISAT) scheme by Torbic et al. (2007). The ISAT was used to decompose the interchange into the following 9 components: interchange configuration, interchange and ramp spacing, approach alignment and cross-section, coherence with geometric standards, ramp design, signing/traffic control systems, maintenance standard (safety barriers, pavement, signals), operational aspects, presence of sidewalks and bicyclists facilities. The RSI score is then calculated as the average score attributed to: I_{RSI1} (geometric features, i.e. items 1-5) and I_{RSI2} (maintenance features, i.e. items 6-9). Each item is scored from 1 to 3 in which, 1, 2, and 3 corresponds to good, medium, and bad respectively. The RSI Human Factor Score (I_{RSE}) is calculated following the PIARC methodology for calculation of HF-Score ( ). The outputs of the three scores, I_{RSI1} , I_{RSI2} , and I_{RSE} indicates the safety performance of that component.

2.3.2.2. RSI Procedures Based on Vehicle Operating Speed

RSIs can also be carried out based on the speeds at which drivers travel. This type of procedure considers explicitly the driving behaviors of road users. This behavior is captured based on the operating speed of drivers. The road components assessed based on operating speeds are the horizontal alignment and/or tangent-to-curve sections.

A summary of the procedures based on operating speed data is presented in Table 2-12.

Table 2-12: Summary of RSI procedures based on speed data

Author	Road component assessed	Speed data used	Safety Index
Ambros et al. (2017) – SAMO Project	Horizontal curve	Multivariate speed prediction models	Speed difference & curve radii
Llopis-Castelló et al. (2018)	Tangent-to-curve sections	Speed prediction models	Inertial Consistency Index (ICI)
Ambros et al. (2024)	Segments	GPS data	Speed-Safety Index (SSI)

2.3.2.2.1. The SAMO Project – Ambros et al. (2017)

This procedure assesses the safety of tangent curve sections based on estimated speed difference and curve radii. The procedure begins by road segmentation to identify the tangent curve segments. Estimation of operating speed is evaluated using multivariate speed prediction models, and the speed consistency is then calculated. Now, based on the speed difference and curve radii, the following three criteria are used to classify the tangent curve sections as such:

- Ascendant ranking of speed difference $\Delta V < -4$ km/h
- Ascendant ranking of curve radii < 400 m
- Descendant ranking of CCR differences > 180 gon/km

The identified curves were ranked on a four-category scale.

2.3.2.2.2. Llopis-Castelló et al. (2018)

This procedure develops an index based on operating speed known as Inertial Consistency Index (ICI) which is used for analyzing safety at tangent-to-curve sections. The index considers the difference between the inertial operating speed profile and the operating speed profile. The inertial operating speed represents the drivers expectations at one point station, estimated as the average operating speed at the previous road segment. On the other hand, the operating speed depends on the road geometric design, and is determined using operating models. A higher difference between these two operating speeds results in a lower consistency and therefore, a higher crash probability. The ranking of the safety performance of these sections based on the ICI is presented in Table 2-13.

Table 2-13: ICI ranking categories

No.	Inertial Consistency Index (ICI)	Class
1	ICI < 10 km/h	Good
2	10km/h < ICI < 20 km/h	Fair
3	ICI > 20 km/h	Poor

The ICI was validated by applying on 1,686 tangent-to-curve sections. The ICI and the crash rates were compared and the results indicated that the higher the ICI is, the higher the crash rate. This makes it suitable for safety analysis of tangent-to-curve road sections.

2.3.2.2.3. Ambros et al. (2024)

This procedure consists of using GPS-based data from different samples of roads. The procedure applied a "Speed Safety Index" (SSI) developed for road segments using three elements: speed, standard deviation of speed, and traffic volume. The SSI was modelled considering the three dimensions of road safety such as exposure, probability, and consequence. The probability or risk component is represented by the standard deviation of speed at the road segment; the consequence is represented by the speed at the road segment, and the exposure is represented by the traffic volume at the road section. The SSI is determined for a road section according to Equation (2-12).

$$\boldsymbol{SSI = \int_0^L \sigma \,.\, S.\, AADT.\, dL} \qquad \textbf{(2-12)}$$

The SSI was validated by correlation analysis with annual average crash frequency using Pearson correlation. All the correlation coefficients obtained from the sample roads were positive with values of 0.7 and 0.6 indicating a higher and moderate relationship respectively.

2.3.2.3. RSI Procedures Based on Human Factors

The Human Factors (HF) approach is another RSI procedure that consists of analyzing the safety performance of road sections based on how HFs interact with the road infrastructure. HFs contribute to the occurrence of accidents in over 90% of crashes (EC, 2001). Generally, the term HFs means a number of psychological and physiological threshold limit values and activity patterns in operating machines, cars, and other technical facilities (Birth, 2013). The main objective of HFs is to reduce the probability of driving operational mistakes. HFs role in road safety considers the change in road environment taking into account human capabilities and limitations that contributes to the reduction of driving mistakes (Borsis and Birth. 20). For several years now, PIARC (World Road Association) has paid special attention to investigating the role HFs play in road safety. For instance, in 2019, PAIRC developed the Human Factors Evaluation Tool (HFET) as a visual inspection procedure that assesses and quantifies the impact of HFs on critical road locations (PIARC, 2019a). A critical location in the road infrastructure is any location that requires the road user to adapt to a new situation for example, a junction, curve, pedestrian crossings and so on ((Borsis and Birth. 20).

In this section on RSI based on HFs, the review shall focus on two procedures that have been developed based on HFs.

2.3.2.3.1. The Human Factor Evaluation Tool - (PIARC., 2019)

This procedure is used to assess the safety performance of critical locations by means of Human Factors aspects. It is developed for the analysis of single black spots. The procedure was formally developed by German researchers (Birth et al. 2017). The HFET was developed following the PIARC three rules of Human Factors: one accounting for the visibility of potentially critical locations, the other for the influence of the field of view, and the final one accounts for the driving logic. The procedure consists of three steps as summarized in Figure 2-5.

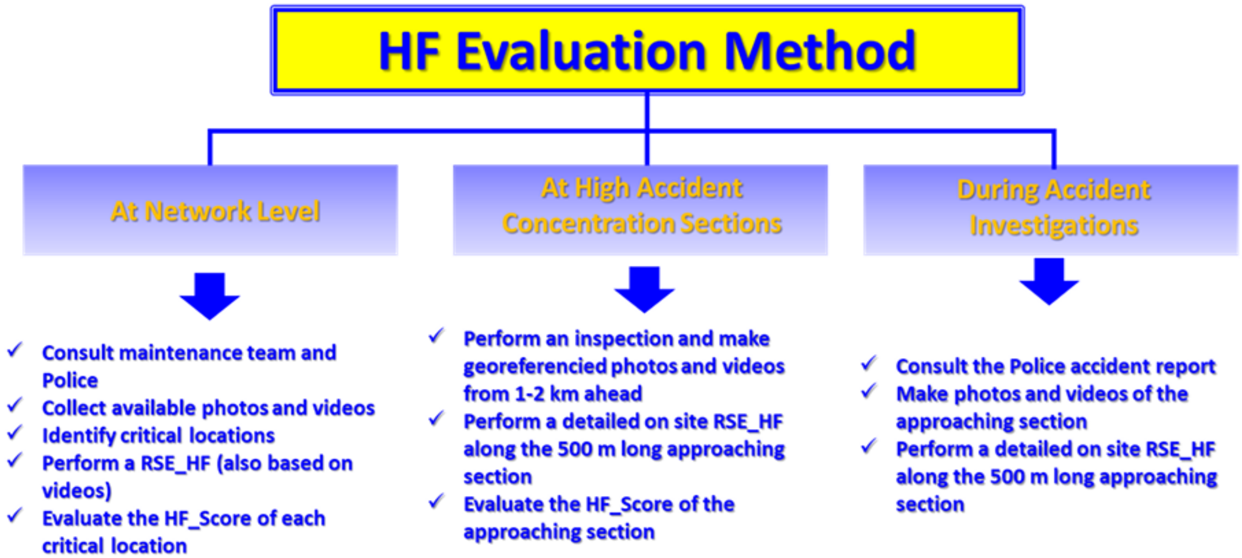


Figure 2-4: Application of the HFET

The HFET is developed for screening single critical locations and not road segments. This means that the procedure provides detailed analysis of critical location details. The HFET consists of three evaluation checklists, one for each HFs rule, and the checklist outputs a numerical value that represents safety risks. The first checklists known as 'investigation topics', is designed to identify the main aspects that requires investigation. The second checklist is 'subsections' and it provides detailed aspects of the road. Lastly, the third aspect is known as 'requirement' which defines the most specific aspects and those that must be voted. Once all the 'requirements' are evaluated and all the cells are filled, the Human Factors Score (HFS) are determined according to Equation (2-13).

$$\mathbf{HFS} = \frac{\sum_{i=1}^{n} \boldsymbol{Actual_i}}{\sum_{i=1}^{n} \boldsymbol{Target_i}} \qquad \textbf{(2-13)}$$

Where; i, is the number of considered condition; n is the total number of conditions; Actual is score in the 'Actual' column; Target is score in the 'Target' column. HFS is calculated for each HF rules separately and summed up to obtained the 'Total HFS'. Based on this total, the HFS is classified into any of the three classes as presented in Table 2-14.

Table 2-14: HFS ranking categories

No.	Human Factor Score (HFS)	Class
1	HFS > 60%	Low risk
2	40% < HFS < 60%	Medium risk
3	HFS < 40%	High risk

The first application of the HFET was carried out by Domenichini et al. 2022 (Domenichini et al. 2022).

2.3.2.3.2. Network-level RSI Procedure Based on Human Factors – (Paliotto & Meocci, 2024) This RSI procedure is an extension of the HFET method. Since the HFET was designed to mainly analyze single locations, which made it very limited in safety assessments, Paliotto and Monica (2024) made some adjustments by extending the application of HFET to a network-wide road safety assessment methodology (NWRSA). Consequently, the new procedure is divided into three different steps shown in Figure 2-6.

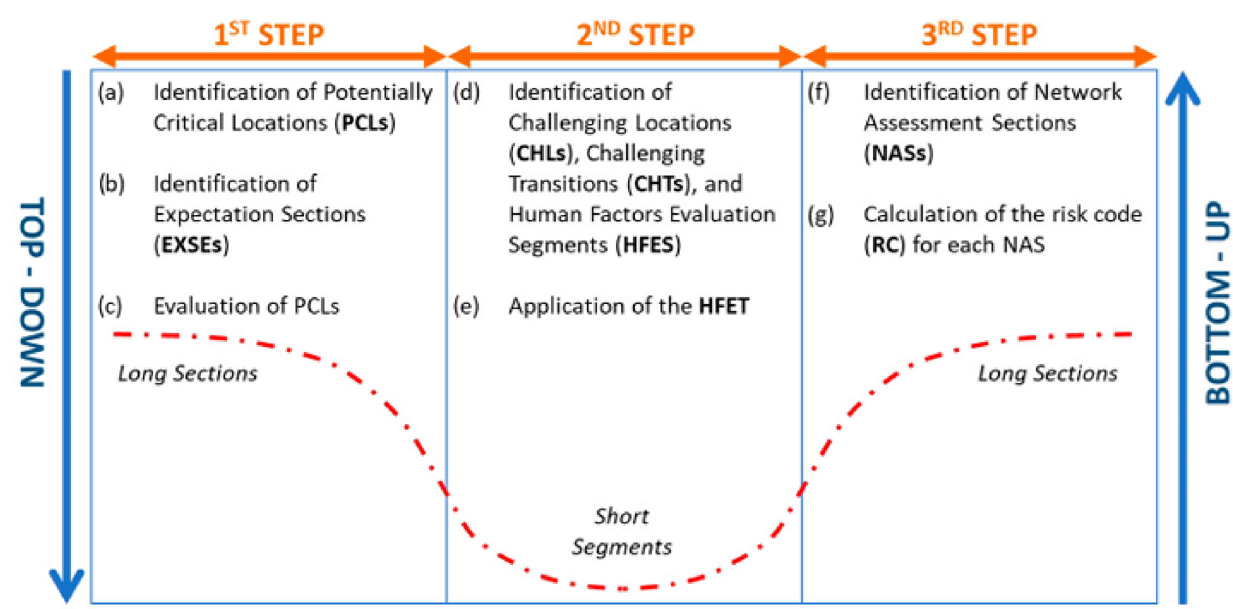


Figure 2-5: The new conceptual framework steps

The first step consists of first screening the road to identify and evaluate the PCLs. The second step is for the evaluation process. The riskiest PCLs are identified and grouped based on their area of influence into segments known as 'Human Factor Evaluation Segments (HFES)'. These are short segments of ranged 300 – 400 meters on average. The third step involves the grouping of many HFES into single Network Assessment Sections (NASs). First, all the NASs are identified and the results are used to rank the road sections. Secondly, for each NAS, a Risk Code (RC) is calculated. The RC identify four different levels of risks, and makes a ranking of the NAS. The NAS final RC is an alphanumerical code that is divided into three parts for instance:

$$\textit{Code format: } \overbrace{\mathbf{AB}}^{1} - \overbrace{\mathbf{C}}^{2} - \overbrace{\mathbf{D/E}}^{3}$$

The first term identifies the safety level of the NAS, while the second term gives a numerical value that represents the most critical HFES within the NAS. The third term is a measure of the variance of the results within the same NAS. This last term shows if within the same NAS, a single critical area is present, and the remaining area of the NAS is in good condition. At the end of step 3, the ranking is obtained for all the NASs belonging to the road network following Table 2-15.

Table 2-15: Ranking criteria within the same risk level group

Priority	**A**	**B**	**C**	**D**	**E**
Higher	R	High value	Low value	Low value	High dispersion
Lower	G	Low value	High value	High value	Low dispersion

The procedure was validated on a case study of six different stretches of two-lane, two-way rural highways in Italy, Germany, and Slovenia, with a total length of about 65 km. The results were validated by comparing the safety levels and the rankings obtained from accident rates and RC. Statistical tests such as the Freeman – Halton extension of Fisher's test was used because of the low number of variables considered. Kendall's coefficient of concordance was also used to measure agreement between different Inspectors who have rank-ordered a set of entities. The results show a high degree of concordance with a risk classification based on the accident rate. Thus, this procedure has the potential to identify and evaluate hazardous road sections.

2.3.2.4. Comparative Analysis of the Proactive Assessment Procedures

The main objective of this section is to compare the three proactive procedures (based on in-built road characteristics, speed, and human factors), and identify the strengths and weaknesses of the procedures. The comparison was carried out under the following teams: data collection system, road segmentation, risk factors/attributes, scoring method, risk formulation, risk ranking, accreditation and training, validation and road component assessed.

2.3.2.4.1. Data collection system

The data collection system refers to the identification and recording of the road attributes required for assessment. This involves identifying the data sources, the type of road inspection, and the method employed for coding the road data.

Data sources: A range of road attribute data sources are often used such as recorded videos, street-view images, aerial imagery, satellite imagery, LIDAR, road asset management datasets. Safety assessment procedures commonly rely on recorded videos (IRAP 2009, Zia et al. 2019, Tripodi 2020,). Some use aerial imagery to assess attributes such as horizontal alignment, access and intersection density (Zia et al. 2019). Open Street Maps have also been used to assess road attributes such as intersection type, area type, and property access points (Tripodi et al. 2020). Street view imagery platforms such as Google street view and Mapillary can be used to assess road attributes such as roadside hazards, land use, and road stereotype (Zia et al 2019), however, it is important to check the date the imagery was recorded. Zia et al. 2019, used road asset management datasets to assess road attributes such as road stereotype, traffic volume, lane width, and shoulder width. Smart Apps have also been used to assess features such as road surface condition (Tripodi et al. 2020).

Type of road inspection: Two types of inspections are often carried out, drive-through inspections and video-based inspections. Drive-through inspections involve the Safety Inspectors recording the road attributes data on a specialized smart tablet as they drive along the road (De Leur and Sayed 2002, IRAP 2009). The next is video-based inspections which involve recording videos of the road as the vehicle travels along (Montella 2005, Cafiso 2007, IRAP 2009, Tripodi 2020). A specialized survey vehicle with an array of cameras aligned to pick up panoramic views of the road is used (IRAP 2010). A normal vehicle is also used in which the camera is fixed on the windscreen to capture a full view of the road (Tripodi et al. 2020). Some inspections are performed during the day and also in the night (Montella 2005, Cantansi 2023) to ensure those aspects not visible during the day are also evaluated during the night.

Coding the road attribute: After identifying the road attribute and classifying it, the next step involves assigning scores to each attribute depending on its condition or characteristics. The process of assigning scores is known as coding. Coding is manually carried for all drive-through inspections, while the process differs for video-based inspections. For instance, IRAP has developed a computer software called 'VIDA' in which, Analyst while viewing the recorded videos, inputs the scores manually, and the program then performs the analysis and ranking of the road sections. In another, some of the attributes are automatically assessed directly from the videos (Tripodi et al. 2020).

2.3.2.4.2. Road segmentation

Road segmentation consists of subdividing the road network into homogeneous segments. The segmentation process begins with the identification of a segmentation approach. There are two main approaches: the first approach considers a road section to consist of segments and junctions, while the second approach considers segments and junctions separately. Habibian et al. (2011) instead decomposed the road into six elements, that is, straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road lane use, while Agarwal et al. (2013) divided the road into straight sections, curve sections, and intersections. Montella (2005) and Cafiso et al. (2007), assess segments without taking junctions into account. After the selection of the approach, the next aspect is to create homogeneous segments; that is, segments with similar geometric and /or operational characteristics. It is then followed by the definition of segment length. Fixed segment lengths can be considered as well as variable segment length along the same road section. Several procedures applied different lengths for fixed segments that vary between 100 meters to 7 kilometers. Three procedures used fixed length of 100 m (IRAP 2009, Demasi et al. 2018, Tripodi et al. 2020), two procedures applied fixed lengths of 200 m (Montella 2005, Cafiso 2007), one procedure used 500 m (Anastasios et al. 2023), two procedures used fixed length of 1 km (Appleton 2009, Zia et al. 2019 for urban roads), two procedures applied fixed length of 5 km (De Leur and Sayed 2002, Zia et al 2019 for rural highways). Li et al. (2010) consider variable segments with average segment length generally less than 1 mile. Vaiana et al. (2014) discretized the road network into square grids with nodes. Each node is considered as an informative node, which contains information related to an area. The radius of this area is set to 250 m. In summary, the most frequently used fixed length used is 100 meters, and only Zia et al. (2019) considered different values of fixed length for rural and urban roads, as shown in Table 2-16.

Table 2-16.. Summary of fixed lengths applied in different procedures

Author/segment length	100 m	160m(1mile)	200 m	500 m	1 km	5 km	Total
De Leur and Sayed (2002)						x	01
Montella (2005)			x				01
Cafiso et al. (2007)			x				01
Appleton (2009)					x		01
iRAP (2009)	x						01
Li et al. (2010)		x					01
Demasi et al. (2018)	x						01
Zia et al. (2019)					x	x	02
Tripodi et al. (2020)	x						01
Anastasios et al. (2023)				x			01
Total	03	01	02	01	02	02	11

2.3.2.4.3. Risk factors/attributes

A risk factor is any road attribute that increases the probability of an accident occurring or worsens the severity of injuries if a crash occurs (ETSC, 2021). They are often referred to as risk factors or risk attributes. They are the design characteristics of the road, used for the calculation of road safety index. Table 2 above indicated that the IRAP (2009) considers the highest number of road attributes in assessing road segments (over 54 infrastructure risk attributes), while Cafiso et al. (2007) used the least number of road attributes (11 risk attributes). Similarly, for road intersections, Maduna et al. (2010) used the highest number of risk attributes (11 risk attributes) while Montella et al. (2020) applied the least number of attributes (9 risk attributes). The most commonly used risk attributes in road intersection are the left/right turns, and markings and signs as shown in Table 2-17.

Table 2-17. Summary of risk attributes for road intersections

Risk attribute	**Maduna et al. (2010)**	**Montella et al. (2012)**	**Montella et al. (2020)**	**Total**
Intersection angle	✓			**1**
Horizontal curvature	✓	✓		**2**
Vertical curvature	✓	✓		**2**
Shoulder width	✓	✓		**2**
Left/right turn lanes	✓	✓	✓	**3**
Signal control type	✓		✓	**2**
Lighting	✓		✓	**2**
Markings and signs	✓	✓	✓	**3**
Roadside hazards	✓			**1**
Channelization		✓	✓	**2**
Signal phasing indicator	✓			**1**
Sight distance		✓	✓	**2**
Pavement surface		✓	✓	**2**
Vulnerable road users			✓	**1**
Intersection type		✓	✓	**2**
Median width	✓			**1**
Drivers behaviour (operating speed)		✓		**1**
Total	**11**	**10**	**09**	**30**

2.3.2.4.4. Method of scoring risk attributes

In RSI procedures, scores are a very significant factor because the entire analysis relies on the type of scores allocated to each risk factor. Two types of scores are often used: qualitative and quantitative scores (Elvis et al. 2025). Qualitative scores are assumed to be numerical values that represent the risk level of a road attribute. They are very subjective as they vary across the different Inspectors depending on their individual experience and training. For instance, De Leur and Sayed

(2002) had each participant drive and then rate the road safety risk based on a subjective 11-point scale, with a score of “0” representing no chance of a near miss, and a score of “10” representing a good chance of a near miss. Regarding the probability risk component, a four point scale was used to assess each road feature. The scores ranged from “0” to “3”, in which, the scores 3, 2, 1 represents high risk, moderate risk, and minor risk respectively. Similarly, Montella (2005) and Cafiso (2007) ranked the safety issues with scores 1.0, 0.5, and 0.0 representing high-level problem, low-level problem, and no problem respectively. Zumrawi (2016) used values ranging from (0) to (10) with “0” being the lowest possible condition, and “10” being the highest and worst possible condition. On the other hand, quantitative scores are values measured for each risk attribute for example, Crash Modification Factors (CMF), which are crash risk values assigned to each road design characteristic depending on its availability and condition. IRAP (2009), Tripodi et al. (2020), and Anastasios et al. (2023) all used CMF values as scores representing the risk level of a road attribute. The CMF values are obtained from the Highway Safety Manual 2010 (AASHTO 2010), IRAP Star Rating Factsheets (IRAP 2009), PRACT Project deliverables (), Road Safety Manual (Rune Elvik 2009), CMF Clearinghouse (FHWA), as well as individual research studies.

2.3.2.4.5. Risk formulation

Generally, in RSI procedures based on infrastructure characteristics, risk formulations are largely developed based on the concept of risks. Risk is defined as the product of its three components: accident exposure, accident frequency and accident severity (Hauer 1982). Based on this, several RSI procedures used the three risk components to develop risk index for road segments (De Leur and Sayed 2002, Montella 2005, Cafiso et al. 2007, IRAP 2009, Li et al. 2010, and Tripodi et al. 2020). For intersections, Maduna et al. 2010 develops risk index based on the three risk components, while Montella et al. (2012), and Montella et al. (2022) uses just two risk components. That is exposure and probability. The ‘Exposure’ component is a measure to quantify the exposure of road users to potential roadway hazards. Probability is a measure to quantify the likelihood of a vehicle being involved in an accident, and severity is the risk of injury of road users given a crash occurred. Appleton (2009) instead calculates personal and collective risks. Personal risk is the risk to the individual driver, while collective risk is the risk to all road users. Other procedures divert from the concept of risks for instance, Habibian (2011) and Agarwal (2013) formulated risk index using the Analytical Hierarchy Process (AHP) through a system of weights suggested by an expert panel. Zumrawi (2016) uses a numerical rating to develop risk index while Zia (2019) determine risk using a multiplicative log equation based on the category score for each road attribute. Mahgoub et al. (2011) and Anastasios et al (2023) applied a scoring system, in which multiplicative scores are applied directly. Regarding speed procedures, Ambros et al. (2024) also formulated the risk index – Speed Safety Index (SSI) based according to the three risk components, nevertheless, what they represent differs from that of RSI based on infrastructure. Instead, the probability component of risk is represented by the standard deviation of speed at the road segment; severity/consequence is represented by the speed at the road segment; exposure remained the same represented by the traffic volume.

2.3.2.4.6. Accreditation and Personnel Required

iRAP recommends two categories of accreditation: (i) Activity accreditation, which is obtained after receiving the training and completing the test. The person then becomes an accredited supplier with membership to be renewed annually based on experience. (ii) Inspection system accreditation which relates to equipment and software used to perform surveys and coding. Inspection systems that are accredited have met the requirements described in the IRAP Inspection System Accreditation Specification, and their manufacturers have signed the IRAP Accredited Supplier Code of Conduct. Inspection system accreditation is renewed every three years and may include retesting of the system.

Regarding the type of personnel recommended, Montella (2005), Cafiso et al. (2007), Montella et al. (2012), Montella et al. (2020), and Maria et al. (2022) recommend a team of at least two people considering they are independent of the design, maintenance, and operation, and also have deep knowledge of road safety principles and are familiar with the RSI procedure. Appleton (2009) require a team of three people to complete the assessment and prepare the report within three days. Habibian et al. (2011) recommend the task to trained road safety auditors or experts.

2.3.2.4.7. Validation

Model validation is the process where the performance of a road safety index is checked against the actual crashes that occurred on the road. The risk index is determined based on safety inspection of the road.

Several validation methods rely on the determination of the correlation between the risk index obtained based on the safety inspection of road and the actual crash data for the road. Also, further test of the validation is carried out by evaluating the level of agreement between the results obtained from the risk index and that from the crash indicators. For instance, De Leur and Sayed (2002), used the Potential for Improvement (PFI) indicator obtained as the difference between the existing collision frequency and the expected collision frequency, and compared it to the risk index obtained through safety inspection. A significant relationship was found between the two indicators.

Different validations have been carried out for iRAP Star Rating methodology (Persia et al. 2020). This include; Mclnerney et al. (2008) examined the relationship between the number of stars and accident costs per vehicle-km, and the study found that as the number of stars decreases, the cost per vehicle-km increases. In another study, Harwood et al. (2010) found a highly significant relationship that showed that as the accident rate decreases, the number of stars increases. Additionally, Vlakveld and Louwerse (2011) found that as the number of stars increases, the average serious accidents rate per million vehicle-km decreases. And lastly, Persia et al. (2020) verified the relationship between calibrated accident prediction models and EuroRAP indicators, and found that the indicators sufficiently explained the different crash indicators.

Several statistical tests have been used to confirm the validation and reliability of the procedures. This include: coefficient of determination (r^2), Pearson's correlation, Spearman's ranked correlation coefficient, Kappa statistics, Root Mean Square Error (RMSE), Chi square test, Mann-Whitney test, Table 2-18.

Table 2-18. Summary of statistical tests used for validation of proactive procedures

Author	Statistical test	Value	Variables	Road type/element	Road length/number
RSI BASED ON INFRASTRUCTURE - SEGMENTS					
De Leur & Sayed (2002)	Kappa statistics	0.419	Between observers	Rural highway / segments	85km
	Coefficient of determination	99% significance	RSRI & PFI		370km
	Spearman coefficient	0.318			
Montella (2005)	Coefficient of determination Spearman coefficient	0.93 0.94	PFI & EB method	2-lane rural highway /segments	406 km

Cafiso et al. (2007)	Coefficient of determination	0.77	SI & EB method	2-lane rural highways / segments	100 km
	Spearman coefficient	0.87			
Appleton (2009)	Coefficient of determination	0.307	Personal risk score & crash rates	Rural road/segment	5 km
		0.6132	Network risk number & number of crashes		
Li et al.(2010)	RMSE	0.96, 0.95, &0.92 for fatal, injury & PDO	SI & EB	Rural & urban highway	193 segments
	Spearman coefficient	0.81, 0.91, & 0.92 for fatal, injury & PDO			
	Chi square test	0.67, 7.08, & 21.06 for fatal, injury & PDO			
	Mann-Whitney U-test	-1.44, -1.71, & -1.15 for fatal, injury & PDO			
Tripodi et al. (2020), validated by Gonzalex et al. (2025)	Coefficient of determination	0.17 & 0.18	GRS & accident frequency	Motorway	1,220 km
RSI BASED ON INFRASTRUCTURE - JUNCTIONS					
Maduna et al. (2010)	RMSE	0.97, 0.99, & 0.98 for fatal, injury & PDO	SI & EB method	Highway intersections	226 intersections
	Spearman coefficient	0.81, 0.92, & 0.96 for fatal, injury & PDO			
	Chi square test	0.40, 1.42, & 2.64 for fatal, injury & PDO			
Montella and Mauriello (2012)	Coefficient of determination Spearman coefficient	0.84 0.84	SI & EB method	Rural 3-leg intersections	22 intersections
Montella et al. (2020)	Coefficient of determination	0.66 for vehicles	SI & EB method	Urban 3 & 4-leg intersections	56 three-legs & 33 four legs (total 89 intersections)
		0.58 for pedestrians			
		0.20 for vehicles	SI & PFI		
		0.19 for pedestrians			
		0.78 for vehicles			

	Spearman coefficient	0.93 for pedestrians	SI & EB method		
		0.29 for vehicles	SI & PFI		
		- 0.52 for pedestrians			
Riccardi et al. (2022)	Coefficient of determination	0.85 roundabout level	SI & EB method	Urban roundabouts	50 roundabouts
		0.56 approach level			
	Spearman coefficient	0.80 roundabout level			
		0.70 approach level			
RSI BASED ON SPEED					
Llopis-Castello et al. (2013)			Inertial Consistency Index & crash rate	Rural road segments	20 road segments including 370 tangent-curve segments
Ambros et al. (2024)	Pearson correlation	0.82 for injury crashes for Czech	Speed Safety Index & crash frequency	Primary roads	21 Czech & 12 Polish through roads
		0.92 for all crashes for Czech			
		0.83 for injury crashes for Polish			
RSI BASED ON HUMAN FACTORS					
Paliotto et al. (2024)	Freeman-Halton extension of Fisher's test		Risk Code & accident rate		
	Kendall's W	0.78			

2.3.3. Review of Integrated Assessment Procedures

Generally, they are two main approaches to road safety assessments: the reactive and proactive approaches. Each of these approaches has unique strengths and weaknesses that can be leveraged to achieve more accurate identification of the safety levels of road sections. In this regard, integrating or combining the strengths of each approach, could improve the effective identification of safety interventions and ultimately the allocation of safety investments. The concept of integrated assessments recently originated from directive (EU) 2019/1936 of the European

Parliament and the Council of 23rd October 2019, amending directive 2008/96/EC on Road Infrastructure Safety Management (European Commission, 2019). The outcome of the directive led to the introduction of a new methodology known as “Network-wide Assessment” (NWA), which consists of the reactive and proactive components. The reactive component assesses roads on the basis of crash data while the proactive focuses on the in-built assessment of risks. The two components are both applied over the same network and the resulting assessment outcomes are combined through an integration methodology, to prioritize the road sections into five different classes. Therefore, integrated assessment methodologies can be considered as safety procedures developed by taking advantage of the strengths and weaknesses of reactive and proactive approaches, resulting to combining the outcomes of the two approaches to produce a unique ranking of the road sections. Based on this, this study revealed the following integrated assessment procedures.

Table 2-19: Summary of the current integrated assessment procedures

Author	Components			Country
	Reactive method	Proactive method	Integration method	
Toraldo et al. (2025)	Crash maps	IRAP	CBA	Italy
Conticini et al. (2025b)	Reactive Index	Proactive Index	Safety Index	Italy
European Commission (2023b)	Crash rates & crash density	Proactive score	Matrix system	Greece, SPAIN,

2.3.3.1. – Toraldo et al. (2025)

This procedure integrates reactive and proactive approaches to enhance decision-making for urban road safety improvement projects. The integration is by Cost Benefit Analysis (CBA) to prioritize safety interventions, ensuring optimum allocation of investments. The reactive component involves the analysis of historical accident data to identify high-frequency accident zones. This is performed by analyzing the geolocated accident data, to identify accident patterns and or clusters of accidents on maps. On the other hand, the proactive component assesses the road based on iRAP Star Rating methodology. This methodology assesses the intrinsic safety of roads by analyzing geometric characteristics, traffic flow, and speed. See section 1.2.3 for IRAP Star Rating methodology.

Then, integration is determined through CBA of the proposed solutions. This is carried out by evaluating the social cost reduction benefits of reducing accidents alongside the costs of implementation. CBA allows for the comparison of various proposals to identify those that maximize benefits relative to costs, directing resources on interventions that have the greatest impact on reducing accident-related social costs.

2.3.3.2. Conticini et al. (2025)

This procedure is developed by ANSFISA (Italian National Agency for Safety of Railway, Road and Motorway Infrastructures) and is based on the combination of the reactive and proactive approaches.

The ANSFISA proactive approach assesses the 'Proactive Index' (PI), which consists of two components of risk: the exposure of road users to hazards (exposure factor), and a Risk Index (RI) which measures the probability of being involved in a crash and the resulting component should a crash occur. Thus, PI is mathematically given as:

$$PI = Expo\ x\ \Pi RI_i = Expo\ x\ RI_{geo}\ x\ RI_{sec}\ x\ RI_{acc}\ x\ RI_{pav}\ x\ RI_{mar}\ x\ RI_{rs}\ x\ RI_{tun} \quad \textbf{(2-14)}$$

Where; PI is the Proactive Index; Expo is equal to $\frac{AADT_{avg}}{1000}\ x\ e^{0.2xP_{av}}$, $AADT_{avg}$ is the Average Annual Daily Traffic in the analysis period, P_{avg} is the average proportion of heavy goods vehicles, RI_{geo} is the risk index of the alignment, RI_{sec} is the risk index of the cross-section, RI_{acc} is the risk index for accesses and minor intersections, RI_{pav} is the risk index for pavement, RI_{mar} is the risk index for markings, RI_{rs} is the risk index for roadsides, and RI_{tun} is the risk index of the tunnels. The procedure proposes minimum segmentation limits such as: 500m, 1000m, and 2000m for undivided rural roads, divided rural road, and for motorways respectively.

The ANSFISA reactive approach assesses the 'Reactive Index' which relies on the Empirical Bayes (EB) method. It is defined as:

$$Reactive\ Index = \frac{EB}{L\ x\ N} \quad \textbf{(2-15)}$$

Where; EB is the expected number of crashes, L is the segment length, and N is the analysis period length.

The Integration approach consists of combining the Proactive Index and the Reactive Index into another index known as "Safety Index" (SI), defined as:

$$SI_i = 0.6\ x\ \frac{PI_i}{PI_{max}} + 0.4\ x\ \frac{RI_i}{RI_{max}} \qquad \textbf{(2-16)}$$

Where; SI_i is the Safety Index of the segment i, PI_i is the Proactive Index of the segment i, PI_{max} is the maximum Proactive Index in the road network, RI_i is the Reactive Index of the segment i, and RI_{max} is the maximum Reactive Index in the road network. The weight of PI is higher than the weight of RI because the crash data accuracy is not constant across the road network.

Based on the SI scores, the road segments are then ranked according to the decreasing value of the Safety Index as illustrated in Table 2-20.

Table 2-20: Risk Classes

Safety Index (SI)	Risk Classes
$\geq SI_{90}$	High
$\geq SI_{70}$ and $< SI_{90}$	Medium-high
$\geq SI_{30}$ and $< SI_{70}$	Medium
$\geq SI_{10}$ and $< SI_{30}$	Medium-low
$< SI_{10}$	Low

2.3.3.3. European Commission (2023)

The Network-wide Road Safety Assessment (NWRSA) is a systematic methodology that combines results from the reactive and proactive assessment methods to prioritize interventions into five ranking categories and propose further actions. The reactive approach is based on crash occurrence analysis, while the proactive approach assesses risks on the road based on the inherent design characteristics of the road. The reactive and proactive results are combined based on an integration matrix to output the results into five priority classes. After prioritization of the road sections, the future works consists of identifying the type of road safety inspections to be conducted based on the priority class. The main advantage of the procedure is that it leverages the strengths and limitations of two procedures, thereby producing more accurate identification of hazardous road sections.

2.3.3.4. Comparative Analysis of Integrated Assessment Procedures

2.3.3.4.1 Integrated methods

The overall objective of integrating two methodologies is to prioritize safety interventions by leveraging the strengths of the two methods involved. The results obtained from the combined outputs enhance strategic decision-making in road safety planning and management. The three different methods applied in combining the results of different integrated methodologies include: the matrix system (European Commission, 2023b), the safety index method (Conticini et al., 2025b), and the CBA method (Toraldo et al., 2025).

The matrix system in the European NWA procedure consists of a set of rules to determine whether the proactive or reactive approach should be prioritized over the other. For roads with no crash data or low crash data, the road section is classified based on the proactive results only. For road sections with sufficient crash data, the following conditions must be fulfilled:

- If the reactive results show the road section is unsafe, that section is classified based on that reactive class, no matter the proactive results.
- If the reactive class is ‘safe’, then use the proactive class results to classify the road section.
- If the reactive class is “unsure”, then the road section is classified based on the proactive class result.

The safety index method in the new Italian NWA combines the proactive index and the reactive index by allocating weights to each index. The weight allocated for the proactive index is 0.6, and that of the reactive index is 0.4. The weight assigned to the reactive index is lower because crash data accuracy is not constant across the road network (Montella et al. 2013, 2019).

The CBA method by Toraldo et al. (2025) quantifies and compares implementation costs with anticipated benefits. Then, based on this, the benefit-cost ratio (BCR) is determined and used to rank interventions across the sites assessed. The benefits here are mainly in terms of reduced accident rates and severity. Unlike the other two methods, the CBA method does not depend only on safety impact, but also considers the economic aspects. Nevertheless, this method is time-consuming and data-intensive compared to the other integration method.

2.4. Discussion

The systematic review identified over 44 road safety assessment procedures currently applied by safety Practitioners worldwide. The procedures were classified into three main groups: reactive, proactive, and integrated safety assessment procedures. This classification is primarily based on the main type of data used as well as the methodological approach adopted. Generally, a road infrastructure can be decomposed into different components such as segments, horizontal curvatures, intersections, roundabouts, interchanges etc. The safety assessment procedure should focus on evaluating the safety performance levels of each of the road components. The review found that some procedures consider the road sections as a whole unit, while other procedures are developed specifically to evaluate a particular road component. The latter procedure is the most preferable since it is economical for road agencies to focus on the road component that has developed safety issues. Table 2-21 illustrates the different approaches and the road component assessed.

Table 2-21. Safety assessment procedures and road components assessed

Road element / **Procedure**	**Segments**	**Curvatures**	**Intersections**	**Roundabout**	**Interchange**
Crash-based methods	✓	-	✓	✓	-
Predictive model-based	✓	-	✓	✓	✓
RSI based on infrastructure	✓	-	✓	✓	✓
RSI based on speed	✓	✓	-	-	-
RSI based on human factors	✓	✓	✓	✓	-

Table 2-22 Strengths and Limitations of the Current Road Safety Assessment Procedures

Safety Assessment Procedure	**Strengths**	**Limitations**
1. Reactive assessments		
• ***Crash-based***	-Very easy to apply if historical crash data is available. -Less costly to implement compared with other procedures. -	-Road users must die or be seriously injured before the procedure is applied. -Most of the procedures do not account for regression-to-mean effects. - Road traffic crash data are often missing or underreported. -Preliminary study to obtain the reference population especially the first time is very expensive. - Often not applicable for implementation on some roads due to lower number of crashes for example secondary roads. - Safety Inspectors must wait for accidents to happen before any analysis are made.
• ***Predictive model-based***	-The methods are very objective since the effects of road geometry and operational characteristics are considered. -Easy to implement after the predictive models have already been established. - Predictive models have the advantage over crash-based methods in that they are able to model accident frequency non-linearity while also taking into account multiple explanatory variables.	- Requires too much data for its development, that is, it is a data-intensive method. - Require a high level of expertise in statistical modeling. -Faced with transferability issues when the predictive models are to be implement in areas different from where they were developed. -

2.Proactive or RSI procedures • ***RSI based on infrastructure characteristics***	- Easy to implement. - Very effective in areas without crash data. - Validated based on actual crash data.	- Depending on the number of road attributes surveyed, the manual coding of the attributes is time-consuming. -Very costly when specialized vehicles are used. - Only a few of the procedures are available for urban road assessment.
• ***RSI based on vehicle operating speed***	-Provided speed data is available, the method is relatively simple to apply. -It is the only assessment procedure applicable for the safety assessment and ranking of horizontal curvatures.	-Time-consuming when speed data is acquired from speed prediction models. - Rely on floating car data which only a small number of vehicles actually use the GPS when driving. - Difficult to implement on continuous road segments using CCTV cameras.
• ***RSI based on human factors***	-They are estimated based on human factors, which are the main crash contributory factor responsible for over 60% of accidents. - These methods are very much oriented towards the safe system principles. -Considers the physiological state of drivers.	-Analyzing all the potentially critical locations that belong to a particular road stretch is very time-consuming. -Data-intensive.
3. Integrated procedures	-Provides accurate identification of crash locations by leveraging the strengths of two procedures. - Very efficient for making safety investment decisions.	-Since one of the procedures used for combination relies on crashes, the integration is often compounded with zero crashes for several road sections. - Also, the procedure is not applicable for all road types, for instance, secondary roads due to the unavailability of crash data.

2.5. Summary of chapter

The main objective of this review was to identify the existing road safety assessment procedures currently applied by Practitioners to improve the safety performance of road infrastructures worldwide. The systematic literature review process was adopted based on the Joana Briggs Institute (JBI) protocol and following the PRISMA flow chart. The findings showed that there are over 44 road safety assessment procedures that can be classified into two main approaches: reactive and proactive approaches. The reactive methods are further divided into crash-based methods and predictive model-based methods. The proactive methods, also known as "RSI" procedure, were divided into three component that is, RSI based on infrastructure characteristics, RSI based on vehicle operating speed, and RSI based on human factors. For each main group (reactive and proactive), a comparative analysis was carried out under different thematic topics to further provide understanding about the main characteristics of each procedure. Also, based on this critical analysis, the strengths and limitations of each procedure were synthesized, and the specific road elements assessed by each procedure were identified. Overall, this review is very essential for road safety Practitioners, Engineers, and Researchers and serves as a guide in selecting the appropriate assessment procedure for a road safety problem.

CHAPTER 3. DEVELOPMENT OF CRASH MODIFICATION FACTOR (CMF) FOR SPEED

Introduction

Speed is generally is recognize as an important road safety factor, and contributes to the increase and/or decrease in the probability and severity of a crash (Imprialou et al., 2016), (Vadeby & Forsman, (2018). However, most road safety network screening methods such as the Highway Safety Manual (HSM) Prediction models (AASHTO, 2010), PRACT Prediction models (La Torre et al., 2016) and the new European Network-wide Assessment (NWA) methodology (European Commission, 2023b) do not consider the safety effects of operating speed. This situation may be due to the absence of CMFs for speed in international CMF databases such as CMF Clearinghouse (FHWA, 2016), HSM 2010, PRACT CMF repository etc. Das et al., (2024) developed the CMF of speed for 12 different road types in the USA using data from Washington and North Carolina. However, due to the large differences between the driving behaviors, vehicle types, and road infrastructure between the USA and Italy, the application of this CMFs for speed in Italy would require some transferability issues fixed. As a consequence, this chapter aimed to develop a CMF function for vehicle operating speed for two-lane, two-way rural highways in Italy. The cross-sectional method was adopted for this study and follows a similar method to that by Das et al., (2024). The operating speed data was obtained from Floating Car data (FCD), and the focus was on tangent segments only.

3.1. Background

The background section demonstrates several inconsistencies regarding some studies that focus on the relationship between speed and crashes, both theoretically and empirically.

3.1.1. Theoretical background – Nilsson's Power Model

Though the Power model remains one of the most widely used modelled that explains the relationship between speed and crashes, there are still inconsistent findings from different studies. The model was proposed by the Swedish researcher Goran Nilsson in 1982 (Nilsson, 1982). It models the relationship between changes in speed and changes in the number of accidents or the number of accident victims in terms of six power functions, all of which have the following form:

$$\frac{Accidents\ after}{Accidents\ before} = \left(\frac{Speed\ after}{Speed\ before}\right)^{Exponent} \qquad (3\text{-}1)$$

The relative change in the number of accidents or killed or injured road users is estimated by raising the relative change in speed to an exponent. Speed in this case, refers to the mean operating speed of vehicles. The value of the exponent varies according to accident or injury severity. Nilsson (2004) evaluated the outcomes from a large number of speed limit changes in Sweden, assessing the changes in fatal and injury crashes, while also recording the changes in mean speeds. The starting speed limits ranged from 90km/h to 130km/h, included increases and/or decreases of 20km/h, and control roads where no change in speed limit occurred. The study found that the changes at all three severity levels were consistent. Also, in that same year, (Elvik R et al., 2004), evaluated the Power model using a meta-analysis of 98 studies containing a total of 460 estimates of the relationship between changes in mean speeds and changes in road crashes. The study found values of some of the exponents slightly different from those proposed by Nilsson. This is illustrated as shown in Table *3.1*.

Table 3-1. *Comparison between Nilsson and Elvik Power exponents*

Crash type	Nilsson (2004)	Elvik et al. (2004)	difference
Fatal crashes	4.0	3.65	+0.35
Fatal and serious injury crashes	3.0	3.29	-0.29
All injury crashes	2.0	2.65	-0.65

Considering the effects of initial speed on the Power model, two re-analyses of the model by Hauer E. & Bonnesson J., (2006) showed that the effect of changes in speed on crashes depends on the initial speed. Hauer (2006) developed an exponential model to account for these variations, and the findings are shown in Table 3-2.

Table 3-2. Comparison of the effects of initial speed on crashes by Hauer (2006), and by Elvik, Christensen and Amundsen (2004). (Source: (Elvik, 2009))

		Original 2004-analysis		2006-re-analysis	
Initial speed (mph)	New speed (mph)	Urban arterials	Freeway or rural highway	Urban arterials	Freeway or rural highway
		Estimates for fatal accidents			
30	27	−32%	−32%	−30%	−42%
40	36	−32%	−32%	−29%	−38%
50	45	−32%	−32%	−28%	−36%
60	54	−32%	−32%	−28%	−34%
70	63	−32%	−32%	−27%	−33%
		Estimates for injury accidents			
30	27	−19%	−19%	−19%	−33%
40	36	−19%	−19%	−18%	−29%
50	45	−19%	−19%	−17%	−26%
60	54	−19%	−19%	−16%	−24%
70	63	−19%	−19%	−16%	−23%
		Estimates for property-damage-only accidents			
30	27	−10%	−10%	−16%	−31%
40	36	−10%	−10%	−15%	−26%
50	45	−10%	−10%	−14%	−23%
60	54	−10%	−10%	−13%	−21%
70	63	−10%	−10%	−13%	−20%

The findings in Table 3-2 showed that the Power model predicts the same percentage change in crashes for the same percentage reduction in speed, which is not acceptable. Instead, Hauer (2006) considered the effects of initial speed, which revealed that the effects of a given percentage change in speed is larger at low speeds than at high speeds. And most importantly, the effects of speed tend to be slightly smaller than predicted by the Power model for fatal accidents and injury accidents on urban arterial roads. In the second analysis by James Bonneson (2006), using a set of differential equations, he found that the effects for fatal accidents are considerable larger than those predicted by the Power model as illustrated in Table 3-2 above.

Based on these two re-analyses of the Power model by Hauer E. & Bonnesson J., (2006)illustrating that the effects of speed changes depend on the initial speed, (Elvik, 2013)disagreed with this analysis for reasons that they relied rather on individual data points and neglected data on residential roads. As a consequence, Elvik, (2013)decided to re-parameterized the Power model by fitting exponential functions to data points. The findings showed that the Power model and the exponential function fit the data extremely especially for fatal crashes as illustrated in Figure 3-1:

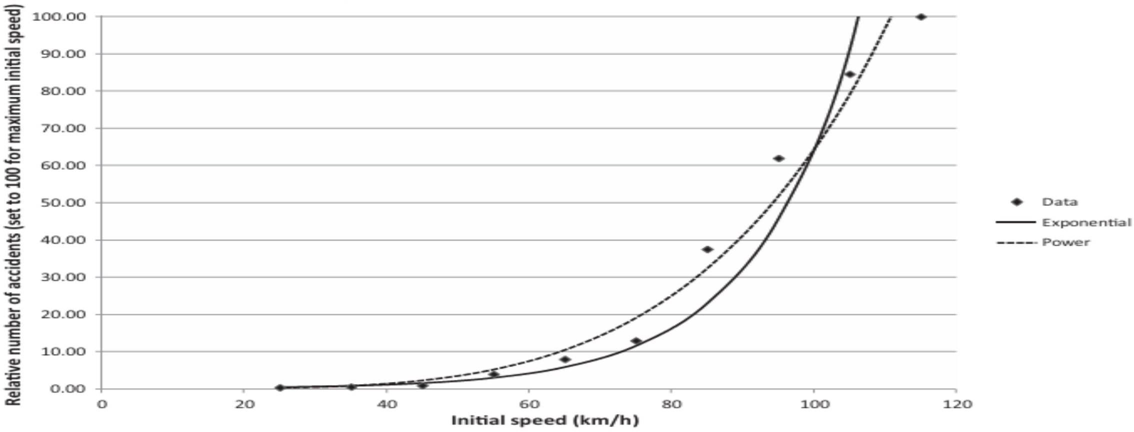


Figure 3-1: Power model and exponential function fitted to fatal crashes. (Source: Elvik, 2013)

Elvik et al., (2019), re-analyzed the Power and exponential models using studies published after 2000, and the findings still confirm that these two models both describe the relationship with great precision. Even though these models confirmed the findings by Elvik in 2013, there's still no universally used method for determining the safety effects of speed on crashes.

3.1.2. Review of empirical studies related to speed-crash relationships

Several empirical studies have investigated the relationship between speed and crashes, however, findings showed inconsistencies. Some studies reported a positive relationship between speed and crashes, with a significant number of crashes occurring at higher speeds. On the other hand, some studies indicated a negative relationship where a very small number of crashes occur at higher speeds. As a consequence, there's no conclusive evidence that captures the relationship between speed and crashes. This section examines some of these studies, considering studies that used average and 85th percentile vehicle operating speeds as primary speed data. A summary of these studies is presented in Table 3-3.

Table 3-3: Summary of studies analyzing speed -crash relationships

Author	Country	Road type	Speed-crash relationship
Rahman et al., (2023)	USA (Kentucky)	Two-lane rural highways	-ve
Das et al., (2021)	USA (Washington)	Rural interstates, two-lane, multi-lane divided and undivided.	+ve & -ve
Dutta & Fontaine, (2019)	USA (Virginia)	Freeways	+ve & -ve
Yu et al., (2018)	China (Shanghai)	Urban expressways	+ve & -ve
Gitelman et al., (2018)	Isreal	Two-lane rural highway	+ve
Imprialou et al., (2016)	England	Motorways	+ve & -ve
Gargoum & El-Basyouny, (2016)		Urban two-lane streets	-ve
Wang et al., (2018)	China (Shanghai)	Urban arterials	+ve
Yu et al., (2014)	USA (Colorado)	Freeways	+ve
Pei et al., (2012)	Hong Kong	Motorway	+ve
Rosén & Sander, (2009)	Germany	Urban roads	+ve
Taylor M.C et al., (2008)	United Kingdom	Motorway	+ve
Nilsson, (2004)	Sweden		+ve

+ve: Positive; -ve: Negative

A brief description of the empirical studies is provided below:

Rahman et al., (2023) used four types of speed metrics including average speeds, 85th percentile speeds, difference between average speed and speed limit, and the difference between the 85th percentile speed and speed limit, to assess the safety effects of speed on two-lane, rural highway segments in Kentucky. The speed datasets were grouped into three subsets: below 30 mph, between 30 and 50 mph, and above 50 mph. They found that speed was not significant for roads in the lower speeds, however, speed was significant in the medium and higher categories. Also, the study found a negative correlation between speed and crash frequencies.

Das et al., (2020) examined operating speed measures for four hours prior to a crash, and the speeds being travelled in the same location and same hour and day of the week, but on a day when no crash occurred. The study was limited to a randomly selected sample dataset from Washington and considered six facility types including; rural interstate, rural two-lane, rural multi-lane undivided, rural multi-lane divided, and rural others. They found that average operating speed increases were associated with increased crashes for two lane rural roadways. But, for interstate roads, average operating speed increases were instead accompanied by a decrease in crashes.

Dutta & Fontaine (2019) developed models for both hourly speed and traffic volume on freeway segments in Virginia, and assessed whether inclusion of speed data could improve model performance. They found that for total crashes, the relationship between speed and crashes was negative, which implies that lower average speed is correlated with higher crash frequency. These models also indicated that as standard deviation of hourly average speeds increases, the likelihood of crashes also increases. Additionally, study also found that inclusion of speed, standard deviation, and difference in speed improves the quality of crash prediction models.

Yu et al., (2018) investigated the impacts of data aggregation approaches on the relationships between operating speed and traffic safety based on the advanced traffic sensing data for urban expressways in Shanghai. Three approaches were employed including segment-based and scenario-based approaches which were first analyzed, and then the disaggregated crash risk analyses were developed at the individual crash level. The first two approaches are for analyzing crash frequency and the other is to examine individual crash risk. The study found that the segment-based approach reported a negative relationship while for the scenario-based approach, the relationship between operating speed and crash occurrence were concluded as a U-shape curve. This means that crash frequency decreases as operating speeds increases before a critical speed is reached. In the third approach, operating speed has negative impacts on crash risks under low and moderate speed conditions, the relationship is vague at high-speed conditions, and at free-flow conditions, a positive relationship was identified.

Gitelman et al., (2018) examined the relationship between travel speeds and crashes on two lane highways based on free-flow speeds under Israeli conditions. Negative binomial models were fitted to injury crash counts for day and night hours, using speed indicators, length of road section, traffic volume, and the homogeneous road groups. The study verified the relationship between speed and crashes, while controlling for other factors that affect crash occurrences such as traffic exposure and infrastructure conditions. The study demonstrated a positive relationship between mean speeds and crashes, while controlling for traffic and road characteristics.

Imprialou et al., (2016) used crash modelling approach and modelled the speed-crash relationship for strategic road networks in England. The study applied two types of datasets: a traditional link-based dataset and a novel condition-based datasets. In the link-based model, a negative speed-crash relationship was obtained, while a positive relationship was found with the condition-based model. The differences in the results are said to be as a result of the different data aggregation methods. For instance, the link-based model used observation datasets while the condition-based models considered crash time and location, which is more explainable and logical. As such, for the condition-based approach, group of average speed are associated with crashes. While for the segment-based approach, the speed-crash relationship is negative, regardless of crash severity.

Gargoum & El-Basyouny, (2016) conducted a study of urban two-lane streets in which they attempted to model the relationship between average speed and crash counts while considering effects from confounding factors. They found that the standard deviation of average speed seems to be negatively related to crash frequencies.

Wang et al., (2018) developed models for predicting crashes on urban arterials in Shanghai using a sample of 176 road segments, with the characteristics of road (length, number of lanes, number of access points), land use, average traffic volume and average travel speed. The speeds were estimated using floating car data extracted from the GPS-equipped taxis that operate in the city. The results showed that higher average speeds were associated with higher crash frequencies during peak periods (7-9 am) but not during off-peak periods (12-14 pm), while controlling for other road, traffic and land use characteristics.

Yu et al., (2014) investigated the effects of microscopic traffic, weather, and roadway geometric factors on the occurrence of specific crash types on I -70 freeways in Colorado. Full Bayesian inference was employed to model crashes using one year's worth of crash data. The study revealed that for average speed, single vehicle crashes have a high probability of happening at higher speeds, whereas the multi-vehicle crashes would probably occur at congested segments.

Pei et al., (2012) evaluated the speed-crash relationship using a database on traffic flow, speed, road design and weather conditions, in various time periods, for 112 motorway road sections in Hong-Kong, where the speeds were estimated based on the global positioning system (GPS) - devices of local taxis. The results indicated a positive correlation between average speed and crash risk when controlling for time-exposure (vehicle-hours) but a negative one when controlling for distance-exposure (vehicle-kilometers travelled). In both cases, higher speeds were associated with higher risk of severe crashes and no impact of speed dispersion on crash risk was found.

Rosén & Sander, (2009) studied pedestrian fatality risks as a function of impact speed using accident reports from Germany. The study derived an improved function for adult pedestrian fatality risk based on real-world data accident data. They found that fatality risks are highly associated with impact speed, that is, fatality risks at 50km/h were more than five times higher than the risk at 30km/h. This showed the importance of keeping impact speeds as low as possible especially in cities because of high volume of pedestrian traffic.

Taylor M.C et al., (2008) conducted a preliminary analysis based on average speeds on different roadways in the United Kingdom. The study found that mean speed was negatively related to crash frequency at the aggregate level. This finding is due to the difference in road quality at the road segments sampled, therefore, they created homogeneous groups through which the effects of road quality on the relationship between crashes and speed could be captured. The findings show that in a given set of road and traffic conditions the frequency of crashes increases with the speed of traffic, and the higher the speed, the more rapidly does crash frequency rise with increases in speed.

Nilsson, (2004) investigated the safety effects of average speed changes on crashes. The study found that average speed is positively correlated with crash rates as well as with crash severity. In further investigating this model, Elvik et al. (2004) performed a meta-analysis using 98 studies containing 460 estimates. The study validated the Power model, thus, the attesting the positive relationship between mean speed and crashes.

3.2. Methodology

The objective of this study was to investigate whether speed is an important risk factor on two-lane, un-divided rural highways in Italy, and if yes, develop the CMF function for speed, related to this type of infrastructure. The CMF function shall represent the crash risks of vehicle operating speed related to this type of infrastructure. The CMF function is developed for two speed measures: average operating speeds and 85th percentile operating speeds.

3.2.1. Data Collection, Preparation, and Processing.

The data collected to conduct this analysis include: road characteristic data, crash data, Floating Car Data (FCD), and traffic volume data. The following section provides detailed description for each of these data types.

3.2.1.1. Road characteristic data

The study focused on two-lane undivided rural highways in three Provinces within the Lazio Region in Italy, that is, Viterbo, Latina, and Frosinone Provinces. Only tangent segments were extracted from the entire road network. The process of extraction of tangent segments began by first recording videos for the selected roads while driving through the entire road. The recorded video logs were later viewed and analyzed, identifying the start and end point coordinates of the selected road segments from the video. Based on the co-ordinates of these tangent segments, the length of each segment was determined using a Python code. The tangent segments located at intersections, mountainous, and built-up areas, were discarded because these locations interrupt the operating speeds of drivers and influenced the FCD. Also, segments less than 0.1 miles (i.e. 160 metres) were excluded, as recommended in the HSM (AASHTO, 2010). Thus, 631 tangent segments were identified and extracted from the three Provinces, and used to develop the CMF function. The total length of the tangent segments extracted was approximately 340 km. Table 3-4, *Table 3-5,, and* Table 3-6 show the roads analyzed, and the number of tangent segments extracted from each of the roadways within the three Provinces.

Table 3-4: Selected roads and number of tangent segments extracted in the Province of Latina

Road name	Reference	Number of Tangent segments	Total length(m)
Migliara 47 & Dei Monti Lepini	SP 58 & SR 156	09	5689.12
Via Appia	SR 7 dir	03	995.62
Di Rocca di Papa	SR 218	05	1268.82
Nettunense	SR 207	14	6697.99
Andea – Fontana dei Papa	SP 1	10	2541.46
Cisterna - Campoleone	SP 2	19	11054.37
Velletri – Anzio 1(Tronco A)	SP 3A	03	1733.30
Velletri – Anzio 1(Tronco B)	SP 3B	05	1359.45
Marittima II (Tronco A)	SP 62	17	18270.64
Velletri – Anzio 1(Tronco C)	SP 3C	03	1563.72
Velletri – Anzio II	SP 15	12	9409.00
Borgo Piave - Acciarello	SP 38	08	5131.21
Guglietta Valletrata	SP 67	18	4879.28
Di Frosinone e Gaeta	SR 637	16	29540.21
Di Frosinone e Gaeta & Ambrifi Pastena	SR 637 & SP 95	04	1578.60
Lenola & Di Frosinone e Gaeta	SP 97 & SR 637	15	4403.13
Di Frosinone e Gaeta	SR 637	16	4102.42
Flacca	SR 213	14	5963.45
Carpinetana	SR 609	10	4206.40
TOTAL		**202**	**120,388.19**

Total = 120.388km

Table 3-5: Selected roads and number of tangent segments extracted in the Province of Viterbo

Road name	Reference	Tangent segments (No)	Total Length
Claudia Braccianese	SP 147	16	9564.54
Tarquiniense + Dogana + Castrense	SP3 + SP4A + SR312	20	18652.75
Vetrallese + Umbro Laziale	SP 8C	18	11912.58
Magliano Sabina + Ortana	SP 150 + SP151	11	5959.81
Ortana	SP 151	25	11546.11
Magliano Sabina	SP 54	02	540.44

Di Passo Corese	SR 313	16	3880.00
Verentana	SP 8	07	3171.30
Verentana tratto Sotteso Marta (Tronco A)	SP 8A + SP8	03	1725.55
Verentana	SP8	05	2118.18
Verentana-tratto sotteso	SP8C	03	718.04
Maremmana	SP 144	07	2161.15
Cimina	SP 144	19	6307.60
Cimina + Nepesina	SP 144 + SP 149	11	7264.88
Nepesina	SP149	14	25351
TOTAL		**217**	**141600**

TOTAL = 141.60km

Table 3-6: Selected roads and number of tangent segments extracted in the Province of Frosinone

Road name	**Reference**	**Tangent segments (No)**	**Total Length**
Raccordo di Fiuggi	SR 155	11	4856.39
Di Fiuggi	SR 155	08	2059.08
Maria (I & II)	SP 278	05	1616.61
Delle Valle del Liri	SR 82	07	1812.63
Di Sora + Di Forca d'Acero	SR 666 + SR 509	16	3684.81
Di Forca d'Acero	SR 509	04	1080.06
Borgo Vicalvi (I & II)	SP 237	06	2755.81
Della Vandra	SR 627	05	2144.77
Della Vandra	SR 627	10	5389.48
Di Forca d'Acero	SR 509	05	4441.64
Piedimonte	SP152+SP237+SP 281	04	2131.42
Allaciamento Stabilimento Fiat	SR 275	05	3279.03
Ausonia	SR 630	21	11411.56
Ausente + Taverna	SP 125 + SP 128	14	4324.81
Della Valle del Garigliano	SR 430	03	689.04
Leuciana (I & II) + Della Valle del Liri	SP 628 + SR 82	22	8104.03
Pontecorvo – San Giovanni Incarico + Della Valle de Liri	SP 257 + SR 82	28	8971.79
Di Frosinone e Gaeta	SR 637	03	1259.45
Dei Monti Lepini	SR 156 dir	02	371.39
Asse Attrezzato Ceccano	SP 279	03	1036.91

Di Frosinone e di Gaeta	SR 637	03	768.65
Pedemontana dei Monti Lepina (Tronco A)	SP 227A	02	441.08
Ausente + Dei Santi (I & II)	SP125 + SP076	21	5656.56
Appia Nuova	SP 81	06	1582.60
TOTAL		**212**	**79869.58**

TOTAL = 79.87km

3.2.1.2. Crash data

The crash data for the entire Lazio Region was obtained from ISTAT (the Italian Institute of Statistics) for the period of five years (2019 -2023). The crash data was merged to the tangent segments in QGIS, and only crashes that occurred on the segments were considered. As such, a total of 310 crashes occurred for five years, on all the tangent segments extracted. The maximum number of crashes obtained for the segment was 17, while the minimum was 0. The number of crashes per segment varies depending on the length of the segment.

3.2.1.3. Operating speed data

The vehicle operating speed data was obtained from the Floating Car Data (FCD) of 2019, provided by ASTRAL spa, the regional company in charge of construction and maintenance of roads within the Lazio Region. Similarly, the FCD was merged to the tangent segments in QGIS, and only the operating speed of vehicles on the tangent segments were considered.

3.2.1.4. Traffic flow data

The traffic flow data were also provided by ASTRAL spa. The detailed traffic volume data for all the road networks considered is provided in the Annex 2.

3.2.2. Method

3.2.2.1. Cross-Sectional Method

Generally, there are typically two main methods used in developing CMFs; the Before and After (B-A) method, and the Cross-Sectional method. The B-A method is the most widely used method for developing CMFs, but often found not applicable in some conditions. Carter et al., (2012) stipulated that the B and A method cannot be used in areas where the treatment dates are not known, or there is insufficient historical crash data for the treatment. Moreover, several years have to elapse after implementing any treatment in order to collect the required data. Also, the HSM recommends that CMFs could be estimated using the cross-sectional method when the date of treatment for the feature is not known (AASHTO, 2010). It is important to note that the treatment in this study is the vehicle operating speed, which cannot be easily controlled or regulated. In this regard, the best alternative is the cross-sectional method.

CMFs from cross-sectional methods are developed by comparing a group of road elements with a specific feature, to a group of road elements without the feature (Carter et al., 2012). This method also has limitations some of which include the fact that they do not take into account the effects of external causal factors (Hauer,2013). Nevertheless, (Wood et al., 2015) compared the CMFs obtained from B-A studies and the cross-sectional method, and the study disclosed that the cross-sectional method yielded results that are consistent with the B-A results. Generally, CMF reflect the causal relationship between safety and a countermeasure or roadway feature. When this causal relationship holds, the CMF also reflects the association between the feature and safety. Since this study was conducted following the cross-sectional approach, which cannot establish causality but only quantify associations, the CMF for speed in this case is interpreted as associative, not causal. For prediction purposes, these CMFs are useful and appropriate.

3.2.2.2. Procedure for CMF development based on the cross-sectional method

The procedure based on cross-sectional method adopted in this study for CMF development is similar to that applied by Das et al., (2024), Banihashemi, (2015), Banihashemi, (2016), and Wu et al., (2017). Das et al., (2024), developed speed related CMFs for 12 different roadway facility types using naturalistic vehicle operating speed data from Washington and Carolina States in the United States. Specifically, the procedure applied in this study is similar to this one, however, the focus in this study is solely on two-lane, two-way rural highways. Previously, Banihashemi, (2015), developed CMFs for horizontal curvature on rural multilane highways based on this method. The method was carried out in two steps. In the first step, the ratios of the observed number of crashes to the predicted number of crashes were evaluated for the whole data as well as the subset of data which was produced by splitting the data into different groups based on the horizontal curvature. Since the ratios deviated from 1 significantly, the conclusion was that the effects of horizontal curvature on crashes were significant. It is important to note that this ratio represents the relative risk for each group. A higher ratio indicates higher risk. In the second step, the ratios that were calculated in the first step were studied to derive a CMF function that was used to capture the effects of horizontal curvature in predicting crashes for the experiment data. One year later, Banihashemi, (2016) applied this same method to develop CMF for horizontal curves on five different types of urban arterials. The exception was the additional split of the data based on the posted speed on the roadway. As such, CMF was developed for each of the arterial types. In addition, Wu et al., (2017) was the first to replicate this similar method to develop CMFs for curves on rural two-lane undivided highways. The study also found that the horizontal curve radius has a significant role in the risk of a crash, and as such, CMF function was developed for this roadway. Based on these previous applications of the cross-sectional approach for CMF development, a similar procedure was applied in this study as follows:

Step 1. Define the relationship between vehicle operating speed and crashes on two-lane rural roads within Lazio Region

The main objective of this step is to determine the relationship that exists between vehicle operating speed and crashes on this road type. To define this relationship, SPFs models were developed using the Generalized Linear Modeling (GLM) technique. The conceptual framework for this study is as shown in Figure 3-1. Identifying this relationship will indicate the speed-crash relationship on these Italian two-lane undivided rural highways. Also, in this process, the crash data is calibrated to this road type.

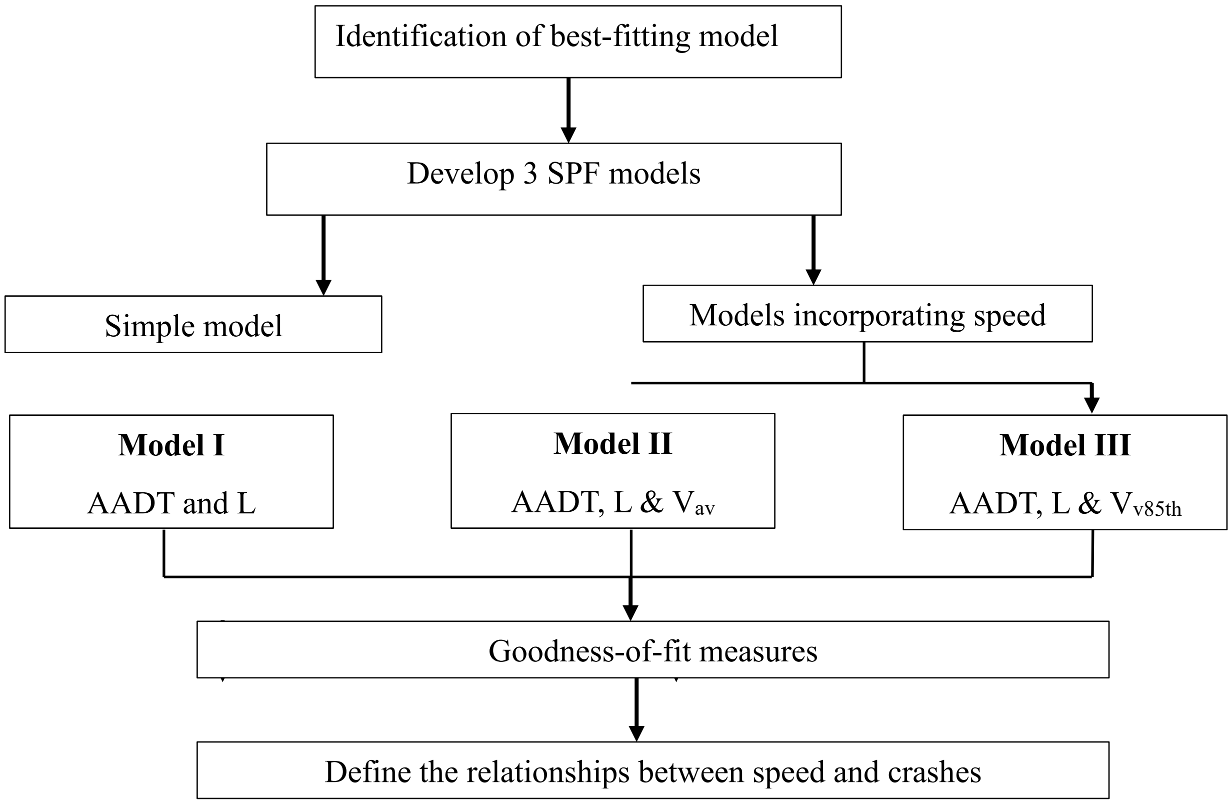


Figure 3-2: Methodological framework for defining speed-crash relationship

GLMs most commonly used in modeling crashes include Poisson regression models and Negative Binomial (NB) models. When modeling road traffic crashes, the first choice is often the Poisson regression model, which assumes that the variance and mean are approximately equal. But, when the data exhibit overdispersion (that is, variance > mean), the NB model distribution is considered. When the crash dataset has a higher preponderance of zero observations, Zero-Inflated (ZI) models such as Zero-Inflated Poisson (ZIP) and Zero-Inflated Negative Binomial (ZINB) can be applied. The ZIP model accounts for zero-inflation but does not handle issues related to overdispersion, while the ZINB models account for overdispersion and additional issues due to presence of excess zeros in the dataset.

Based on the conceptual framework in Figure 3-1 above, the study started by determining the best-fitting model for this type of dataset. This examination was carried out as illustrated in the flow chart in Figure 3-2.

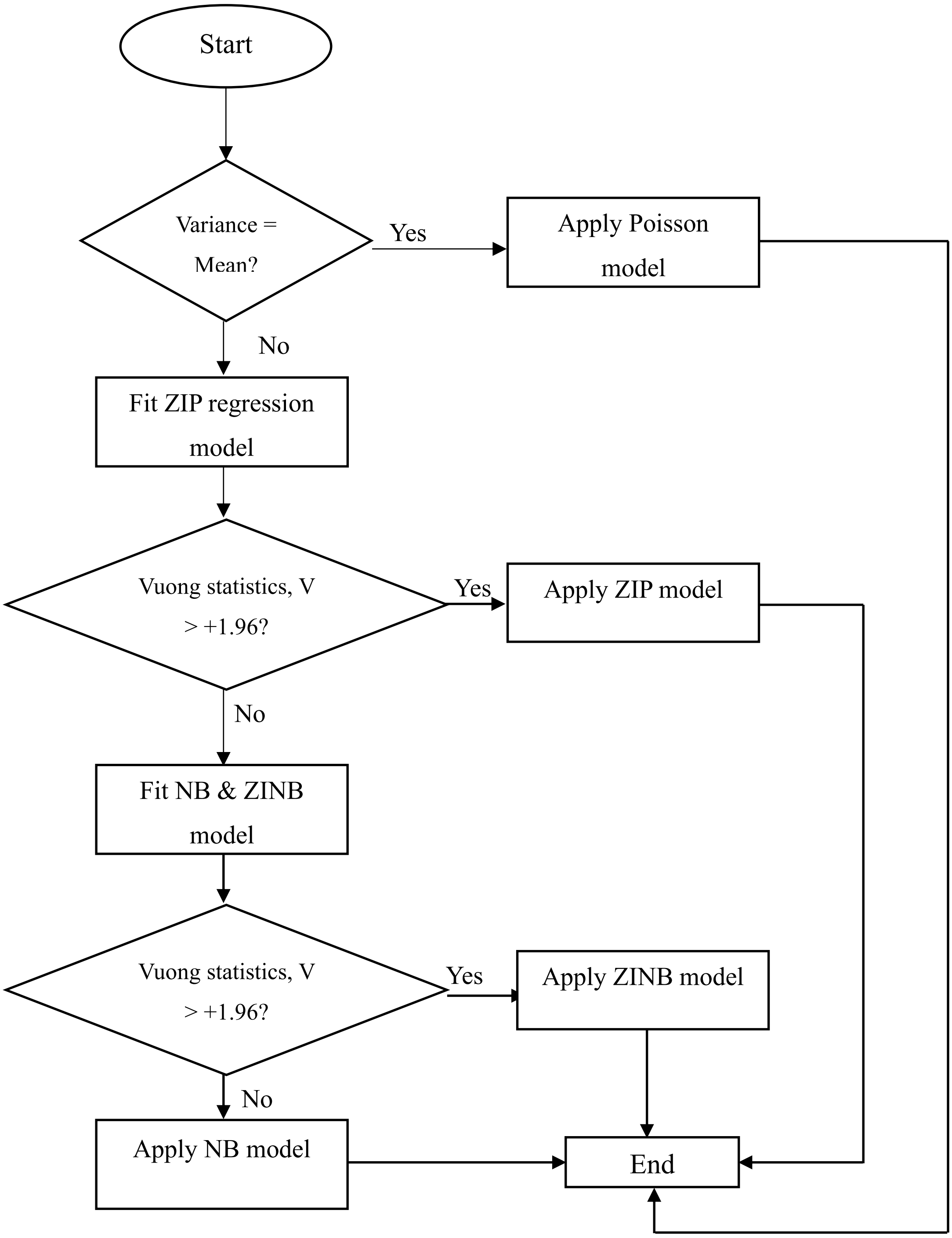


Figure 3-3. Procedure for identifying the best-fitting model

The verification procedure started by investigating the possibility of applying the Poisson distribution model. And since Variance ≠ Mean, the Poisson model was rejected. Next, the study assessed the possibility of applying the ZIP regression model over the Poisson model. Generally, ZIP is recommended when the data have excess zeros compared to standard Poisson model. In this study, to assess the appropriateness of using the ZIP regression model over the Poisson model, Vuong Statistics tests (V) was applied. Generally, Vuong statistic, V, is used to assess the suitability of using Zero-Inflated model over ordinary Poisson and ordinary Negative Binomial. It is defined as:

$$\boldsymbol{V = \frac{\bar{M}\sqrt{n}}{S_m}} \tag{3-1}$$

$$\boldsymbol{\bar{M} = \frac{1}{n}\sum_{i=1}^{n}.} \tag{3-2}$$

$$\boldsymbol{S_m = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(m_{i-\bar{m}}).^2}} \tag{3-3}$$

Where; $\boldsymbol{\bar{M}}$ is the mean; $\boldsymbol{S_m}$ is the standard deviation; and n, is the sample size. A value of **V**>1.96 (at 95% confidence interval) favours the ZIP or ZINB, while a value of **V**<-1.96 favours Poisson or NB distribution. Any values between -1.96 and 1.96 indicates that no decision can be made.

Since the Vuong test indicated that Poisson model is more favored over ZIP regression model (since **V**=2.04), the process continued with investigating the suitability of applying either the NB or the ZINB regression models. Originally, the study indicated that the NB regression model was applicable since Variance > Mean. Nevertheless, due to the presence of a high preponderance of zero observations along the tangent segments, it was important to investigate the suitability of the ZINB regression model. This again is carried out using the Vuong statistics test, V. The results indicated that the ZINB model is the most favored for modeling this dataset (since V = 2.47). To further examine the suitability of ZINB regression model in this study, the number of zero observations in this dataset was counted. The results indicated that over 70 percent of the tangent segments had zero observations. It is important to note that there is no threshold that has been defined in previous studies that warrants the use of Zero-Inflated models, thus, the threshold percentage remains debatable (*M. Sun et al,. 2021, G. Gamaleldin 2022, A. Abdulhafedh,2023*). Though, existing literature has employed

Zero-Inflated models with zero observations ranging from 10% to over 60% (*J.L. Crunkeleton and P.J Tarnoff 2015, J.Q. Li et al,. 2022, P.C. Anastasopoulous 2016*).

Modeling

Based on Vuong statistics test, ZINB regression model was selected for modeling. ZINB model is a statistical model approach that is formed by integrating a logit model and a NB model (*V. Ob Bello and O.Gurege, 2017*). The first component of the model, which is a logit model, is associated with excess zeros while the second component of the model, which is the NB distribution model, addressed overdispersion issues. To model the relationship between speed and crash frequency, three different types of models were developed in which, the first model consists of only the traffic characteristics and segment length; the second and third models additionally incorporated average vehicle operating speed (V_{avg}) and 85th percentile vehicle operating speed (V_{85th}) respectively, as shown below:

I) AADT and length only

II) AADT, length, and V_{avg}, and

III) AADT, length, and V_{85th}.

The ZINB regression model was defined as follows:

$$P(T_i = t_i) = q_i + (1 - q_i)\left[\frac{1}{1+\alpha\mu_i}\right]^{\frac{1}{\alpha}}; t_i = 0 \quad (3\text{-}4)$$

$$P(T_i = t_i) = (1 - q_i)\left[\frac{\Gamma\left(t_i+\frac{1}{\alpha}\right)\left(\frac{1}{1+\alpha\mu_i}\right)^{\frac{1}{\alpha}}\left(\frac{\alpha\mu_i}{1+\alpha\mu_i}\right)^{t_i}}{\Gamma\left(\frac{1}{\alpha}\right)t_i!}\right]; \quad t_i = 1, \ldots\ldots, n \quad (3\text{-}5)$$

Where $\boldsymbol{\tau}$ is a scalar parameter.

The mean and variance of T_i were defined as:

$$P(T_i) = \mu_i = (1 - q_i)\,\lambda_i \quad (3\text{-}6)$$

$$Var(T_i) = \mu_i + \left(\frac{q_i + \alpha}{1 - q_i}\right)\mu_i^2 \quad (3\text{-}7)$$

Where;

$$\boldsymbol{\lambda_i = e^{(m_i + \gamma_1 AADT + \gamma_2 L + \gamma_3 V)}} \quad (3\text{-}8)$$

Applying natural logarithm to transform AADT, length, and speed metrics as they exhibited a skewed distribution. Thus, the model form obtained in this study is defined as:

$$\boldsymbol{\mu_i = e^{m_i} . AADT^{\gamma_1} . L^{\gamma_2} . V^{\gamma_3}} \quad (3\text{-}9)$$

Where; μ_i represents the expected crash frequency in 5 years, AADT, L, and V are the explanatory variables, m_i is an error term that follows a gamma distribution.

In developing the model, 75% of the dataset was used for training, and the remaining 25% for testing the model. The training dataset was used to obtain the regression coefficients, while the testing dataset was used to evaluate the model's performance. The modeling was then conducted in R-Programming.

Goodness of fit measures

Goodness-of-fit (GOF) is a statistical measure that refers to how well a model matches the observed data.

Model Performance: The GOF measures selected to assess the relative performance of the three models included: *the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC)*. Generally, AIC and BIC are not strictly a test of the model acceptability, rather, it is a means for comparing models that is, a tool for model selection.

$$\boldsymbol{AIC = -2logL + 2K} \quad (3\text{-}10)$$

$$\boldsymbol{BIC = -2logL + (In(i))K} \quad (3\text{-}11)$$

Where L is the maximized likelihood function for the model, K denotes the number of parameters included in the model, and *I,* is the total number of observations. Generally, models with lower values of AIC and BIC are considered as best-fitting.

Model Accuracy: Regarding the predictive accuracy of the models, the study examined three GOF metrics including:

-Root Mean Square Error (RMSE): It is calculated by taking the square root of the mean squared error (MSE), obtained by averaging the squared errors of predicted crash frequencies across all tangent segments.

-Mean Absolute Deviation (MAD): This measure quantifies the average absolute difference between the predicted crash frequency by the model and the actual crash frequency.

-Mean Absolute Percentage Error (MAPE): Finally, this measure calculates the absolute error by comparing it to the actual crash frequency while excluding tangent segments with no crashes.

Results

Tables 3-1 and 3-2 provide a summary of the results for all the parameters of the three models, including regression coefficients, AIC, BIC, RMSE, MAD, and MAPE.

Table 3-7. Model Comparison

Model	RMSE	MAD	MSPE	AIC	BIC
Model 1: AADT + Length	1.7066	0.7854	2.9124	799.64	820.43
Model 2: AADT + Length + Avg Speed	1.7065	0.7847	2.9121	801.63	826.58
Model 3: AADT + Length + V85th	1.7069	0.7797	2.9135	801.13	826.08

Based on the AIC and BIC values obtained, model I provides the best fit to the data. Nevertheless, models incorporating the safety effects of operating speed, showed that the models that considered 85^{th} operating speed fitted the data better than the models incorporating average operating speed.

Table 3-8. Detailed Model Parameters

Model	Term	Estimate	Std. Error	Z-value	P-value	AIC	BIC	RMSE	MAD	MSPE
Model 1	(Intercept)	0.9020	1.3467	0.670	0.5030	799.64	820.43	1.7066	0.7854	2.9124
	log_AADT	0.0171	0.1199	0.143	0.8866					
	log_Length	-0.3130	0.1801	-1.738	0.0822					
	Log(theta)	-1.4350	0.1701	-8.436	<0.001					
Model 2	(Intercept)	1.0336	2.0881	0.495	0.6206	801.63	826.58	1.7065	0.7847	2.9121
	log_AADT	0.0190	0.1218	0.156	0.8758					
	log_Length	-0.3116	0.1813	-1.718	0.0857					
	log_avg_speed	0.0381	0.4632	-0.082	0.9345					
	Log(theta)	-1.4347	0.1702	-8.431	<0.001					
Model 3	(Intercept)	2.6478	2.8391	0.933	0.3510	801.13	826.08	1.7069	0.7797	2.9135
	log_AADT	0.0380	0.1232	0.308	0.7578					
	log_Length	-0.2702	0.1892	-1.428	0.1534					
	log_V85	0.4990	0.7125	-0.700	0.4837					
	Log(theta)	-1.4296	0.1703	-8.395	<0.001					

The results in Table 3-2 above showed a positive correlation between average operating speed and crash frequency, suggesting that more crashes tend to occur at higher speeds.

Also, it is observed that both AADT exhibited a significant positive correlation with the crash frequency, and length exhibited a negative correlation. Overall, the above results indicate that speed is certainly a significant contributor of crashes on two-lane undivided rural highways within Lazio Region.

Step 2. Gather all the tangent segments from the road network

This step consists of gathering all the tangent segments from the road networks under study as shown in Table 3-4, Table 3-5, and Table 3-6.

Step 3. Create different speed category groups based on the average and 85^th^ percentiles of vehicle operating data.

First, assign all the speed data from the Floating Car Data (FCD) to all the road tangent segments in QGIS software, and apply a Python code to calculate the average and 85th percentile speeds for each of the road segments. Based on the values obtained, we created five different categories of operating speed groups for the average and 85th percentile speed measures calculated. Then, the tangent segments were grouped considering the corresponding values of operating speeds on the segments to each of the speed groups.

Step 4. Determine the predicted crash frequency

In this step, calculate the predicted crashes for all the tangent segments for each speed group by applying Equation (*3-9*). The predicted crash frequencies for each tangent segment is obtained thus:

$$\boldsymbol{\mu_i} = e^{0.9020} . AADT^{0.0171} . L^{-0.3130} \quad (3\text{-}12)$$

Step 5. Calculate the Ratios of Observed to Predicted crashes for each speed group

According to Carter et al. (2012), CMFs computed by the Cross-Sectional method can be obtained by taking the ratios of the average crash frequency of sites with the feature to the average crash frequency of sites without the feature. In this step, for each speed group, the ratio of the observed and predicted crashes is calculated. The average crash frequency of sites with the feature is represented by the observed crashes while the average crash frequency of sites without the feature (that is, operating speed) is represented by the predicted crashes. The ratios obtained for each of the speed groups, represent the safety effects of that group. The speed group with ratios significantly different from 1.0, indicates that speed significantly had an influence on crash occurrence within the group.

Step 6. Develop the CMF function for each average and 85^th^ percentile speed

In this step, the ratios obtained in step 5 above are first normalized to ensure a common variation in the values. Normalization is performed by considering the ratio of one speed group as the base condition (usually the group with the highest speed) and the initial ratios are divided by that of the base group. At this point, the values of the normalized ratios are plotted against the midpoint value for each operating speed group for both the average and 85th percentile speed measures. Then, a tentative curve is fitted. If a pattern is observed within the plot, the curve is then adjusted to fit well, and the CMF function is derived.

A summary of the steps above are illustrated as shown in **Figure 3-4.**

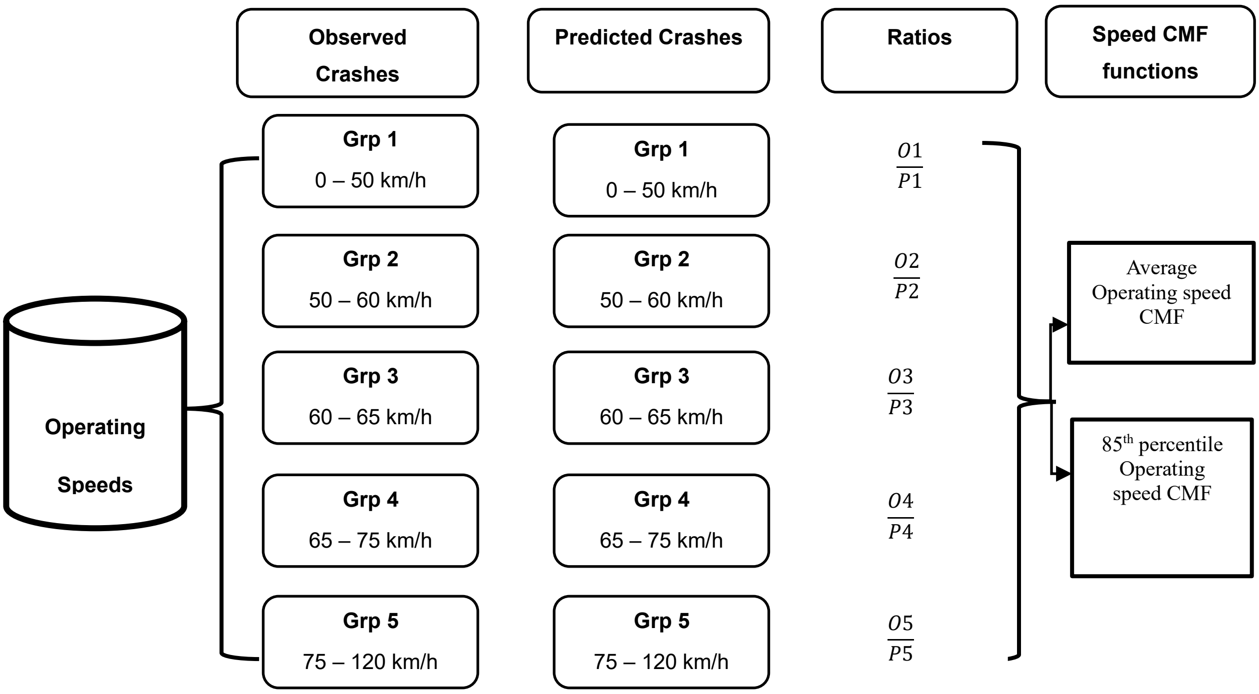


Figure 3-4: Summary of the procedural steps for the development of speed CMF functions

3.2.2.3. Validation Procedure

The original SPF without the new CMF for speed, is applied to all the tangent segments in the validation data. These predictions are called "*Predictions without new CMF*". Then, the SPF plus the new CMF for speed (ie SPF * CMF for speed) are also applied to the tangent segments. These predictions are named "*Predictions with new CMF* ". The observed crashes are then compared with the two predictions; "*Predictions without new CMF and Predictions with new CMF".* This comparison will show whether the newly developed CMF of speed is valid or not. Goodness-of-fit measures can then be used to measure the accuracy of these predictions.

3.2.2.4. Goodness-of-fit measures (GOF)

The following GOF measures can be used: Mean Absolute Deviation (MAD), Root Mean Square Error (RMSE), and Cumulative Residual (CURE) plots.

(i) Mean Absolute Deviation (MAD)

This is the average absolute difference between the predicted crash frequency and the observed crash frequency. It is given as:

$$\mathbf{MAD} = \frac{\Sigma|yi - \bar{y}i\,|}{\boldsymbol{n}} \tag{3-13}$$

Where; Where; $\boldsymbol{yi}$ are the observed values and $\bar{y}\boldsymbol{i}$ are the predicted values.

Note that lower values for MAD indicates better accuracy.

(ii) Root Mean Square Error (RMSE)

This is the standard deviation of the predicted errors that are the square difference between the predicted crash frequency and the observed crash frequency.

$$\mathbf{RMSE} = \sqrt{\frac{1}{n}\Sigma\,(yi - \bar{y}i)^2} \tag{3-14}$$

Where; $\boldsymbol{yi}$ are the observed values and $\bar{y}\boldsymbol{i}$ are the predicted values.

Also note that lower values for RMSE indicates better accuracy.

(iii) Cumulative residual (CURE) Plots:

These plots are used to assess how well the predictions fit the observed data over the full range of an independent variable. According to (Hauer E & Bamfo J., 1997) the cumulative residual is plotted against an independent variable. The main goal is to graphically observe how well the CMF speed function fits the validation dataset. They also derived boundary limits for the plot (+2σ and -2σ). The plot of cumulative residuals should oscillate around 0, and close to 0, and should not exceed the boundary limits. An upward or downward drift indicates that the model consistently predicts fewer or more crashes than when counted. A good fit of the CMF function could be observed if the plot of residuals does not show any drift.

3.3. Analysis of results and discussion

3.3.1. Road segments and speed categories

The speed data was initially calculated for average and 85th percentile operating speeds for all tangent segments. Five speed categories were created and the tangent segments with their corresponding average and 85th percentile speeds were grouped within each category as presented in Table 3-13.

Table 3-9: Summary of Average and 85th percentile speeds for the different speed categories

Average operating speed (Vav)			**85th percentile operating speed (Vv-85)**		
Speed categories (km/h)	Number of segments	Total length (km)	Speed categories (km/h)	Number of segments	Total length (km)
0 - 50	112	74,657.45	0 - 65	61	45,190.39
50 - 60	111	78,784.68	65 - 75	172	94,358.10
60 - 65	112	60,248.89	75 - 80	115	61,581.61
65 - 75	180	95,078.54	80 - 90	178	103,720
75- 120	116	78,468.44	90 - 120	105	82,387.90
Total	**631**	**387,238**	**Total**	**631**	**387,238**

Considering the average operating speed measure, Table 3-13 above, indicated that the drivers on the two-lane undivided rural highway travel mainly at a mean speed between

60 – 70 km/h, while for 85th percentile measure, the drivers mostly travel at 70 – 80 km/h. Therefore, considering both speed measures, the operating speeds mostly travelled at on this road type vary from 60 – 80 km/h.

3.3.2. CMF function for average operating speed

The initial ratios for the observed and calibrated predicted crashes were calculated and presented in column 4, in Table 3-17. The ratios vary between 0.44 – 2.27, and since these ratios are different from 1.0, it therefore, indicates that speed was very significant within all the speed categories. To further magnify the safety effects of vehicle operating speed, the initial ratios were normalized. The speed category with the highest travel speeds (that is, 80-100km/h) was selected as the base condition, and the initial ratio of each group was divided by the ratio. The normalized ratios are shown in column 5, of Table 3-10.

Table 3-10: Ratios of Observed to Predicted Crashes for Average Operating Speed

Speed category	Observed crashes	Predicted crashes	Ratios of Observed to Predicted Crashes	Normalized ratios
0 - 50	57.00	53.02	1.08	1.00
50 - 60	54.00	49.13	1.09	1.01
60 - 65	63.00	57.01	1.11	1.03
65 - 75	85.00	76.02	1.12	1.04
75 - 120	51.00	40.89	1.25	1.16

To develop the CMF function, the values of the normalized ratios were plotted against the mean values of each speed category. A power curve was then fitted to the data, and the CMF function for average operating speed was derived as shown in Figure 3-5.

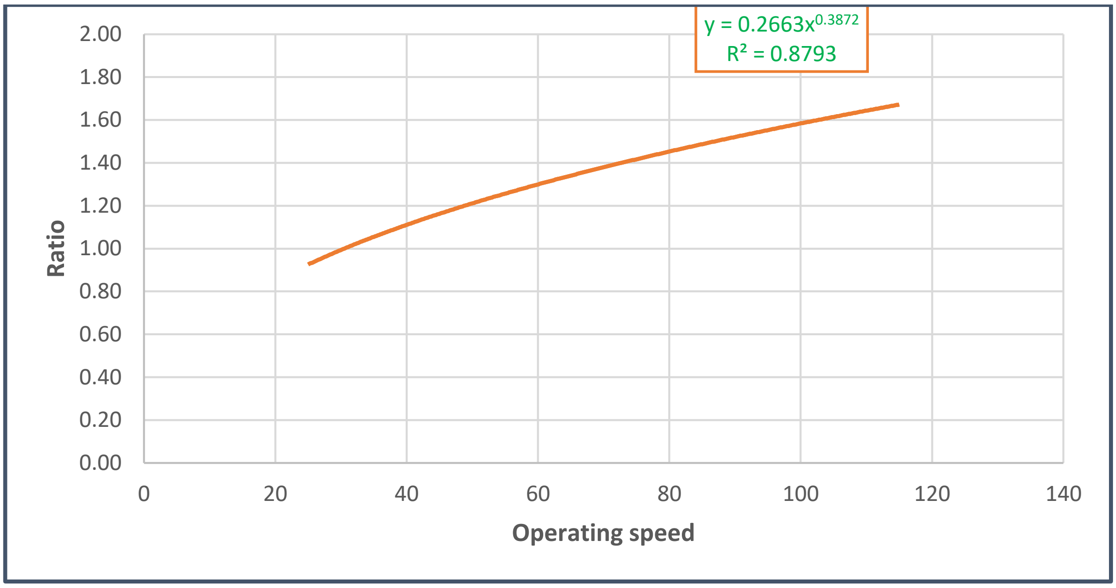


Figure 3-5: Normalized ratios and average vehicle operating speed

From the curve fitted in Figure 3-3, the CMF function for average vehicle operating was obtained as:

$$\mathbf{CMF_{V.AV} = 0.2663\ x\ V^{0.3872}} \qquad \textbf{(3-15)}$$

Where, **$CMF_{V.AV}$** is the CMF for average operating speed; V is the average operating speed for each tangent segment. This function can be used to quantify the crash risks for average vehicle operating speeds on two-lane undivided rural highways.

3.3.3. CMF function for 85th percentile operating speed

Similarly, the initial ratios for the observed and calibrated predicted crashes for 85th percentile speeds were calculated and presented as shown in column 4, in Table 3-20. The ratios vary between 0.21 – 6.57, and since the ratio for the lowest speed category was very high, indicating the effects of an outlier, the speed category for this ratio was excluded in the curve fitting. As a consequence, the ratios considered vary from 0.21 to 1.71. To further magnify the safety effects of the 85th percentile operating speeds, the initial ratios were normalized. The speed category with the highest speeds (that is, 80-100km/h) was selected as the base condition, and the initial ratio of each group was divided by it. The normalized ratios vary between 0.33 and 2.71 as shown in column 5, of Table 3-11.

Table 3-11: Ratios of Observed to Predicted Crashes for 85th Operating Speed

Speed category	Observed crashes	Calibrated Predicted crashes	Ratios of Observed to Predicted Crashes	Normalized ratios
0 - 65	10.00	9.20	1.09	1.00
65 - 75	39.00	34.56	1.13	1.04
75 - 80	49.00	42.32	1.16	1.07
80 - 90	114.00	94.21	1.21	1.11
90 - 120	251.00	184.55	1.36	1.25

Also, to develop the CMF function for the 85th percentile operating speed, the values of the normalized ratios were plotted against the mean values of each speed category. A power curve was fitted, and the CMF function was deduced as illustrated in Figure 3-7.

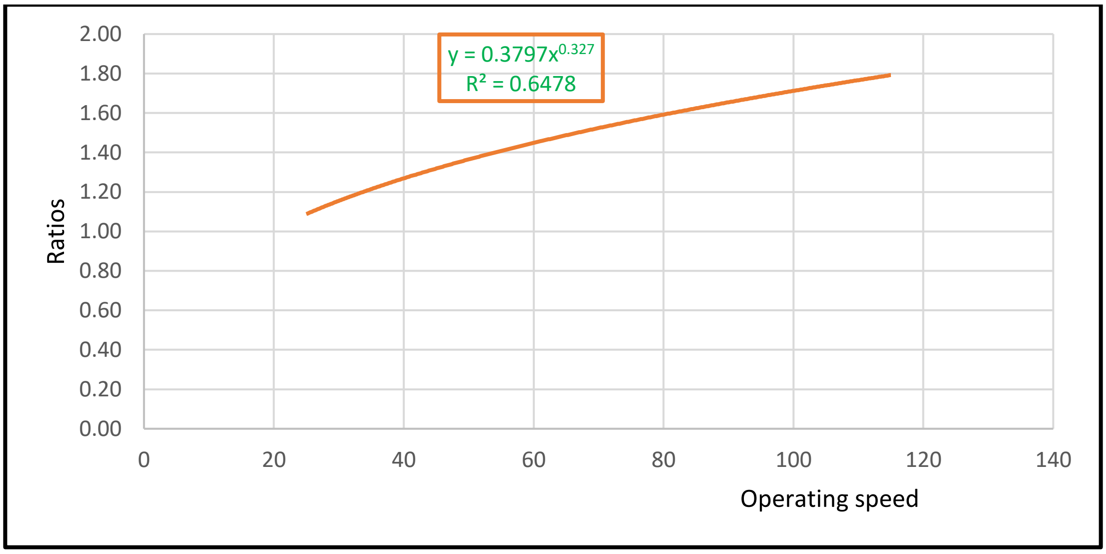


Figure 3-6: Normalized ratios and 85th percentile vehicle operating speed

From the curve fitted in Figure 3-4, the CMF function for 85th percentile vehicle operating was obtained as:

$$CMF_{v.\ V\text{-}85} = 0.3797\ x\ V^{0.327} \qquad \textbf{(3-16)}$$

Where, $CMF_{v.\ V\text{-}85}$ is the CMF for 85th percentile operating speed; V is the 85th percentile operating speed for each tangent segment. This function can be used to quantify the crash risks for 85th percentile vehicle operating speeds on two-lane undivided rural highways.

3.3.4. Validation

3.3.4.1. Validation data

Validation refers to the comparison of model results to independent observed data not used in parameter estimation. The validation in this study was performed using independent data from another Province in Lazio Region, called "Rieti Province". Also, in this Province, only tangent segments for two-lane rural highways were considered, excluding built-up areas, junctions, and hilly/mountainous terrain. The data obtained is presented in Table 3-12.

Table 3-7: Segments for validation in Rieti Province

Road name	**Reference**	**Tangent segments (No)**	**Total Length (m)**
Licinese	SR 314	32	9314.26
Ternana	SR 79	18	4664.42
Di Morro	SR 521	14	4236.91
Del Lago di Campotosto	SR 577	05	1347.85
Selvapiana + Turistica del Terminillo	SP69 + SP10	08	1716.64
Dell Terminillo	SR 4bis	06	1620.64
Turanense	SP 34	25	6827.55
Sublacense	SR 411	22	7208.98
Trevi Filettino	SP28	06	1831.44
Di Campocatino + Sublacense	SR dir + SR411	12	3284.15
Di Fiuggi*	SR 155	31	6293.89
TOTAL		**180**	**53,262.58**

Total = 53.26km

3.3.4.2. Validation analysis and results

The original calibrated prediction model calculated with the initial data was applied to the validation data. This step produces the "Predictions without speed". Then the calibration prediction model multiplied with the new CMF of speed, was applied to the validation data. This step produces the "Predictions with speed". Both predictions were compared with the observed crashes for the validation data to evaluate the impact of CMF speed. To confirm the performance of these predictions, three goodness-of-fit measures were considered for the analysis. There include: Mean Absolute Deviation (MAD), Root Mean Square Error (RMSE), and Cumulative Residual (CURE) plots.

3.3.4.3. MAD and RMSE

The results for MAD and RMSE are presented as illustrated in Table 3-13.

Table 3-8: Goodness-of-fit measures outcomes for MAD & RMSE

Speed CMF	**MAD**	**RMSE**
Average operating speed		
SPF Without Speed CMF	0.252	0.437
SPF With Speed CMF	0.226	0.417
85th percentile speed		
SPF Without Speed CMF	0.290	0.238
SPF With Speed CMF	0.491	0.442

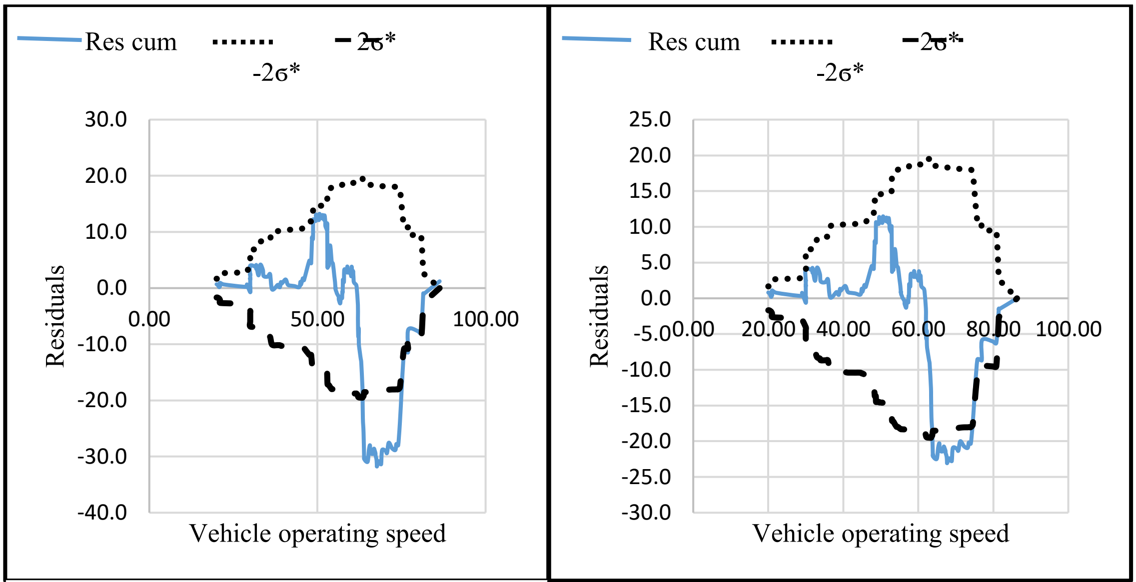
For the average operating speed measure, both MAD and RMSE indicated that when the original prediction model was multiplied by the CMF of speed, the predictions were closer to the actual observed values than for the models without speed. This implies, the safety effects of vehicle operating speed is an important factor in crash predictions. Similarly, for the 85th percentile operating speed measure, both MAD and RMSE for "predictions with speed" performed better than when the CMF of speed was not considered. Overall, the two goodness-of-fit measures indicated speed is a very significant factor in crash predictions.

3.3.4.4. Cumulative Residual (CURE) Plots

The CURE plots were derived for both the average and 85th percentile operating speeds.

CURE Plots for Average Operating Speed

Figure 3-7 illustrates the CURE plots for average operating speed.



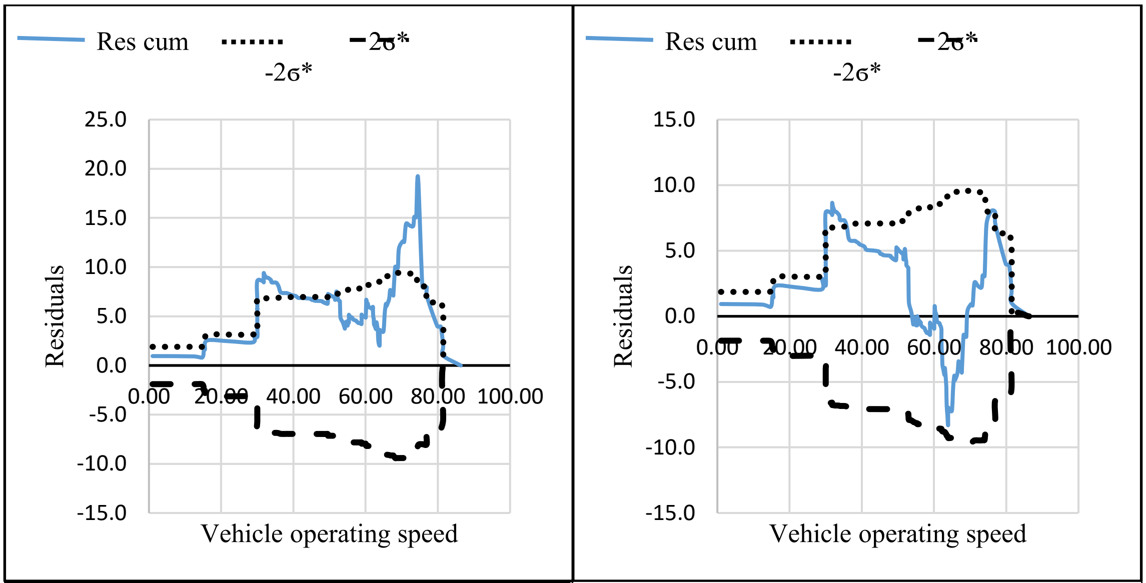
Crash prediction without speed CMF	Crash prediction with speed CMF

Figure 3-7: CURE plots for average operating speed for all crashes

The CURE plots in Figure 3-13 confirmed that the predictions with speed performed better than the predictions without speed, since most of the data covered the boundary line. Also, the plot suggests that for crash prediction without speed CMF, there is consistent under-predicting up to around 70km/h, then a sharp shift upwards, indicating more under-prediction occurred. However, predictions considering the speed CMF, showed that the function performed well up till 60km/h, and then experienced a sharp shift downwards.

CURE Plots for 85th percentile Operating Speed

Figure 3-13 illustrates the CURE plots for 85th percentile operating speed.



Crash prediction without speed CMF	Crash prediction with speed CMF

Figure 3-8: CURE plots for 85th percentile operating speed

This CURE plot suggests that for both predictions with or without speed, there is a noticeable pattern of consistently underpredicting values. Also, the CURE plots in this case, rather indicates that the model performs better without speed. However, this may be due to the influence of higher values of 85th percentile speeds, noticed especially with the higher categories of speed.

3.3.5. Limitations and further research

One of the main limitations of this type of cross-sectional method is found in the creation of operating speeds groups. The process of dividing the vehicle operating speed into different groups affects the resulting ratios and hence, the developed CMF function. Nevertheless, Banihashemi (2015) recommended a balanced set of groups in relation to the number of road segments. As such, in this study, the splitting of speed data was carried out such that the gap between the number of segments within each speed group is reduced. This is also one of the reasons why the speed groups between the average and 85th percentile speeds have different speed ranges. Another limitation is that the vehicle operating speed data used in this study were obtained from FCD only, meanwhile some studies argued that only around 5% of vehicles are connected to the GPS. Thus, this might have affected the grouping of segments into the corresponding speed categories, and therefore influenced the ratios and the CMF functions. Also, the differences in the number of segments within each speed category could have an impact on the results. So far, the authors of this method have not provided any guidelines regarding the minimum or maximum number of segments within each category. Therefore, further research into determining the effects of different number of segments within the created groups would enhance this approach.

Conclusion

The safety effects of vehicle operating speeds on two-lane tangent segments for rural highways in Italy were investigated by developing a CMF function for two operating speed measures. Since speed cannot be easily controlled, the most apparent method applied is the cross-sectional approach, which compares the safety performance of two entities, one containing a feature and the other without the feature (the feature in this case is speed). The operating speeds were divided into five different speed categories and merged with the corresponding tangent segments. The predicted crashes for the tangent segments belonging to each category, were calculated using the calibrated HSM SPF recently developed. As such, the ratios between the observed and the predicted number of crashes for each speed category were analyzed and further developed into a CMF function. First, the results indicated that operating speed is an important risk factor on this type of road infrastructure since all the ratios for the two speed measures were significantly different from 1.0. Secondly, the findings also showed that when the safety effects of vehicle operating speeds are considered, the model performed better, producing predictions that were closer to the actual observed values, thereby validating the CMF functions developed. These CMF functions can therefore be applied for different purposes like determining the number of expected crashes for different driving speeds of drivers, and ultimately, can also be used to estimate the crash risks associated with each driving speed in road safety assessment as shown in chapter 3 of this thesis.

CHAPTER 4. THE MODIFIED NETWORK-WIDE ASSESSMENT (NWA) PROACTIVE MODEL

4.1. Introduction

Generally, the speed at which vehicles travel poses a lot of risks related to the road infrastructure. And, it is estimated that 10 to 15% of all crashes and 30% of all fatal crashes are the direct result of speeding (Van et al. 2021). Thus, speed is an important risk attribute in road safety as it increases the probability and severity of a crash. However, limited attention has been given to speed-related risks in safety assessment procedures. Out of 18 RSI procedures related to the infrastructures identified in chapter two, only 5 of these procedures considered the safety effects of vehicle operating speed. One of these procedures is the iRAP Star Rating procedure (iRAP 2009) that incorporates speed-crash risks related to road users. The speed-crash risk in iRAP is represented by five curves, as illustrated in Figure 4-1. Three of these curves represent the risks for both vehicle occupants and motorcyclists, and each of the other curves represents the risks for pedestrians and bicyclists.

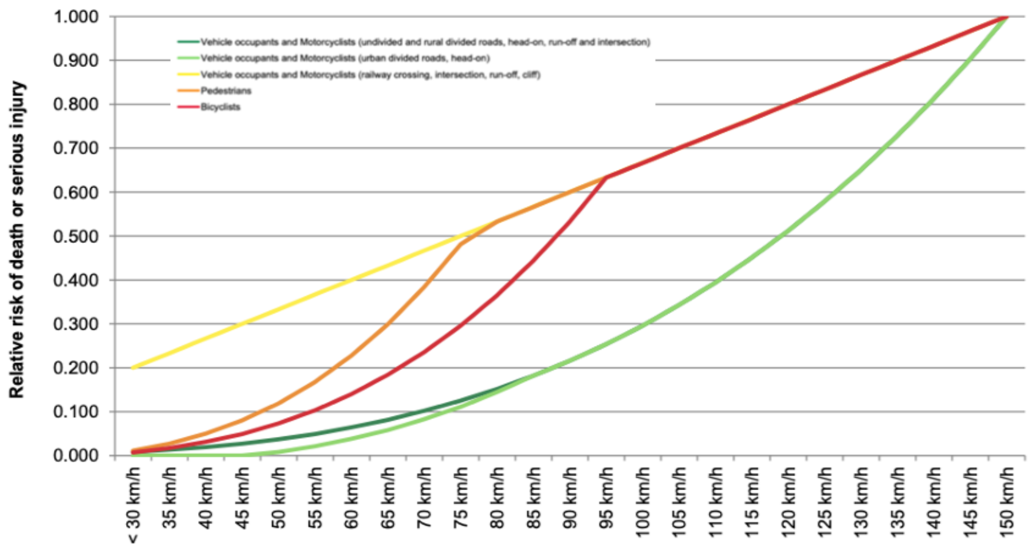


Figure 4-1: Combined (likelihood x severity) speed risk factor curves used in iRAP Star Rating

The risk factors obtained from the curves represent the risk of a fatal injury. The yellow line represents crash types with a severity outcome independent of speed. The speed value taken into account in the curves is the higher speed recorded between the operating speed and the speed limit.

Tripodi et al. (2020) also consider speed-crash risks related to the road users. The operating speed risk is represented using the Sigmoid curves by Wramborg (2005) as illustrated in **Figure 3-2.**

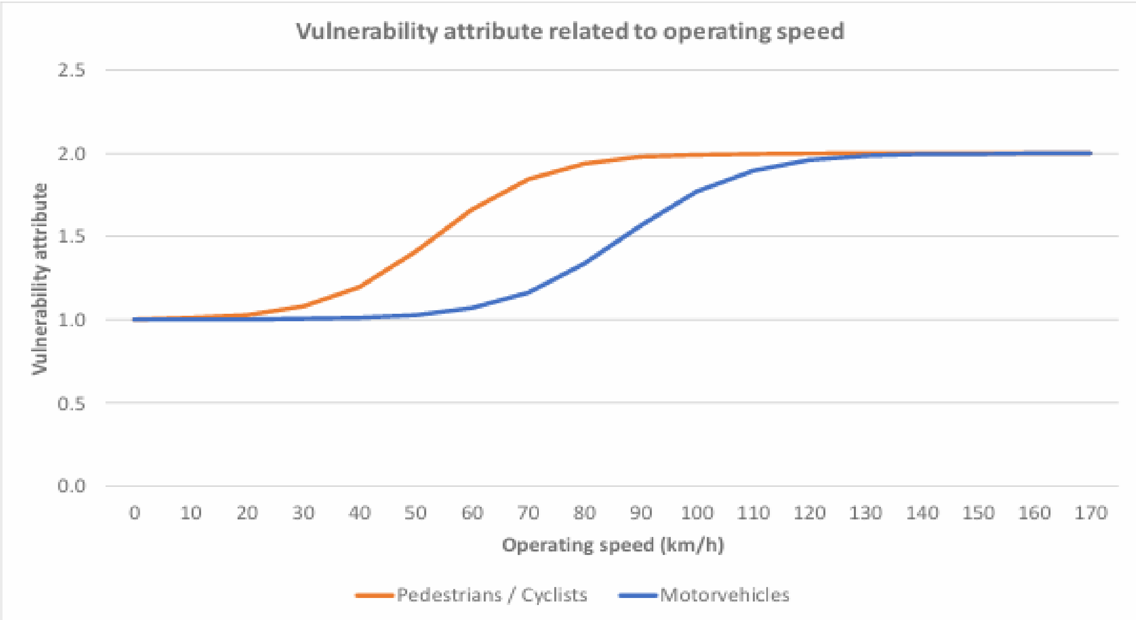


Figure 4-2: Road attribute related to operating speed

Though the curves are hypothetical, they are still eligible to assess speed-crash risks for pedestrians, cyclists, and vehicles. The curve is used in this procedure as a calibration factor for the estimation of speed-crash risk, and speed is considered as a crash severity risk component, calculated as:

$$\boldsymbol{Crash\ severity} = SW\ x \ldots \ldots \ldots. \qquad (4\text{-}1)$$

Where; SW is the attribute related to speed and the calibration factor is estimated from the Sigmoid curve above.

Leur and Sayed (2002) incorporated the safety effects of speed in the risk severity component for rural roads only, obtained as a ratio between the posted speed limits, as shown in Equation (4-2).

$$\boldsymbol{Consequence} = \left(\frac{PS_i}{PS_{max}}\right) x\ 3.0 \qquad (4\text{-}2)$$

Where; PS_i is the Posted Speed at the location of a specific feature and PS_{max} is the maximum Posted Speed.

Cafiso et al. (2007) considered operating speed risks in the evaluation of the accident severity factor for the road segment computed using Equation (4-3).

$$\boldsymbol{Accident\ severity\ factor} = \left(\frac{V_{85}}{V_{base}}\right) x \dots\dots \qquad (4\text{-}3)$$

Where; V_{85} is the average 85th percentile of speed along the road segment and V_{base} is the base operating speed for two-lane rural highways assumed equal to the legal speed limit of 90km/h.

Zia et al. (2019) incorporated the safety effects of speed based on speed limits only for rural roads. In the scoring process, speed limit is combined with horizontal alignment to estimate the operating speed factor as follows:

$$\boldsymbol{Infrastructure\ risk\ score} = Log_{10}\ (\dots\dots..X\ Operating\ Speed\ Factor) \qquad (4\text{-}4)$$

If the speed limit changes within a homogeneous section, the speed limit that applies to most of the section is considered. The risk values used for the operating speed factor are presented in Table 4-2.

Table 4-1. *Operating speed risk factors (source: Zia et al. 2019)*

Speed limit	Horizontal alignment			
	Straight	Curved	Winding	Tortuous
< = 30km/h	0.15	0.15	0.13	0.13
40km/h	0.31	0.31	0.27	0.27
50km/h	0.55	0.55	0.49	0.33
60km/h	0.81	0.81	0.81	0.42
70km/h	1.25	1.25	1.11	0.47
80km/h	1.82	1.82	1.30	0.52
90km/h	2.54	2.54	1.41	0.58
100km/h	3.24	3.24	1.52	0.64
110km/h	4.28	3.24	-	-

The NWA Proactive model *(European Commission, 2023),* which is the focus of this study, does not take into account the safety effects of speed related to the road infrastructure. Instead, in this procedure, speed is considered as an input and not a risk attribute. As such, this study proposed to use the CMF function (developed in Chapter 3) to capture the speed-crash risks of vehicle operating speed on two-lane undivided rural highways. The CMF function is used to quantify the risks related to different operating speeds on the road. Rather than relying on the difference between the actual operating speed and speed limits to obtain the speed crash risks, the CMF function can be used to extract the speed-crash risks for different traveling speeds. The main goal of incorporating the speed-crash risks of vehicle operating speeds into the NWA Proactive model is to improve the predictive performance of the model since speed is a major crash contributory factor. Therefore, the overall objective of this chapter is to investigate whether considering the safety effects of vehicle operating speeds related to the road infrastructure improves the safety performance of the NWA Proactive model. This is carried out by considering the NWA Proactive model with and without speed, and applying the model on the same road sections with the intention of comparatively analyzing their performance. The impacts of both models on the integration of NWA results were also evaluated. The remaining part of this chapter is structured as follows: Section 4.2 provides the methodological framework for the study, which is divided into six steps; Section 4.3 is for the analysis of the results; Section 4.4 provides the detailed discussion of the results; and then, the chapter ends with the conclusion.

4.2. Methodology

The methodology is designed to investigate whether incorporating the safety effects of vehicle operating speed into the current NWA Proactive model could improve the reliability and validity of the model. The methodological framework is illustrated in **Figure 4-3.**

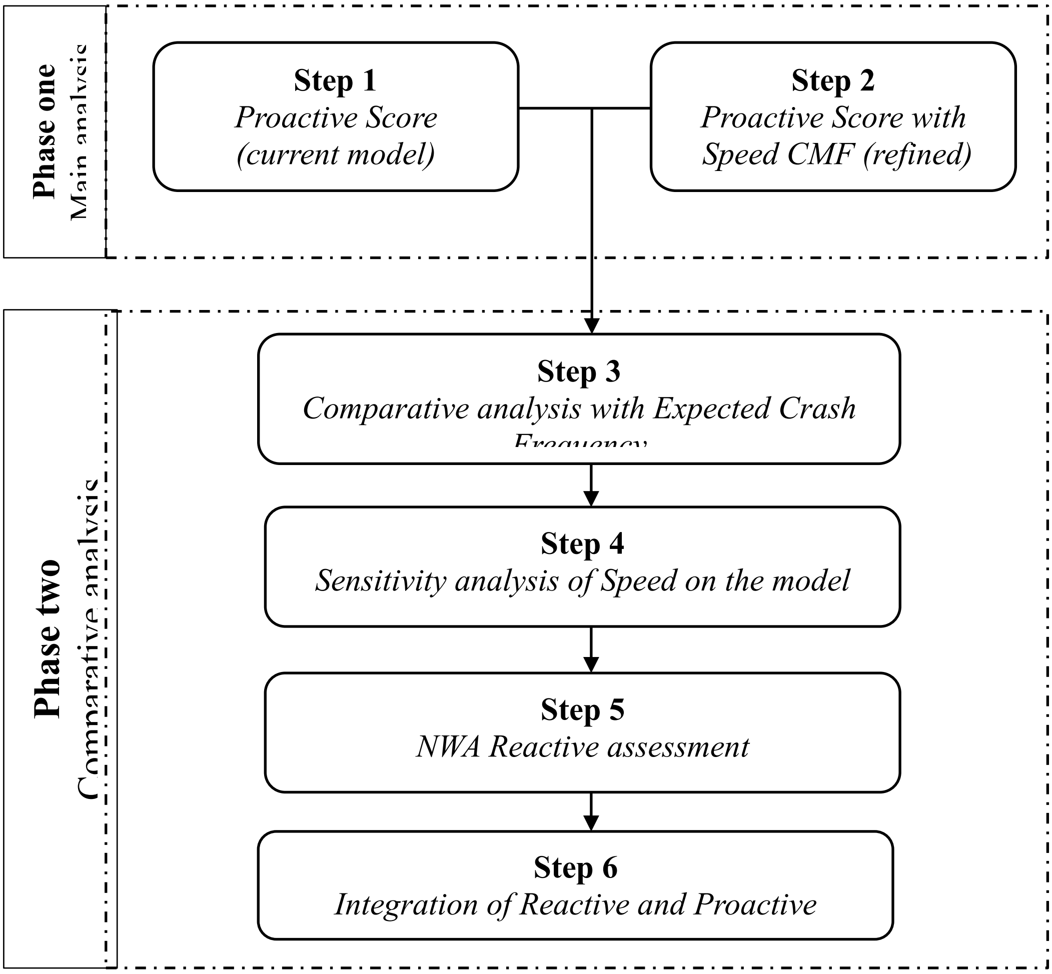


Figure 4-3: Methodological framework for the analysis

Step 1: Proactive score

The NWA Proactive model assesses road sections based on the in-built design characteristics of the road. The Proactive Score (PS), is the risk index computed for each road section. It is obtained through the safety inspection and evaluation of road attributes. Scores allocated for each attribute vary depending on its availability and condition. The scores are assigned using CMF values for each road parameter. In applying the CMFs, it is the inverse of the CMF values that is used, known as Reduction Factors (RF). The CMF values that are less than one are normalized before used to ensure that the corresponding RF maximum score is 1.0. Equations (4-5) and (4-6) are used for the normalization of the CMF values and for the conversion of these values into RFs respectively.

$$\boldsymbol{CMF_{j,norm} = \frac{CMFj}{CMF\ min}} \qquad \textit{(4-5)}$$

$$\boldsymbol{RF_j = \frac{1}{CMFj}} \qquad \textit{(4-6)}$$

Next, the NWA Proactive score is calculated as shown in Equation (3)

$$\boldsymbol{Proactive\ score_i = 100\ x\ RF_{1i}\ x\ RF_{2i}\ x \dots \dots \dots \dots .\ RF_{ni}} \qquad \textit{(4-7)}$$

Where; *RFi are the Reduction factors for each road parameter assessed*

Step 2: Proactive score with CMF Speed

The current NWA Proactive model does not consider speed as a risk attribute. Since vehicle operating speed is a significant risk factor, the CMF of speed developed in Chapter 3, was incorporated into the NWA Proactive model as a risk attribute, to produce a "Modified Proactive Model". The introduction of 'Speed CMF' means that the safety effects of vehicle operating speed related to the road infrastructure are considered. Therefore, the contribution of speed, which is an important risk factor that contributes to the likelihood and severity of a crash, is taken into account. The main objective for incorporating the safety effects of speed into the NWA Proactive model, is to improve the predictive accuracy of the model, since speed is an important risk factor. The new speed risk attribute is represented as $\boldsymbol{RF_{Speed}}$ and incorporating it would produce a new model as shown in Equation **(4-8).**

$$\boldsymbol{Modified\ Proactive\ Score_i = \ 100\ x\ \Pi RF_{ni}\ x\ RF_{Speed}} \qquad \textit{(4-8)}$$

Where; ΠRF$_{ni}$ are the *reduction factors for in-built road design characteristics,* $\boldsymbol{RF_{Speed}}$ is the *reduction factor vehicle operating speed related to the infrastructure.*

Considering the CMF function derived for average operating speed in Chapter 3, and to ensure uniformity in the RF values applied, the following $\boldsymbol{RF_{Speed}}$ values were proposed for the analysis as presented in Table 4-2.

Table 4-2: Reduction factors for different speed categories

No.	Average speed (km/h)	CMF Values	Reduction Factor
1	≤ 50	1.000	1.000
2	55 - 60	2.122	0.964
3	60- 65	2.052	0.932
4	65 - 70	1.990	0.904
5	70 - 75	1.934	0.879
6	75 - 80	1.884	0.835
7	80 - 85	1.838	0.816
8	90 - 95	1.756	0.798
9	95 -100	1.720	0.766
10	≥ 100	1.687	0.766

Based on the Proactive Scores from steps 1 and 2, the road sections can be ranked into any of the following three classes:

- 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

Step 3: Comparison of NWA Proactive Score (with and without speed) and Expected crashes

In this step, the NWA Proactive Scores (with and without speed) are compared with the estimated expected crash frequencies obtained from Empirical Bayes (EB) method. The process begins by estimating the predicted number of crashes, subjecting it to the EB technique, to obtain the expected number of crashes, and comparing the results to those obtained for NWA Proactive Score (with and without speed). The predicted crash frequency was obtained by applying the Accident Prediction Model (APM) developed for a typical Italian, two-lane undivided rural highway (Cafiso et al., 2010). The general form of the APM is:

$$E(Y) = e^{ao} . \ L \ . AADT^{a1} \ . e \sum_{j=0}^{m} bj \ XJ \ [acc/year] \qquad (4\text{-}9)$$

Where E(Y) is the expected injury accident frequency / year; L is the length of the segment under consideration (km), AADT is the Average Annual Daily Traffic (veh/day), Xj is any of m-additional variables; a_0, a_1, and b_j are the model parameters. The study chose the base model with model parameters defined as shown in Table 4-3.

Table 4-3: Model parameters and model performance characteristics (Cafiso, 2010)

Parameter	Estimate	K	AIC	Pearson χ^2	$\chi^2_{0.05}$
a_0	-7.132	0.93	417.6	85.4	129.9
a_1	0.731				

For each of the selected road networks, five years' crash data (2019 – 2023) was obtained from the Italian Institute of Statistics (ISTAT) and AADT for each road obtained from ASTRAL spa (the regional construction company in Lazio Region in Italy) was applied.

Expected crash frequency

The EB method was employed to combine the predicted crash frequency and the observed crashes in estimating the expected crash frequency at each section. This is estimated using Equation (4-10).

$$Nexpected = \omega \ x \ Npredicted + (1 - \omega) \ x \ Nobserved \qquad (4\text{-}10)$$

Where, **ω,** represent weights assigned to the predicted and observed number of crashes. The weight, w, is calculated using Equation (31).

$$\omega = \frac{1}{1+K+Npredicted} \qquad (4\text{-}11)$$

Where K, is the overdispersion parameter given in Table 4-3.

Step 4: Sensitivity analysis of speeds with respect NWA Proactive model

Sensitivity analysis is conducted by considering the impact of different values of operating speeds on the Modified Proactive model, using all the roads under study.

Step 5: NWA Reactive assessment

Crash rate and Crash density

For reactive assessment, two safety performance metrics are determined: crash rate and crash density using Equations **(4-11)**and **(4-12).**

$$\textit{Crash Rate (Ri)} = \frac{N_i * 10^8}{365.25 * AADTi * y * L_i} \quad \textbf{\textit{(4-11)}}$$

Where; Ri is the crash rate, Ni is the number of crashes at road section / junction, i, occurring in the analysis period. AADTi is the Average Annual Daily Traffic of the section / junction, y is the analysis period (years), and L_i is the length of section, i (km).

$$\textit{Crash Density (di)} = \frac{f_i}{L_i} \quad \textbf{\textit{(4-12)}}$$

Where; $\mathbf{f_i}$ is the crash frequency at road section/junction **I**, L_i is the length of section, **i** (km).

Reference Population

Reference populations are a set of roads with similar operational and design characteristics. They represent the average crash rates and average crash densities for each reference population group. These values serve as thresholds for assessing the safety level of each section.

Road safety ranking

The different safety classes for ranking are obtained by first applying the Poisson method to determine the upper and lower thresholds for the observed number of crashes for each road section using Equations (4-13) and (4-14).

$$\textit{Lower confidence interval:} \quad chisquare\,[\tfrac{\alpha}{2},\ 2\,x\,k] / 2 \quad \textbf{\textit{(4-13)}}$$

$$\textit{Upper confidence interval:} \quad chisquare\,[1-\frac{\alpha}{2},\ 2\,x\,(k+1)]\Big/_{2} \qquad \textbf{(4-14)}$$

Where: k, is the observed number of crashes in a section/junction during the analysis period and **α** is the confidence interval. It is recommended to consider **α** as 0.05. According to the methodology, three ranking classes are defined as such:

- If the safety performance metric for the reference population is lower than the lower threshold, the corresponding section is classified as "High Risk".
- If the safety performance metric for the reference population is higher than the upper threshold, the corresponding section is classified as "Low Risk".
- If the 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 is classified as "Unsure".

Step 6: Integration of the Reactive and Proactive assessment results

Based on the rankings from the proactive and reactive assessments, the integration of the results is performed as shown in **Figure 4-*4***, where the final results are classified into any of the five prioritization classes.

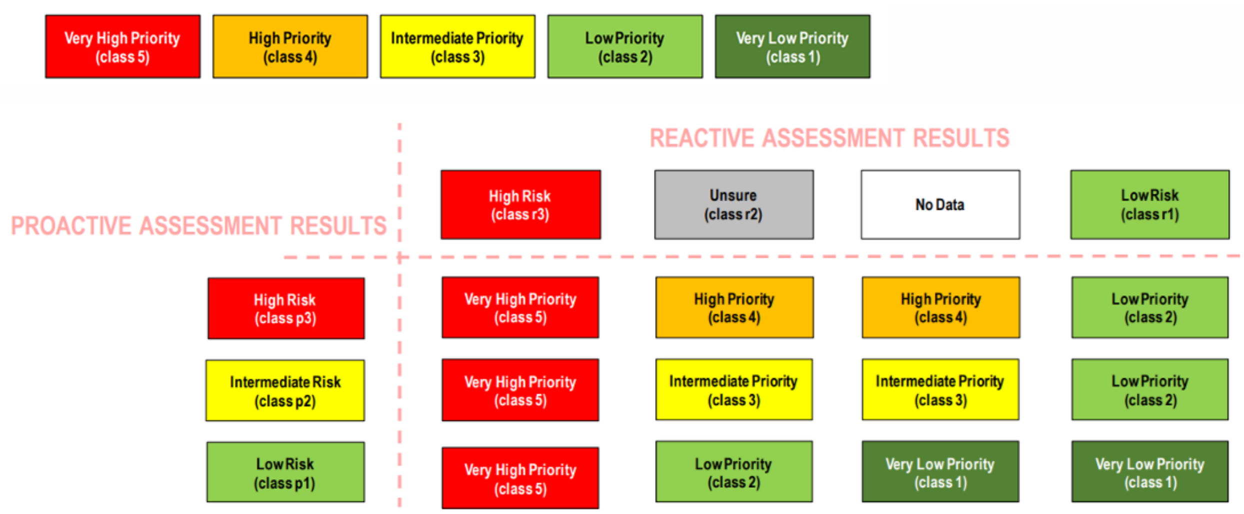


Figure 4-4: The matrix for ranking the integrated results

4.3. Analysis of results

4.3.1. Analysis of NWA Proactive results

This section is divided into four subsections: firstly, an analysis of the rankings of road sections for NWA Proactive score with and without CMF Speed; secondly, a comparative analysis of the Proactive Scores with the observed crash history; thirdly, a sensitivity analysis of CMF Speed in respect to in-built assessment; and finally, how considering the safety effects of speed influence the overall NWA results.

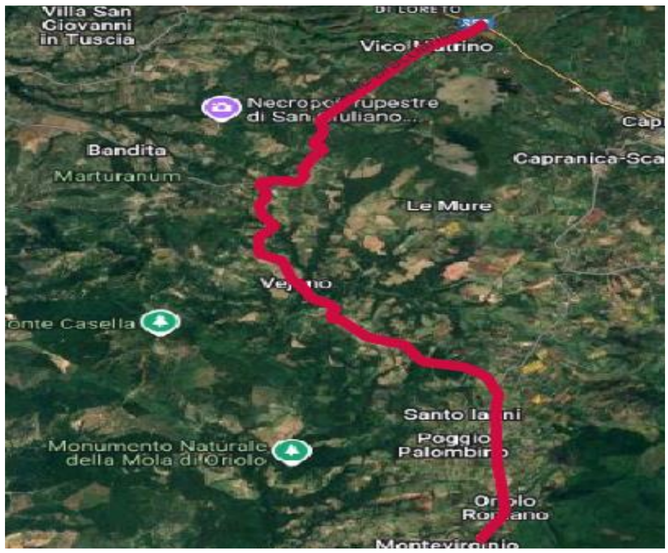
Road sections selected

Table 4-4. *Road sections assessed*

No	*Name of road*	*Reference*	*Province*	***Road interval***		*Section length (km)*
				Start point	**Endpoint**	
1	Claudia Braccianese	SP 147	Viterbo	33.330	52.900	19.570
2	Borgo Piave Acciarella	SP 38	Latina	0.000	10.481	10.481
3	Maria	SP 278	Frosinone	0.000	17.900	17.900
4	Tuscanese	SP 02	Viterbo	2.850	21.350	18.500
					Total length	**66.451**

Case I **- Claudia Braccianese, SP 147.**

1.1 Site description: This road section is the Provincial road, named "Claudia Braccianese" (a State Provincial road number 147), located in Viterbo Province, within the Lazio Region, in Italy. It is a two-lane undivided rural highway, of length 19.570km. The location of the road section and a summary of its characteristics are as illustrated below.



Road section characteristics	
Total length	19.570km
Number of lanes	2
Average speed	65km/h
Number of 500m sections	37
Shoulder type	Paved
Terrain type	Flat
Area type	Mixed
Pavement surface	Paved

Figure 4.5. Location and characteristics of Claudia Braccianese road section

1.2 Data collection & segmentation

The RSI was conducted on 23rd November 2024, by recording videos of the road section. The videos were later analyzed and sections of fixed length, 500 meters assessed. Based on the availability and condition of the road attribute, scores were assigned according to the defined criteria. The PS for each road section with and without the safety effects of vehicle operating speeds were analyzed, and the results are presented as in Figure 4-6.

1.3 **Ranking of road sections**

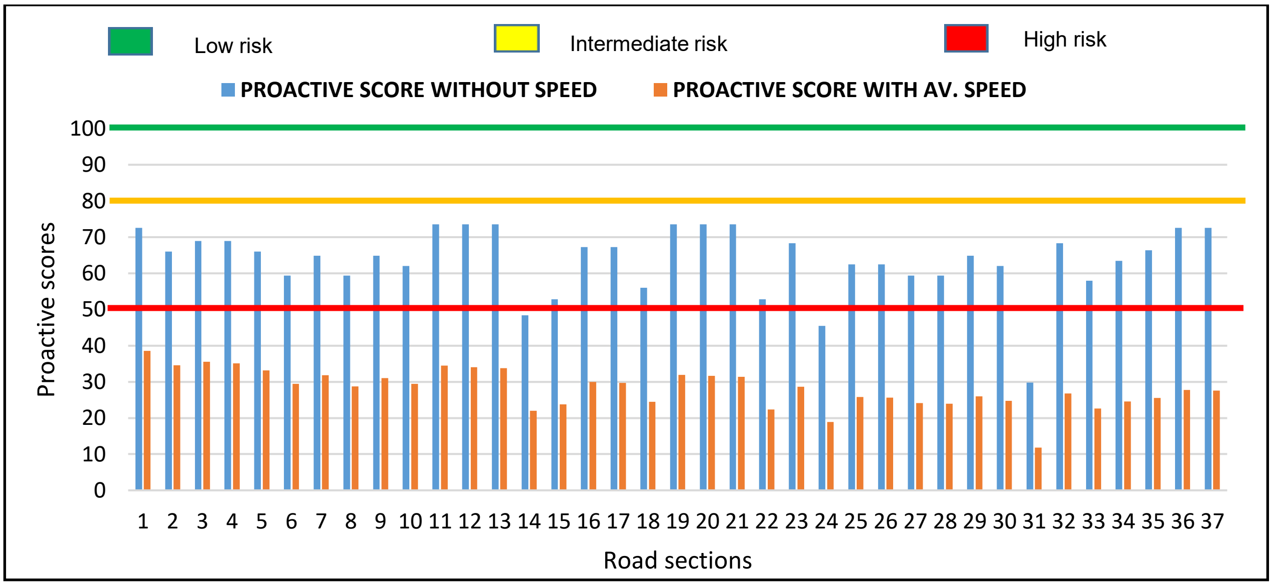


Figure 4-6. *Claudia Braccianese road section ranking with and without speed*

From the 37 road sections in this road network, only three were classified as high-risk sections for proactive scores without speed. The rest of the 34 sections were classified as belonging to the intermediate risks. On the other hand, proactive scores with the safety effects of speed considered show that all the road sections are of high-risks. These contrary results revealed that the road sections assessed without considering the safety effects of vehicle operating speeds are safer, than those that were assessed considering speed.

1.4 Proactive score and observed crash frequency

It is important to verify if incorporating the safety effects of speed brings the predictions closer to the observed crash frequencies than when it is not. The results for this road stretch show that the R^2 values for PS without and with speed are equal to 0.1069 and 0.2038, respectively. This shows that the coefficient of correlation for PS with speed almost doubles that obtained for PS without speed.

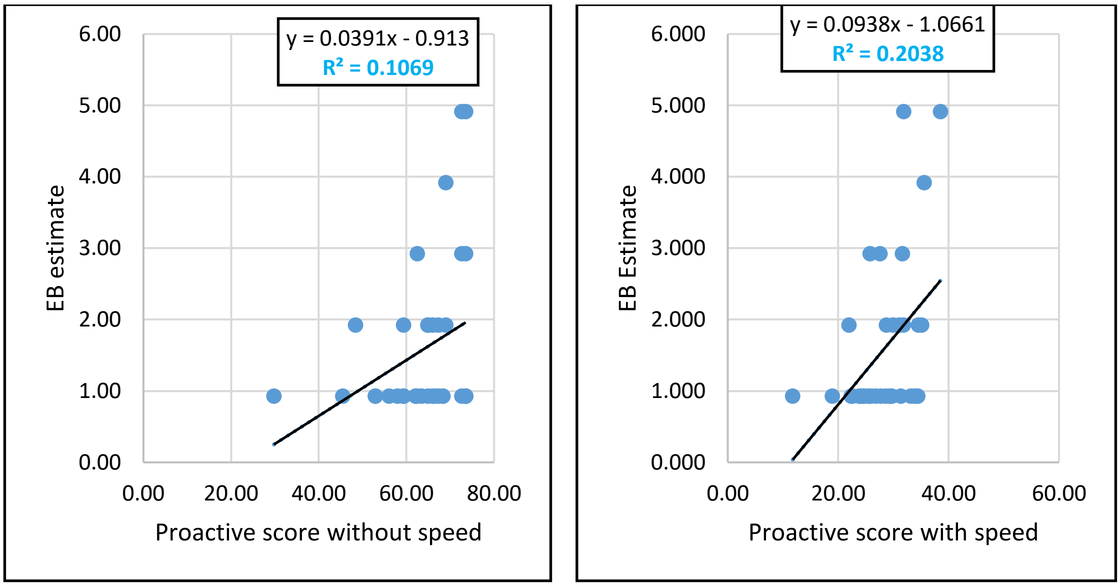


Figure 4-7. *Correlation between EB estimates and Proactive Scores with and without speed for Claudia Braccianese road*

***Case II* - Borgo Piave Acciarella road, SP 38.**

2.1 Site description: This road section is the Provincial road, named "Borga Piave Acciarella" (a State Provincial road number 38), located in Latina Province, within the Lazio Region, in Italy. It is a two-lane undivided rural highway, of length 10.481km, and connects the two towns, Acciarella (km 0 + 000) through Borgo Santa Maria and ends at Borga Piave. The location of the road section and a summary of its characteristics are as illustrated below.

Road section characteristics	
Total length	10.481km
Number of lanes	2
Average speed	70km/h
Number of 500m sections	21
Shoulder type	Paved
Terrain type	Flat
Area type	Rural
Pavement surface	Paved

Figure 4-*8*. *Location and characteristics of Borgo Piave Acciarella road section*

2.2 Data collection & segmentation

The visual Road Safety Inspection (RSI) was conducted on 23rd November 2024, by recording videos of the road section. The videos were later analyzed and sections of fixed length, 500 meters assessed. Based on the availability and condition of the road attribute, scores were assigned according. The Proactive scores for each road section with and without the safety effects of vehicle operating speeds were analyzed and the results were presented as follows.

2.3 **Ranking of road sections**

From the 21 sections in this road network, 7 are of intermediate risks and 14 are of high risks in the case of PS without speed. On the other hand, 2 sections were classified as intermediate-risk, and 19 sections are of high risk for PS without speed. The different results revealed the importance of speed-crash risks in identifying the safety levels of road sections.

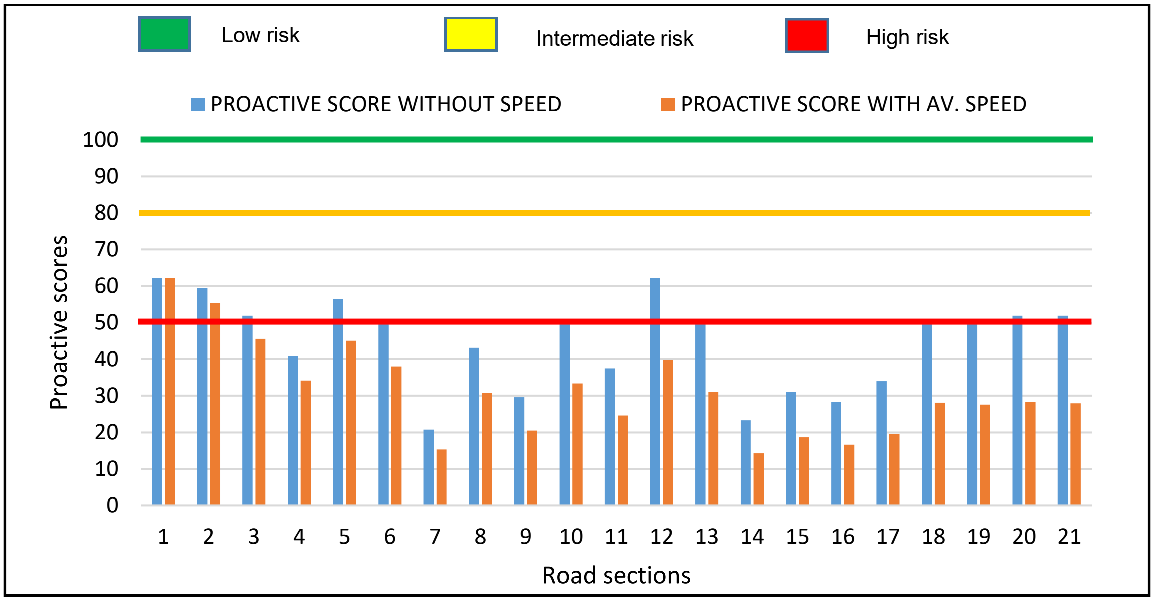


Figure 4-*9*. *Borgo Piave Acciarella road sections ranking with and without speed*

2.4 Proactive score and crash frequency

In terms of model performance, the results revealed that the R^2 values for PS without and with speed are equal to 0.1514 and 0.2329, respectively. The results show that the correlation for PS plus speed doubles that obtained for PS without speed. Therefore, considering the safety effects of speed improves the predictive accuracy of the model.

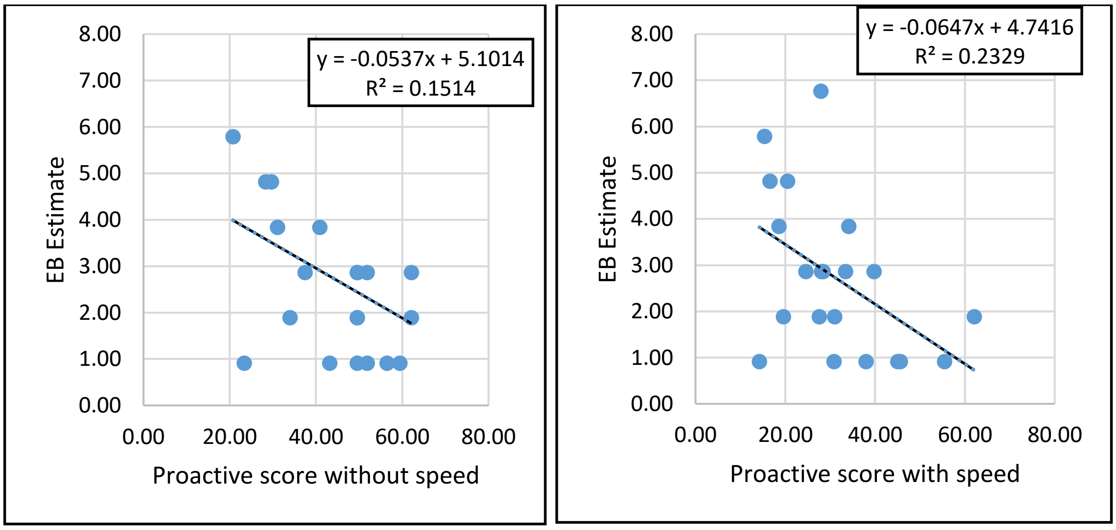


Figure 4-*10*. *Borgo Piave Acciarella correlation between EB estimates and Proactive Scores with and without speed*

Case III - **Maria I & II road, SP 278.**

3.1 Site description: This road section is the Provincial road, named "Maria" (a State Provincial road number 278), located in Frosinone Province, within the Lazio Region, in Italy. It is a two-lane undivided rural highway of length 17.900km. The location of the road section and a summary of its characteristics are as illustrated below.

Road section characteristics	
Total length	17.900km
Number of lanes	2
Average speed	70km/h
Number of 500m sections	21
Shoulder type	Paved
Terrain type	Flat
Area type	Rural
Pavement surface	Paved

Figure 4-*11*. *Location and characteristics of the Maria I&II road*

3.2 Data collection & segmentation

The RSI was conducted on 23rd November 2024, by recording videos of the road section. The videos were later analyzed and sections of fixed length, 500 meters assessed. Based on the availability and condition of the road attribute, scores were assigned according. The Proactive scores for each road section with and without the safety effects of vehicle operating speeds were analyzed, and the results were presented as follows.

3.3 **Ranking of road sections**

From the 39 road sections in this road stretch, 24 sections are of intermediate risk, and 15 are of high risk for PS without speed. On the other hand, all the road sections for PS plus speed were classified as high-risk. Therefore, all the road sections assessed considering the safety effects of speed were identified as high-risk, and only 15 sections are of high-risk for PS without speed.

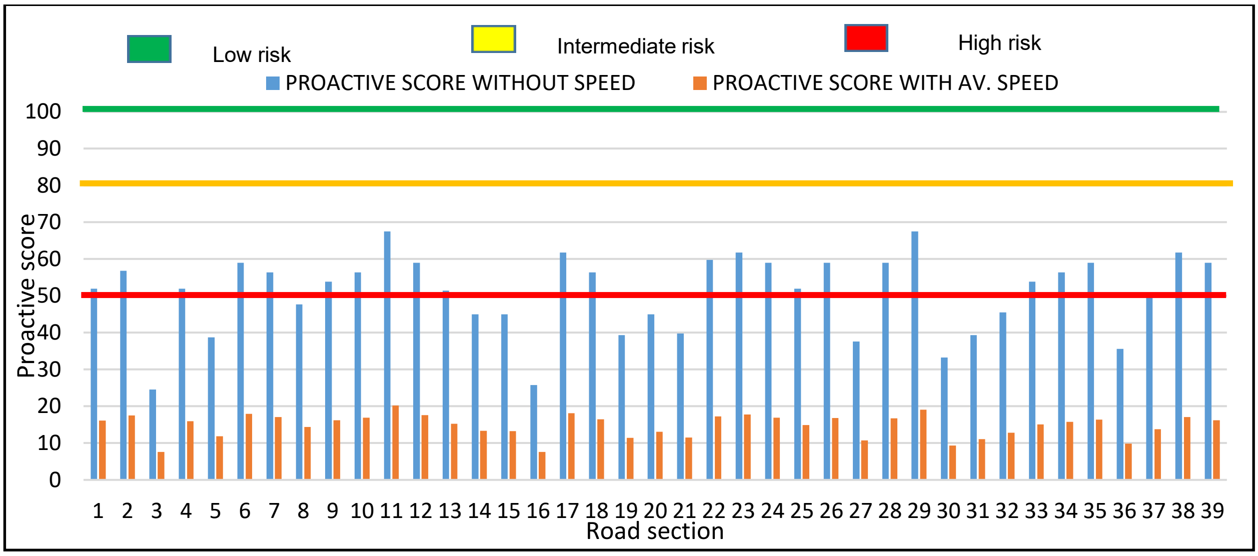


Figure 4-*12*. *Maria I & II road sections ranking with and without speed*

3.4 **Proactive score and observed crash frequency**

In terms of model performance, the results show that the R^2 values for proactive scores without and with speed are equal to 0.164 and 0.2096, respectively. These results also show that the safety effects of speed, the model performs better than when speed is not considered.

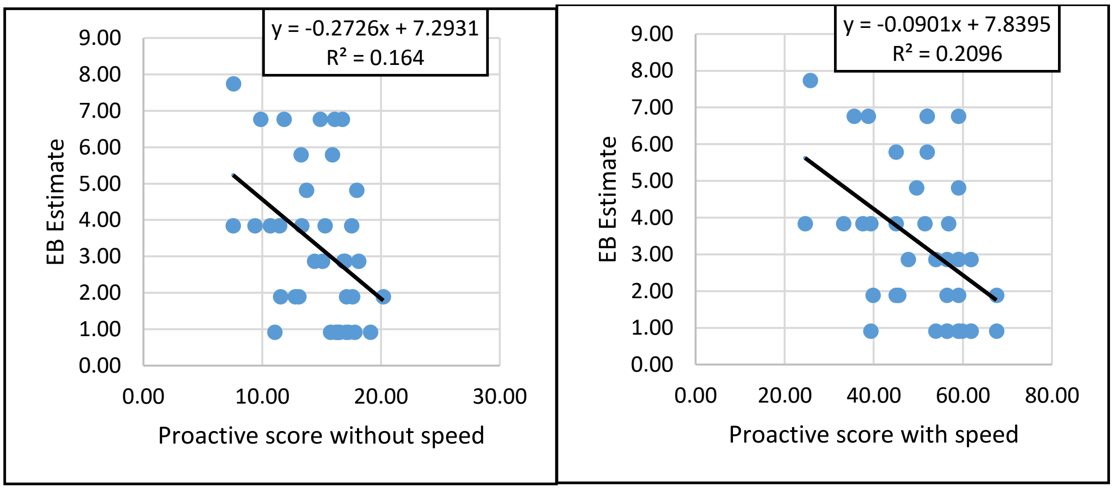
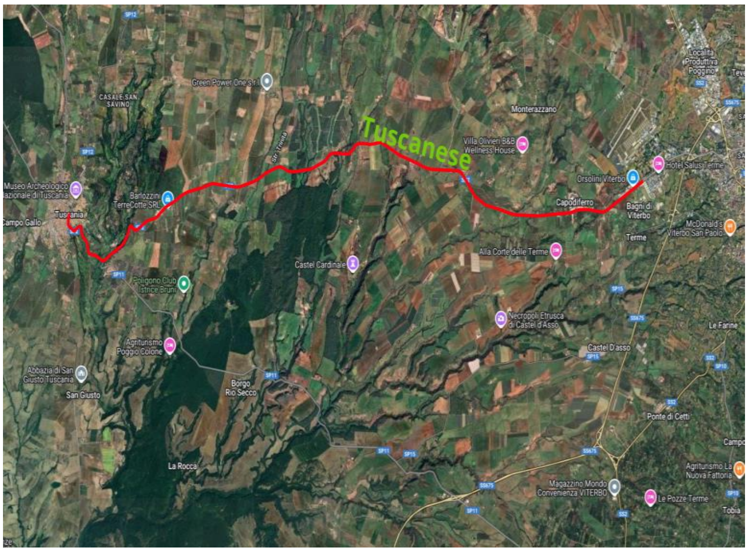


Figure 4-*13*. *Maria I & II correlation between EB estimates and Proactive Scores with and without speed*

Case IV – Tuscanese road, SP 02.

4.1 Site description: This road section is the Provincial road, named "Tuscanese" (a State Provincial road number 02), located in Viterbo Province, within the Lazio Region, in Italy. It is a two-lane undivided rural highway, of length 18.500km. The location of the road section and a summary of its characteristics are as illustrated below.



Road section characteristics	
Total length	18.500km
Number of lanes	2
Average speed	75km/h
Number of 500m sections	21
Shoulder type	Paved
Terrain type	Flat
Area type	Rural
Pavement surface	Paved

Figure 4-*14*. *Location and characteristics of the Tuscanese road*

4.2 Data collection & segmentation

The RSI was conducted on 23rd November 2024, by recording videos of the road section. The videos were later analyzed and sections of fixed length, 500 meters assessed. Based on the availability and condition of the road attribute, scores were assigned according. The PS for each road section with and without the safety effects of vehicle operating speeds were analyzed and the results were presented as follows.

4.3 **Ranking of road sections**

From the 43 road sections in this road stretch, 40 sections are of intermediate risk, and only 3 sections are of high risk for PS without speed. On the other hand, all the road sections for PS plus speed were classified as high-risk.

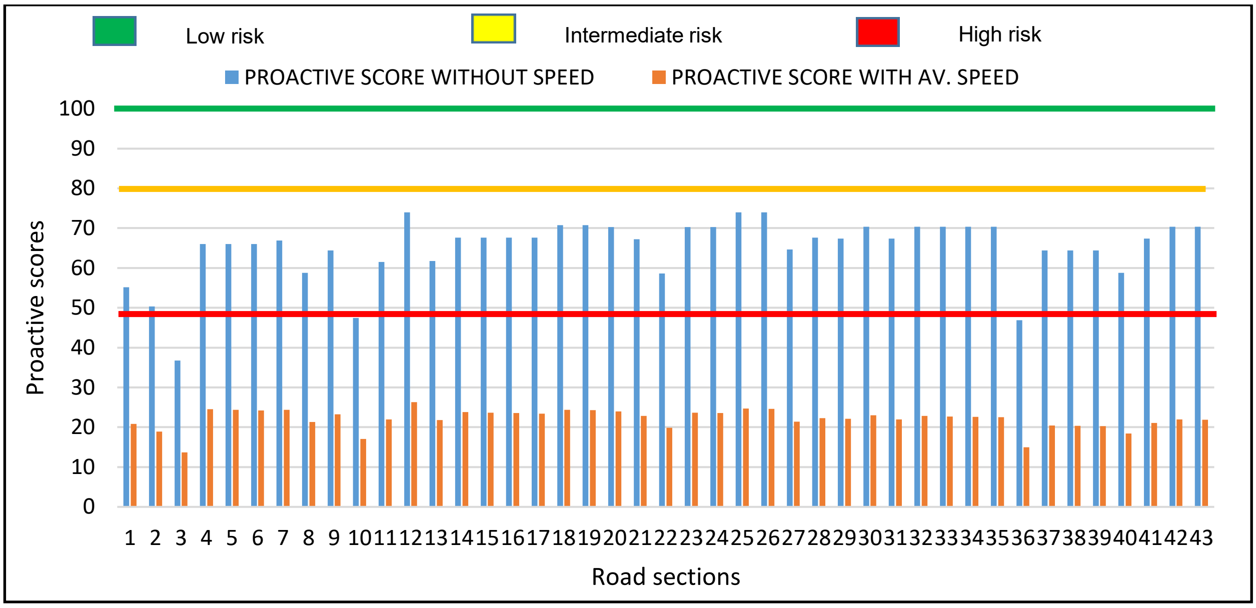


Figure 4-*15*. *Tuscanese road sections ranking with and without speed*

4.4 Proactive score and observed crash frequency

In terms of model performance, the results showed that the R^2 values for PS without and with speed are equal to 0.0083 and 0.0167, respectively. These results revealed that by considering the safety effects of speed, the model performs better than when speed is not considered.

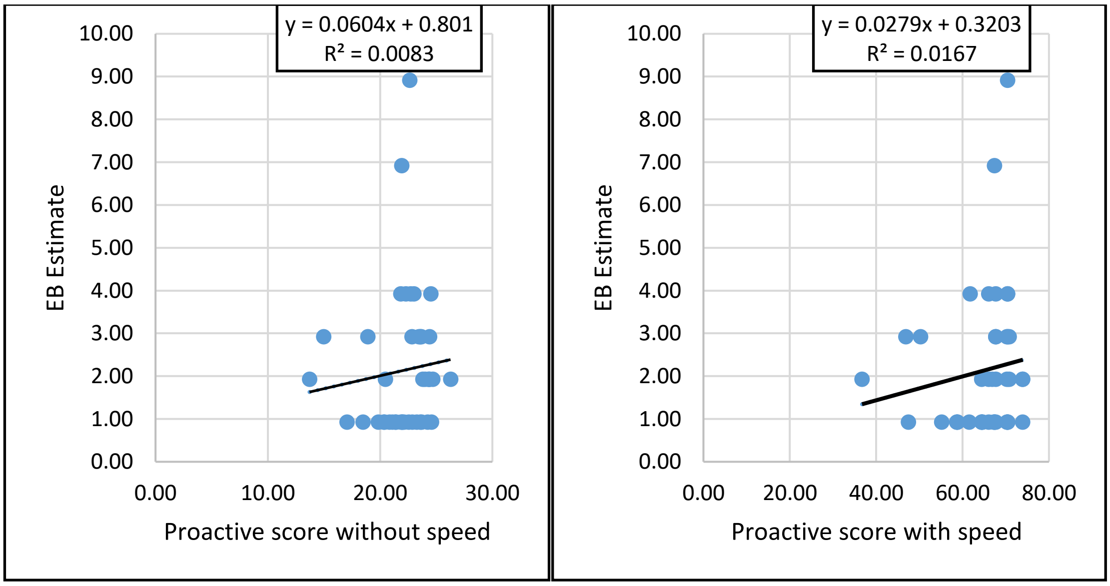


Figure 4-*16*. *Tuscanese correlation between EB estimates and Proactive Scores with and without speed*

A summary of the results for the above section rankings and correlation analysis for the four case studies is as shown below in ***Table 4-5*** and ***Table 4-6.***

Table 4-5. *Summary of Proactive sections rankings*

Road network	**Ranking of road sections**	
	Proactive Score without speed	**Proactive Score with speed**
1.Claudia Braccianese	- 3 High risks - 34 intermediate risks	- All 37 high risks
2.Borgo Piava Acciarella	- 14 high risks - 7 intermediate risks	- 19 high risks - 2 intermediate risks
3.Maria I&II	- 15 high risks -24 intermediate risks	- All 39 high risks
4.Tuscanese	- 3 high risk -40 intermediate risks	- All 43 high risks

Table 4-6. *Summary of correlation results*

Road network	**Correlation coefficients**	
	Proactive Score without speed	**Proactive Score with speed**
1.Claudia Braccianese	0.1069	0.2038
2.Borgo Piava Acciarella	0.1514	0.2329
3.Maria I&II	0.164	0.2096
4.Tuscanese	0.0083	0.0167

4.3.2. Sensitivity analysis

The sensitivity of the NWA Proactive model to traffic speeds was also investigated. The sensitivity analysis was carried out to test the impacts of different values of average operating speeds on the Proactive scores. This would help determine what speed values should be set and enforced to achieve an acceptable level of risk. The outcome of the analysis as shown in Figure 4-15, shows how Proactive score values obtained according to the present condition of the road infrastructure vary for different values of speed on the four road sections under analysis. The Proactive scores are plotted against different values of operating speeds, and then the trend is investigated in respect to the three NWA Proactive risk classes represented as thus: High risk correspond to red lines with Proactive scores that vary between 0 – 50; intermediate risk corresponds to the yellow line with Proactive scores that vary between 50 – 80; and low risk corresponds to the green line with Proactive scores that vary between 80 – 100.

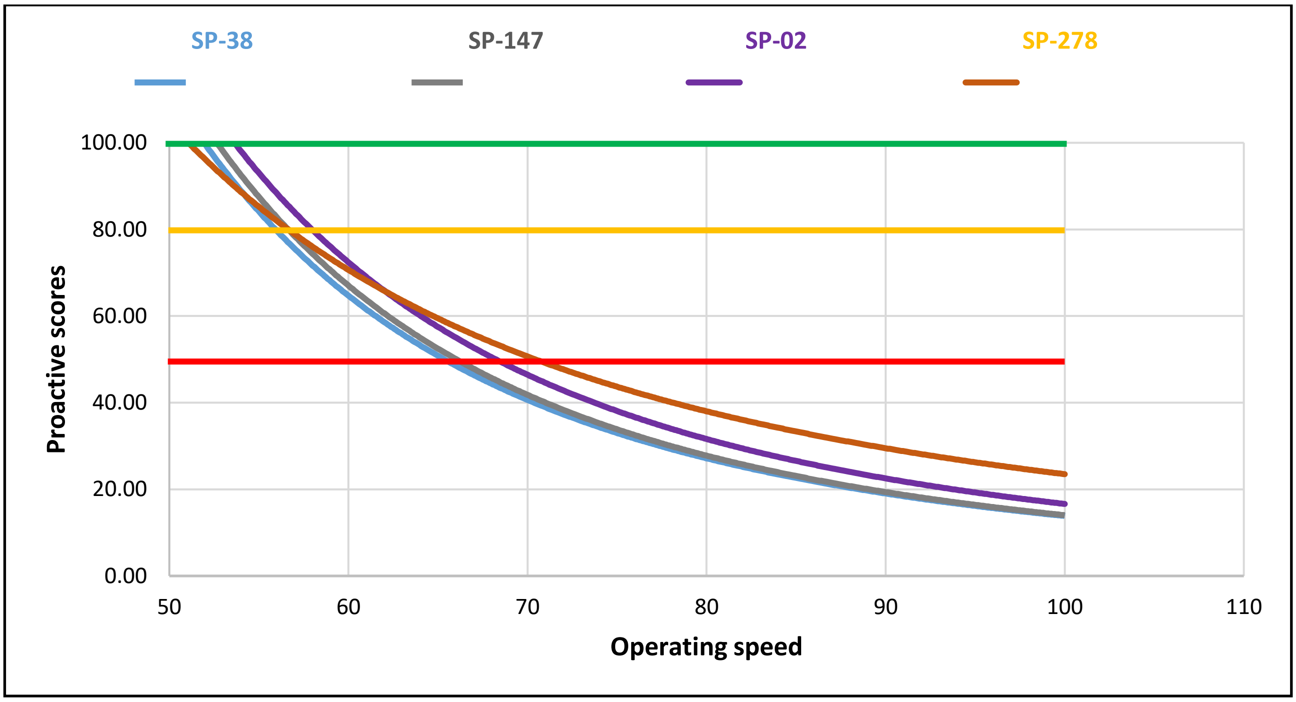


Figure 4-*17*. Trend of proactive score varying against different operating speed values

The above sensitivity analysis shows that reaching the low-risk category on the two-lanes undivided rural highway is possible solely for speeds ≤ 60km/h in the current state of the road networks. And for operating speeds above 75 km/h, based on the present state of the road networks, is very dangerous as all the road sections are of high risks. Therefore, based on the present conditions of the road networks and applying the NWA Proactive model, the maximum operating speeds to be enforced on the roads under study is 70 km/h.

4.3.3. NWA Reactive Assessment

4.3.3.1. Data collection

The data applied for this assessment included crash data, traffic volume data, and road geometry data. Crash data for each road network was obtained from ISTAT (the Italian Institute of Statistics) for a period of five years (2019-2023). The crash data consists of fatal and injury crashes. Since the road sections under study are all two-lane undivided roads, the crash data collected was independent of the direction of travel. Traffic volume data for the selected roads was also obtained independent of the direction of travel. Considering that the average crash densities and average crash rates are not readily available for rural highways in Italy, the study assumed that the total sections form the reference population. This means that a section is compared against average statistics estimated across the total length of the four road sections under study, which is 66.451km. The same procedure was applied on some motorways in Greece, and a similar assumption was made (Katerina et al. 2023). Table 4-7 presents a summary of the reference population.

Table 4-7*. Summary of the Reference Population*

Data type	Total
Total number of crashes	209
Total km of road	66.451 km
Average AADT	6804
Average crash rate	25.31
Average crash density	0.63

4.3.3.2. Road Segmentation

All the roads under study are two-lane, undivided rural highways which the methodology recommends section lengths between 10 ± 5km (maximum length = 15km). In this study, road sections include both road segments and junctions. Road sections with tunnels as well as toll booths were excluded as required by the methodology. The data used for the segmentation included solely the horizontal curvature, and the segmentation results are presented in ***Table 4-8.***

Table 4-8. *Summary of the data used for the assessment of the road networks*

Roadway	Data type	Total
Claudia Braccianese, SP 147.	*Number of years of crash data*	5
	Total number of crashes	24
	AADT (Vehs/day)	7,500
	Number of road sections	37
	Total length of all sections (km)	19.570
Borgo Piave, SP 38.	*Number of years of crash data*	5
	Total number of crashes	39
	AADT (Vehs/day)	500
	Number of road sections	21
	Total length of all sections (km)	10.481
Maria, SP 278.	*Number of years of crash data*	5
	Total number of crashes	94
	AADT (Vehs/day)	500
	Number of road sections	39
	Total length of all sections (km)	17.900
Tuscanese, SP 02.	*Number of years of crash data*	5
	Total number of crashes	52
	AADT (Vehs/day)	15,000
	Number of road sections	43
	Total length of all sections (km)	18.500

4.3.3.3. Reactive assessment results

The aggregated results for the four roads under study are summarized in Table 4-9. Overall, the reactive assessment results indicated that two of the road networks are mainly made up of high- risk segments, that is, the Borgo Piave and the Maria I & II highways. Also, of all the four road networks, none of the road segments featured in the low-risk category. Nevertheless, due to low number of crashes, majority of the road segments were classified in the "unsure" category because they were not statistically viable.

Table 4-9. *Summary of reactive assessment results*

Road	Classes	Total length(km)	No. of sections
Claudia Braccianese, SP 147.	High Risk	1.00	02
	Low Risk	0.00	00
	Unsure	17.5	35
Borgo Piave, SP 38.	High Risk	7.50	15
	Low Risk	0.00	00
	Unsure	3.00	06
Maria I & II, SP 278.	High Risk	5.00	10
	Low Risk	0.00	00
	Unsure	14.50	29
Tuscanese, SP 02.	High Risk	0.50	01
	Low Risk	0.00	00
	Unsure	21.00	42

4.3.4. NWA Integrated Assessment

The third step in network-wide assessment methodology is directed towards integrating the proactive and reactive assessment results according to the proposed matrix indicated in Table 4-10 in the methodology section. However, in this analysis, the reactive assessment results are combined with two different proactive assessment results (that is, proactive assessment with speed, and proactive assessment without speed). The aim is to demonstrate how the modified NWA Proactive model could influence the prioritization results for the different road networks. This analysis was performed for each of the four road networks under study.

Case I. Claudia Braccianese, SP 147 road.

The integration results for this road network showed that out of the 37 road sections, the integration with "proactive results without speed" indicated that 2 very high priority sections were obtained, 3 high priority sections, and 32 intermediate priority sections. On the other hand, integration of reactive assessment results with "proactive results plus speed", produced 2 very high priority sections and 35 high priority sections.

Table 4-10. *Integration results for Claudia Braccianese road*

Section	Proactive without Speed	Proactive with speed	Reactive result	Integrated without speed	Integrated with speed
1	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
2	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
3	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
4	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
5	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
6	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
7	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
8	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
9	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
10	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
11	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
12	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
13	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
14	High Risk	High Risk	Unsure	High Priority	High Priority
15	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
16	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
17	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
18	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
19	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
20	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
21	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
22	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
23	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
24	High Risk	High Risk	Unsure	High Priority	High Priority
25	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
26	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
27	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
28	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
29	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
30	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
31	High Risk	High Risk	Unsure	High Priority	High Priority
32	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
33	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
34	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
35	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
36	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
37	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority

The disparities in the results revealed that the integrated results when speed is not taken into account outputs prioritized road sections that appeared to be less hazardous, requiring periodic inspections later, while, when speed is taken into account, the prioritized road sections appeared to be more risky, demanding immediate inspections.

***Case II.* Borgo Piave, SP 38 road.**

The integration results for this road network showed that out of the 21 road sections, the integration with "proactive results without speed" we obtained: 15 very high priority sections, 3 high priority sections, and 3 intermediate priority sections. On the other hand, integration of reactive assessment results with "proactive results plus speed", produced 15 very high priority sections, 5 high priority sections, and 1intermediate priority section.

Table 4-11. *Integration results for Borgo Piave, SP 38 road*

Section	Proactive without Speed	Proactive with speed	Reactive result	Integrated without speed	Integrated with speed
1	Intermediate Risk	Intermediate Risk	High Risk	Very High Priority	Very High Priority
2	Intermediate Risk	Intermediate Risk	Unsure	Intermediate Priority	Intermediate Priority
3	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
4	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
5	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
6	High Risk	High Risk	Unsure	High Priority	High Priority
7	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
8	High Risk	High Risk	Unsure	High Priority	High Priority
9	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
10	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
11	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
12	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
13	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
14	High Risk	High Risk	Unsure	High Priority	High Priority
15	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
16	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
17	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
18	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
19	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
20	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
21	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority

Also, the disparities in the results revealed that the integrated results when speed is not taken into account outputs prioritized road sections that appeared to be less hazardous, requiring periodic inspections later, while, when speed is taken into account, the prioritized road sections appeared to be more risky, demanding immediate inspections.

Case III. **Maria I& II, SP 278 highway.**

The integration results for this road network showed that out of the 39 road sections, the integration with "proactive results without speed" we obtained: 11 very high priority sections, 11 high priority sections, and 17 intermediate priority sections. On the other hand, integration of reactive assessment results with "proactive results plus speed", produced 10 very high priority sections and 29 high priority sections.

Table 4-12. *Integration results for Maria I&II, SP 278 highway*

Section	Proactive without Speed	Proactive with speed	Reactive result	Integrated without speed	Integrated with speed
1	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
2	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
3	High Risk	High Risk	Unsure	High Priority	High Priority
4	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
5	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
6	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
7	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
8	High Risk	High Risk	Unsure	High Priority	High Priority
9	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
10	Intermediate Risk	High Risk	Unsure	High Priority	High Priority
11	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
12	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
13	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
14	High Risk	High Risk	Unsure	High Priority	High Priority
15	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
16	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
17	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
18	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
19	High Risk	High Risk	Unsure	High Priority	High Priority
20	High Risk	High Risk	Unsure	High Priority	High Priority
21	High Risk	High Risk	Unsure	High Priority	High Priority
22	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
23	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
24	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
25	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
26	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
27	High Risk	High Risk	Unsure	High Priority	High Priority
28	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
29	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
30	High Risk	High Risk	Unsure	High Priority	High Priority
31	High Risk	High Risk	Unsure	High Priority	High Priority
32	High Risk	High Risk	Unsure	High Priority	High Priority
33	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
34	Intermediate Risk	High Risk	Unsure	Very High Priority	High Priority
35	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
36	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
37	High Risk	High Risk	High Risk	Very High Priority	Very High Priority
38	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
39	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority

In this third case, the disparities in the results also revealed that the integrated results when speed is not taken into account outputs prioritized road sections that appeared to be less hazardous, requiring periodic inspections later, while, when speed is taken into account, the prioritized road sections appeared to be more risky, demanding immediate inspections.

***Case IV.* TUSCANESE, SP 02 highway.**

The integration results for this road network showed that out of the 43 road sections, the integration with "proactive results without speed" we obtained: 1 very high priority section, 3 high priority sections, and 39 intermediate priority sections. On the other hand, integration of reactive assessment results with "proactive results plus speed", produced 1 very high priority section and 42 high priority sections.

Table 4-13. *Integration results for Tuscanese, SP 02 highway*

Section	Proactive without Speed	Proactive with speed	Reactive result	Integrated without speed	Integrated with speed
1	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
2	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
3	High Risk	High Risk	Unsure	High Priority	High Priority
4	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
5	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
6	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
7	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
8	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
9	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
10	High Risk	High Risk	Unsure	High Priority	High Priority
11	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
12	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
13	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
14	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
15	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
16	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
17	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
18	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
19	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
20	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
21	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
22	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
23	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
24	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
25	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
26	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
27	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
28	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
29	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
30	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
31	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
32	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
33	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
34	Intermediate Risk	High Risk	High Risk	Very High Priority	Very High Priority
35	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
36	High Risk	High Risk	Unsure	High Priority	High Priority
37	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
38	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
39	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
40	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
41	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
42	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority
43	Intermediate Risk	High Risk	Unsure	Intermediate Priority	High Priority

In this third case, the disparities in the results also revealed that the integrated results when speed is not taken into account outputs prioritized road sections that appeared to be less hazardous, requiring periodic inspections later, while, when speed is taken into account, the prioritized road sections appeared to be more risky, demanding immediate inspections.

4.4. Discussion

Overall, the results revealed that incorporating the safety effects of vehicle operating speeds into the NWA Proactive model would lead to the improvement of the predictive accuracy of the model. In all four different rural highways under study, the sections under the "PS without speed" appeared to be safer than in cases where speed is considered. This indicates additional risks from vehicle operating speeds contributed positively to the increment, thus high speeds on two-lane roads correspond to higher speed-crash risks related to the road infrastructure. Lauragrazie et al. (2023) found similar results applying the iRAP methodology in which high speed limits and operating speeds corresponded to higher risk sections. Also, the impacts of different operating speeds on the NWA Proactive model showed that the model is very sensitive to speed, with low Proactive scores corresponding to higher values of operating speed. This is in line with the NWA ranking criterion, where lower PS indicates high risks, while higher PS indicates low risks. In other words, higher operating speeds correspond to a high probability and severity of risk, and vice versa for lower Proactive scores. The overall integration of NWA reactive and proactive assessment results, with and without speed-crash risk, revealed that by incorporating operating speed, the final rankings are mainly within the "very high priority" classes, and without speed, the rankings are mainly in the "intermediate priority" class. For Practitioners, this result suggests the inclusion of the risk attribute for operating speed in NWA Proactive assessments to account for the safety effects of speed, since speed is a major contributor to road traffic fatalities and serious injuries. The study also had some limitations in the analysis. First, 50km/h was considered as safest traveling speed for two-lane rural highways under study as such, a RF of one was assigned to this speed. Based on this, all the other factors were normalized according with values showing a decreasing order. However, empirical research is required to define the exact safe speed for rural undivided highways, which can serve as the safe condition in which all the other values can be normalized. The second limitation concerns the average crash rates and densities, also referred to as "reference population", on whose basis the ranking criteria for reactive assessments are defined. Due to the unavailability of these values for Italian rural highways, the study assumed the assumed the total length of the road sections under this study forms the reference population. Similar assumptions have been made in the application of the NWA methodology in road sections without reliable reference populations (Katerina et al. 2023). Future research could extend to the assessment of other road types, such as multilane undivided rural highways, divided rural highways, freeways etc using the modified NWA Proactive model.

4.5. Conclusion

The main goal of this chapter was to incorporate the safety effects of speed into the current NWA Proactive model. The methodology was carried out by comparing the existing NWA Proactive model, which does not take into account speed, and the proposed NWA Proactive model that incorporates the safety effects of speed. Safety inspections were conducted on four different road sections selected within the Lazio region, and the two NWA Proactive scores were estimated. The results were compared against the observed crashes that occurred on the road networks under study, and the results showed that the proposed NWA Proactive models that considered speeding risks outperformed the existing NWA Proactive model without speeds on all the road networks under study. Sensitivity analysis was carried out to test the impacts of different values of operating speeds on the NWA Proactive scores obtained based on the present state of the road infrastructure. The analysis has shown that as vehicle operating speed increases, the risks within the road sections decrease. This aligns with the fact that lower values of Proactive scores correspond with the ranking of the road section as high-risk. In addition, NWA Reactive assessment was carried out for all the four road networks under study, and the results, integrated with those of NWA Proactive without speed and NWA Proactive with speed. Overall, the comparison of integration results showed that majority of the road sections integrated with the NWA Proactive with speed required immediate interventions, while those integrated with NWA Proactive without speed, requires periodic interventions.

CHAPTER 5. TRANSFERABILITY OF THE EUROPEAN NETWORKWIDE ASSESSMENT (NWA) METHODOLOGY

5.1. Introduction

The recent global status report on road safety indicated that Africa has the highest number of road fatalities in the world, with an estimated 19.4 deaths per 100,000 population in 2021 (WHO, 2023). Unlike other continents, Africa has therefore witnessed an increase of about 17% of deaths as a result of road crashes. According to the IRAP's Safety Insights Explorer, achieving UN target 4 for greater than 75% of travel on 3-star or better roads for all road users in Africa by 2030 stands to save an estimated 98,265 lives each year and more than 56 million fatalities and injuries over the 20-year life of road treatments with an economic benefit of USD $52.4 billion, nearly $10 for every $1 spent (iRAP, 2025). The United Nations Economic Commission for Africa (UNECA) 2021-2030 Strategic Directions for Road Safety and Africa Road Safety Action Plan specifies clear targets and actions for improving the safety of road infrastructure. One of the KPIs is to undertake crash-risk mapping and proactive assessments and inspections on the target network. One of the most recent tools for the safety assessments of road infrastructure is the European Network-wide Road Safety Assessment (NWRSA) methodology (European Commission, 2023b). The NWRSA is a systematic risk mapping process that consists of merging the reactive and proactive methods to prioritize road sections that require further inspection and intervention. It is important to note that the reactive and proactive methods are independently evaluated, before the two results are integrated to prioritize. The reactive method is assessed based on crash occurrence analysis and the proactive methods are assessed based on the safety inspections of the design characteristics of the road infrastructure. In the absence of historical crashes as in Sweden, where crashes are very low, and countries with poor crash data collection systems as in Africa, only the proactive component can be implemented. As such, the main objective of this chapter is to investigate the applicability of the European NWA Proactive methodology on a typical highway in

Sub-Saharan Africa, which consists of a two-lane undivided road carrying mixed traffic and linking major cities. The highway selected for this investigation is the Douala – Yaounde highway in Cameroon, in West Africa, which is part of the Trans-African Highway (TAH), serving as a major corridor to neighboring landlocked countries like Chad and Central African Republic. The remainder of this chapter is structured as follows: The next section presents a background study, followed by testing the NWA Proactive index with two different methods. The results are presented, and the Pareto principle is applied to identify the 20% road attributes accounting for 80% of the causes of road crashes. And then, ends with the discussion and conclusion sections.

5.2. Background

5.2.1. Relationship between Road Safety Inspection Procedures and Crash History

Road Safety Inspections (RSIs) based on road infrastructure characteristics have been very complementary with crash history in several developed countries. These procedures are meant to replace traditional safety assessment methods that rely on the statistical analysis of crash data. RSIs are known to have begun during the early 2000s' with the subjective evaluation technique in Canada (De Leur & Sayed, 2002). The method developed its risk index as a driver-based, subjective assessment of potential road safety risks, which proved successful in the identification of critical road sections. The risk index was applied on a 26km road, and 60 drivers assessed the road safety risk at specific locations along the route. The risk was evaluated by having each test participant drive the route at a comfortable, self-selected speed, and then asked to give a rating of the road safety risk at 45 locations along the route. A rating scale of 11 points, with a score of zero representing 'no chance of a near miss' and a score of 10 representing 'no chance of a near miss' was used. On the other hand, the objective safety rating was determined by calculating the accident rate based on historical crash data. Using Spearman's ranked correlation, the results showed a positive correlation coefficient of 0.37, indicating the risk index was able to identify critical locations to an extent. In the USA, Li et al., (2010) established a Safety Index (SI) for assessing the risks of vehicle crashes and tested on 193 highway segments. Around 27 safety issues were used to assess the SI for each road section, and the results were compared with those obtained for fatal, injury, and Property Damage Only (PDO) crashes. They found a higher correlation between the SI and the three crash types (minimum correlation coefficient of 0.92 for all crash types). Also, there was a higher level of agreement between the two results with ranking correlation coefficients of 0.81, 0.91, and 0.92 for all three crash types, respectively. In Australia, Zia et al., (2019) developed a multiplicative road safety index known as "Infrastructure Risk Rating" (IRR) assessed based on the safety inspections of 52 detailed risk elements. The relationship between the IRR score against the injury crash rate indicated a good correlation coefficient (r^2 = 0.974) on all the road types.

Across European countries, RSI procedures have been very successful in identifying the safety performance of road networks. Italy is one of the European countries that has been leading in the development and successful implementation of these procedures. The first of these procedures in Italy was developed by Montella, (2005). It consists of the evaluation of safety issues known to have an impact on safety. Over 31 road safety issues were identified and evaluated using the road safety index known as the "Potential for Improvement Index" (PFI). The PFI was then tested on a 406 km rural two-lane highway in the Italian Province of Avellino, and the results were compared with the actual crash data. They showed a very high correlation coefficient of 0.93, indicating successful application of the safety index. Also, looking at the rankings of the safety levels of the safety index and crash history, they found a higher agreement between the rankings. Two years later, the European project "Identification of Hazard Location" (IASP) led to the development of another procedure in Italy (Cafiso et al., 2007). The procedure quantitatively measures the safety performance of road sections based on eight main safety issues, and using the road index "Safety Index" (SI). The developed SI was tested on a 100 km two-lane, rural highway, and the results were verified with those of crash frequency. The procedure was very successful with a higher correlation between the SI and crash frequencies (coefficient 0.77). Regarding the rankings, the results were statistically significant with a correlation coefficient of 0.87. Another

Italian study in 2014 (Rosolino et al., 2014) employed a Risk Index (RI) developed based on 6 risk factors to provide real-time information about risks on road networks. The RI was tested by the systematic comparison between RSI data from test site and the estimated RI in selected road segments. A satisfactory matching between the sets of data was found, confirming the validity of the RI. One of the first developed and implemented RSI procedures in Europe was the European Road Assessment Programme (EuroRAP) in 2002, which led to the formulation of the Star Rating methodology in 2004 (Lynam et al., 2004). The methodology determines its road safety index known as “Star Rating Score” (SRS) by aggregating the individual scores for different crash types. Several studies have investigated the relationship between the SRS and crash frequencies, and all the results were positive. The first study was conducted in Australia (AustRAP, 2008) and involved the investigation of the relationship between Star Ratings and the average crash costs per kilometre travelled for each homogeneous road segment. The study found that a lower Star Rating is associated with a higher crash cost per vehicle-km travelled. Another study investigated the relationship between the Star Ratings and crash rates for selected roadways in the United States (Harwood et al., 2010). They found that statistically, crash rates decrease as star rating increases for two-lane undivided highways, 4 lane undivided highways, and 4 lane divided non-freeways.

5.2.2. Transferability of Road Safety Inspection Procedures

Model transferability is defined as the possibility of using a model developed in one country to suit the road context, climate conditions, and user typology and behavior of another country (Erieba et al., 2024). Transferability is carried out to determine whether the model is useful in new conditions. Road safety assessment predictive models such as the HSM SPFs have been widely transferred to different countries over the years. However, less attention has been directed towards the investigation of the transferability of RSIs methodologies. The potentials in the transferability of the European IASP model (Cafiso et al., 2007) have been carried out both in developed and developing countries. In Europe, the transferability of the model was first investigated in Poland

(Cafiso et al., 2015) involving a sample of 184 km of two-lane regional roads in Poland. The safety inspections were conducted based on the IASP and Polish RSI methods. The RI evaluated was compared with the accident rate, and the study revealed a strong agreement between the Polish guidelines and the evaluation procedures. Also, the study showed a high efficiency and success in transferring the IASP procedure to Poland, since the coefficient of determination between RI and expected crashes per km was 0.8, thus statistically significant. In another study, the possibility of transferring the IASP procedure was investigated in Egypt (Erieba et al., 2024). In Egypt, the procedure was applied on a 6km segment of two-lane two-way rural road. The RI and the SPF values were found to be visually matched in terms of ranking. Also, using Spearman's ranked correlation coefficient, a value of 0.75 was found indicating a higher statistically significant RI. The study showed not only a significant similarity in the safety levels of infrastructure between Egypt and Italy but also in speed behavior. The positive results may be due the fact that both Egypt and Italy are mediterranean countries that shares similarities in climate, infrastructure, and road user behavior. Before the mid of this (Borsos et al., 2025) also investigated the transferability of the IASP procedure to Hungary through conducting a questionnaire survey amongst 20 experienced road safety Inspectors. Each inspector was required to complete the checklist, and compute the RI for each road section. The study found that there were varying levels of agreement between the Inspectors. Also, a moderate relationship was found between the risk index and the crash rate.

5.3. Methodology

The overall objective of the transferability of this methodology is to test its applicability on roads outside of Europe, with particular interest in Sub-Saharan Africa highways. The methodological framework consists of investigating whether the NWA Proactive index, known as "Proactive Score" (PS) is capable of identifying the high crash locations on this network. Two methods have been chosen for this evaluation. The first method consists of the comparison of PS index and the predicted crash frequency on this road. Due to the absence of locally developed SPFs, the predicted crashes are determined by applying the Highway Safety Manual (HSM) SPFs for a two-lane, two-way rural highway and calibrated using the calculated calibration factor and the site specific characteristics that differ from the base conditions. The second method is for the comparison of PS index and the calibrated accident prediction model. The methodological framework is illustrated in Figure 5-1.

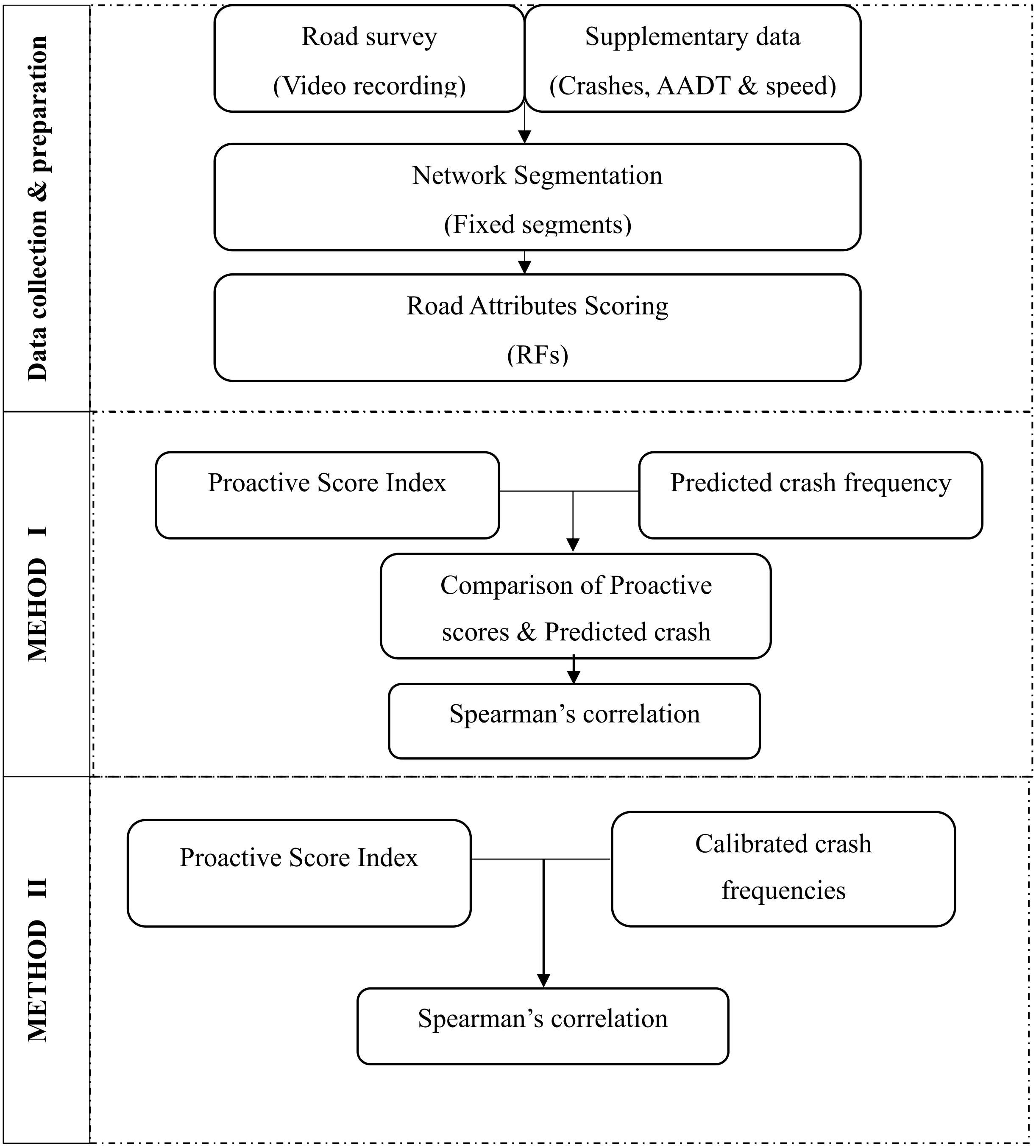


Figure 5-1: Methodological framework

5.3.1. Data Collection and Preparation

5.3.1.1. Site description

In Sub-Saharan Africa, a typical motorway is a two-lane, two-way rural road, carrying mixed traffic and linking two major cities and/or countries. In this study, the road section selected is located in Cameroon, in West Africa. The road section links the administrative capital (named, Yaounde) to the economic capital (named Douala). Also, the road is part of the major corridors of the Trans-African Highway serving landlocked neighboring countries such as Chad and the Central African Republic. The road stretch is 215 km long starting from Mvan interchange (in Yaounde), and ends at Dibamba bridge (in Douala). In terms of geometry, the road is a two-lane, two-way undivided rural highway passing through several villages and local towns. The road is also known as National Road number 3 (N-3).

Figure 5-2: The Yaounde - Douala Highway

5.3.1.2. Accident history

With respect to historical crashes, the road remains one of the deadliest roads in the country for instance in 2015, WHO reported that the road killed more than malaria in the country (WHO Report, 2015). The historical crash data for four years period (2017, 2018, 2019, & 2021) was obtained from the National Gendamerie and Police units. The crash data for 2020 was not available due to the COVID 2019 pandemic. A total of 416 crashes were recorded for four years for the two directions of travel. The crash data consists of fatal, serious, and Property Damage Only (PDO) crashes. However, the main limitation in the crash data is the absence of GPS locations. Instead, crashes are recorded using the names of the villages and quarters where the crash occurred.

5.3.1.3. Road safety inspection survey

The road survey was conducted on the 14th and 15th of January 2025. The inspection involved the use of dashcam camera to record videos of the entire road stretch and also paying attention to specific locations of the road. The videos were later processed by allocating safety scores to each road parameter, depending on its availability and condition as defined by the NWA Proactive methodology.

5.3.1.4. Traffic flow

The traffic volume data (AADT) was available only for 2017 and was provided by the Ministry of Transport.

5.3.1.5. Road segmentation

The road stretch was divided into fixed segments of 500 meters each according to the methodology. The methodology also recommends homogeneous segmentation based on the road geometry and operational characteristics. Nevertheless, this could not be performed due to the unavailability of detailed road characteristic data.

5.3.1.6. Data Availability

Generally, European roads are of higher standards than Sub-Saharan African roads. Nevertheless, major highway corridors in Africa rely on European design manuals for construction. For instance, in Cameroon, the French road design manual is commonly used. Therefore, in terms of investigating if the NWA parameters are available in Africa, Table 5-1 below shows that these parameters are highly accessible and obtainable.

Table 5-1. NWA data availability in Sub-Saharan Africa

Parameter	Available	Not available	Remark
1.Lane width			
- Undivided	✓		Ok
- Divided	✓		
2.Roadside	✓		Ok
3.Curvature	✓		Ok
4.Density of property access points	✓		Ok
5.Junction type	✓		Available but under-developed
6.Facilities for pedestrians & bicyclist	X	✓	Ok
7.Shoulder width	✓		Ok
8.Passing lanes	✓		Inadequate
9.Markings & signs	✓		Inadequate

5.3.1.7. Allocation of road attribute scores

The Proactive scores index is determined based on the safety inspection of 9 in-built design characteristics of the road. These road characteristics are: lane width, roadside, curvature, density of property access points, junctions, conflicts between pedestrians, bicyclists, and motorized traffic, shoulder type and width, passing lanes, and signs and markings. Each of these characteristics are further divided into different criteria, and with their corresponding scores. Reduction Factors (RF) are assigned as scores to each road parameter depending on its availability, standard, and condition. Nevertheless, not all the parameters defined in the methodology are found on this road network, for instance, there are no bicycle traffic and signalized intersections. It is important to note that due to the absence of data on the geometric characteristics of the road, the recorded videos of the road were processed using a software called "Road Analyst". The software is developed by the Research Centre of Transport and Logistics, at Sapienza University of Rome, and was used for the extraction of road geometric data such as lane width, shoulder width, and curve radius. The road attributes assessed with their corresponding scores allocated are discussed below.

I) Lane width

From the RSI report, the lane width varied from 2.82 to 3.45 m. As such, the reduction factors used for this assessment are presented in Table 5-1.

Table 5-2: Lane width NWA Parameters with CMF and RFs

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	**RF value**
Lane width (LW)	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

ii) Roadside

The roadsides showed there is enough clear zone, recoverable and traversable slopes, and safety barriers were present at some strategic locations. However, within the forest areas along the highway, trees were located less than 5 meters from the road, posing a danger to the road users. Also, electric poles were seen less than 3 meters beside the road in urban and built-up areas where the highway passes through. Table 5-2. shows the reduction factors for roadside applied for this road.

Table 5-3: Roadside NWA Parameters with CMF and RFs

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	**RF value**
	-1. CZ > 9.14m Flatter than 1V: 4H	0.875	1.000

Roadside Hazard Rating (RHR)	**-2**. 6.10m ≤ CZ < 7.62m About 1V: 4H	0.935	1.000
	-3. CZ ～ 3.05, guardrail > 1.98m About 1V: 4H	1.000	1.000
	-4. 1.52m ≤ CZ < 3.05m, with guardrail offset 1.52m to 1.98m About 1V: 3H or 1V: 4H	1.069	0.935
	-5. 1.52m ≤ CZ < 3.05m, with guardrail offset < 1.52m About 1V: 3H	1.143	0.875
	-6. CZ ≤ 1.52m About 1V: 2H, exposed to rigid objects	1.222	0.818
	-7. CZ ≤ 1.52m About 1V: 2H or steeper, exposed to cliff or vertical rock	1.306	0.766

iii) Curvature

The horizontal curves are assessed based on the radius of curvature and the speed at which vehicles travel on this section. If the radius of curvature is greater than 1000 meters, then the curve poses no risk at the section, as such, a reduction factor of one is assigned. Curves are considered as a risk factor when the radius is less than 1000 meters. For this assessment, the vehicle operating speeds used was the posted speed limits due to the absence of operating speed data for the road network. The radius of curvature and the operating speed are then inserted into Equation (5-1) to obtain the CMF score.

$$\mathbf{CMF = 1.00 + 0.7937\ x\ (0.09134V)4\ x\ \frac{(0.9134V)^2}{32.2\ x\ (R/0.3048^2}} \quad \textbf{(5-1)}$$

The inverse of the CMF score gives the reduction factor for the curve. The reduction factors used during the assessment varied from 0.936 – 1.000.

iv) Density of Property Access Points

Property access points refer to road sections where access is provided from the highway to a private property. Since the assessment was for fixed segments of length 500 meters, the number of access points varied from 0 – 6 for each segment. The reduction factors used for scoring this attribute is presented in Table 5-3.

Table 5-4: NWA density of property access points with CMF and RFs

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	RF value
Density of property access points	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	1.312	0.762

v) Junction

The junction types found on this highway are 3 and 4 leg unsignalized intersections, and roundabouts. Table 5-4 shows the reduction factors that were used for this risk factor.

Table 5-5: NWA road junction parameters with CMF and RFs

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	RF value
	Roundabout	1.000	1.000
	3-leg un-signalized with turn lane	1.130	0.885
	3-leg un-signalized without turn lane	1.391	0.719
	4-leg un-signalized with turn lane	1.515	0.660
	4-leg un-signalized without turn lane	2.178	0.459

vi) Conflicts between Pedestrians, Bicyclists, and Motorized traffic

There is no bicycle traffic on this highway, even on sections passing through urban areas and villages. Therefore, only pedestrian and motorized traffic were considered. The reduction factor scores used are as shown in Table 5-5.

Table 5-6: NWA parameters assessed for conflicts, with CMF and RFs values.

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	**RF value**
Conflicts between pedestrians, Bicyclists & Motorized traffic	Grade separated facility	1.00	1.00
	No facility for pedestrian crossing speed limit > 70km/h	16.75	0.060
	No facility for pedestrian crossing speed limit ≤ 70km/h	12.00	0.083
	No pedestrian traffic	1.00	1.00
	Segregated-protected pedestrian path	1.00	1.00
	No facility for pedestrians walking along	20.00	0.05
	No bicycle traffic	1.00	1.00

vii) Shoulder type and width

The RSI survey showed that the shoulder types were mostly graveled, and the minimum shoulder width found on a few sections was 0.8 meters. The reduction factors applied for shoulder type and width are presented in Table 5-7.

Table 5-7: NWA parameters for shoulder type and width with CMF and RFs

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	**RF value**
Shoulder type and width	$SW \geq 1.83$	1.00 (1.071)	1.00 (0.983)
	$1.23 \leq SW < 1.83$	1.063 (1.077)	0.941 (0.929)
	$0.91 \leq SW < 1.23$	1.097 (1.106)	0.912 (0.904)
	$0.61 \leq SW < 0.91$	1.127 (1.136)	0.887 (0.880)
	$0.00 \leq SW < 0.61$	1.211 (1.211)	0.826 (0.826)

Viii) Passing lanes

Passing lanes were assessed at sections located in hilly and mountainous areas. Table 5-8 presents the reduction factors used.

Table 5-8: NWA parameters for passing lanes with CMF and RFs

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	**RF value**
Passing lanes	Un-divided 2-lane road with slope > 4% for more than 500m – passing lanes in both directions	1.000	1.000
	> 4% for more than 500m – passing lanes in one direction	1.149	0.870
	4% for more than 500m, no passing lanes	1.502	0.666

Xi) Signs and Markings

Safety inspections were conducted only during the day, as such, the quality of road markings and signs are examined for daylight conditions only. The reduction factors for signs and markings attribute are shown in Table 5-9.

Table 5-9: NWA parameters for signs and markings with CMF and RFs

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	**RF value**
Signs & markings	In place, high quality and in good condition	-	1.00
	In place, medium quality and in poor condition	-	0.95
	Critical markings and signs missing	-	0.90

5.3.2. Method I: Proactive Score (PS) index with Predicted Crash Frequencies

This method consists of comparing the Proactive Scores obtained through safety inspections, and the predicted crashes obtained based on HSM SPFs. Further investigation is carried out by comparing the rankings from Proactive Scores and those from the calibrated Predicted Crashes. Spearman's rank correlation was applied to investigate whether there is a relationship in the rankings between the PS values and the predicted crash frequencies.

5.3.2.1. Proactive Score Index

The Proactive Scores (PS) for each road section is determined as follows:

$$\boldsymbol{Proactive\ score_i = 100\ x\ RF_{1i}\ x\ RF_{2i}\ x\ \ldots\ldots\ldots\ldots RF_{ni}} \quad \textit{(5-2)}$$

Where; *RFi are the Reduction factors for each road parameter assessed*

The scores were calculated for all 430 road sections. Note that the road sections are fixed, of length 500 meters each.

5.3.2.2. Predicted Crash Frequency

The HSM SPFs are statistical models, calibrated on historical crash data, and used to predict crash frequencies based on related explanatory variables. At the time of conducting this assessment, no locally developed SPFs were available in this country. As such, the study chose to use the HSM SPFs. The updated HSM SPFs for a two-lane undivided rural highway (Ivan et al. 2023) was applied as shown in Equation (5-3).

$$\mathbf{N_{SPF}} = \boldsymbol{e^{-7.463+In(AADT)+In(L)}} \quad (5\text{-}3)$$

Where; $\mathbf{N_{SPF}}$ is the predicted crash frequency for roadway under the base conditions, AADT is the Average Annual Daily Traffic (vehicle per day), L is the length of roadway segment (miles). The road characteristics for the base condition include:

- Lane width = 12 feet (3.65m)
- Shoulder width = 6 feet (1.82m)
- Shoulder type = Paved
- Roadside hazard rating = 3

- Driveway density = 5 / mile (5/1.61km)

Calibration

The HSM recommends the calibration of SPFs when applied on conditions different from the ones they were created. Two methods of calibration were employed: first, the HSM SPFs are calibrated for conditions that differ from those of the base conditions, by multiplying with CMFs. For instance, the HSM SPFs for a two-lane two-way rural highway do not consider horizontal and vertical curvature, passing lanes, intersections, lighting etc. And secondly, the Calibration Factor (CF) for the highway was determined and used to adjust the predicted crash frequency. The CF is calculated as follows:

$$\boldsymbol{Calibration\ Factor\ (CF)} = \frac{\boldsymbol{\Sigma Observed\ crashes}}{\boldsymbol{\Sigma Predicted\ crashes}} \tag{5-4}$$

The CF is then multiplied by the predicted crashes obtained previously using the HSM SPFs, to get the locally calibrated crash predictions.

$$\boldsymbol{Calibrated\ Predicted\ Crashes} = C.F\ x\ Predicted\ Crashes \tag{5-5}$$

5.3.2.3. Comparing Proactive Scores with predicted crashes

I) Correlation between Proactive Score values and predicted crashes

At this stage, the PS index and the calibrated predicted crash frequencies are plotted and graphically presented. The graphs are then analyzed to deduce the relationship between the two scores.

II) Comparison between Rankings

The comparison of rankings from PS index and predicted crashes is then carried out using Spearman's ranked correlation method. The Spearman's rank correlation is a non-parametric measure of the association between the ranking of two variables, in this case, the Proactive score index and the calibrated crashes (Siegel and Castellan, 1988). The ranked coefficient is used to know the level of agreement between the rankings sorted for Proactive Score and Predicted crash frequency. The correlation coefficient (r), is calculated as:

$$r = 1 - \frac{6\sum di^2}{n(n^2-1)} \quad (5\text{-}6)$$

Where: r is the Spearman's rank-correlation coefficient; di are the differences between ranks, and n is the number of paired sets.

5.3.3. Method II: Proactive Score (PS) index and *Expected Crash Frequencies*

The second method consists of comparing the PS index with the expected crashes obtained based on calibrating the accident prediction models. It consists of applying a model that predicts crash frequencies using the segment length and the AADT as covariates. Generalized Linear Modeling (GLM) based on Negative Binomial (NB) techniques was used to fit the models. The regression analysis was carried out in Python.

5.3.3.1. Road network segmentation

Considering that this method is intended to compare the PS index to the actual crash history, it is important to ensure that crashes are aligned to the road sections. The crash data obtained from the Police had issues related to missing variables, for instance, the absence of GPS locations to identify the exact points where the crashes occurred. Instead, the crashes were recorded following the names of the places where the crash occurred, thus making it difficult to know the exact crash point. The feasible solution was to group the crashes with respect to the municipalities that the highway passes through. Thus, the 215 km road network was divided into 30 sections.

5.3.3.2. Proactive scores index

Initially, the PSs were calculated for fixed sections of length 500 meters, and since the actual observed crashes are of variable segment lengths, the PSs will require aggregation to smoothen the results. The concept of aggregating risk index values to match with longer sections is very common in safety inspection procedures, for example, in ANRAM Star Rating procedure, the scores are initially obtained for fixed segments of 100 meters and then further aggregated to match with longer sections of 3 kilometers (Jurewicz et al., 2014). Nevertheless, in this study, the aggregation method adopted is similar to the ones applied by Cafiso et al. (2015), Persia et al. (2020), and González-Hernández et al. (2025). Specifically, this study used two different methods of aggregating the PS values: Simple averaging of Proactive Scores (PS_{sim}) and using the minimum values of Proactive Scores (PS_{min}) as shown in Table 4. Unlike other procedures that apply the maximum values per section, in this study, the minimum values are considered because in the NWA Proactive procedure, the lowest value of PSs corresponds to high risks. Table 5-10 presents the two different methods for aggregating the PS values.

Table 5-*10* *Different methods for the aggregation of Proactive score values*

Method	PS calculation
Simple average	*Average value of the series of PS values obtained for the road section (PS_{sim})*
Minimum value	*Minimum value of the series of PS values obtained for the road section (PS_{min})*

5.3.3.3. Model form

The model form used is given as:

$$\hat{E}(y) = e^{a_o} \; x \; L^{a_1} \; x \; AADT^{a_2} \qquad (5\text{-}7)$$

Where; $\hat{E}(y)$ is the predicted crash frequency (in 4 years period), L is the length of the road section (km), AADT is the Average Annual Daily Traffic (vehicles per day), a_o, a_1, a_2 are the coefficients.

5.3.3.4. Predicted and Expected Crash Frequency

Considering the model coefficients determined, the predicted and expected crashes were calculated and presented as shown in Table 13. The expected crashes were obtained using the EB technique to correct for regression-to-mean bias as follows:

$$EB = \left(\frac{\hat{E}(y)}{k + \hat{E}(y)}\right) x \; (k + count) \qquad (5\text{-}8)$$

Where: **'EB'** is the Empirical Bayes estimate of the crash frequency; **Ê(y)** is the predicted crash frequency; **'k'** is the overdispersion parameter; and **'count'** is the observed crash frequency.

5.4. Analysis of results

5.4.1. Comparing the Proactive Score value with the predicted crash frequency (Method I)

The graphical results for the PS index and their corresponding predicted crash frequencies for all the high-risk segments are presented below. Regarding PS values, it is important to note that higher values (usually ≥ 80) indicate lower risks, while lower PS values (usually ≤ 50) indicate high risks. Therefore, high-risk segments which corresponds to lower PS values should correspond with higher values of predicted crash frequencies. And lower values of predicted crash frequencies are expected to correspond with higher values of PS (that is, low-risk segments). This implies that the relationship between PS index and predicted crashes is expected to be negatively correlated. For majority of the road sections, PS and predicted crashes are found not to visually matched in more than 60% of the sections. Nevertheless, some deviations were noticed with road sections number 24, 92, 95, 98, 121, and 132 where higher values of predicted crashes were almost equal to the PS, indicating no correlation.

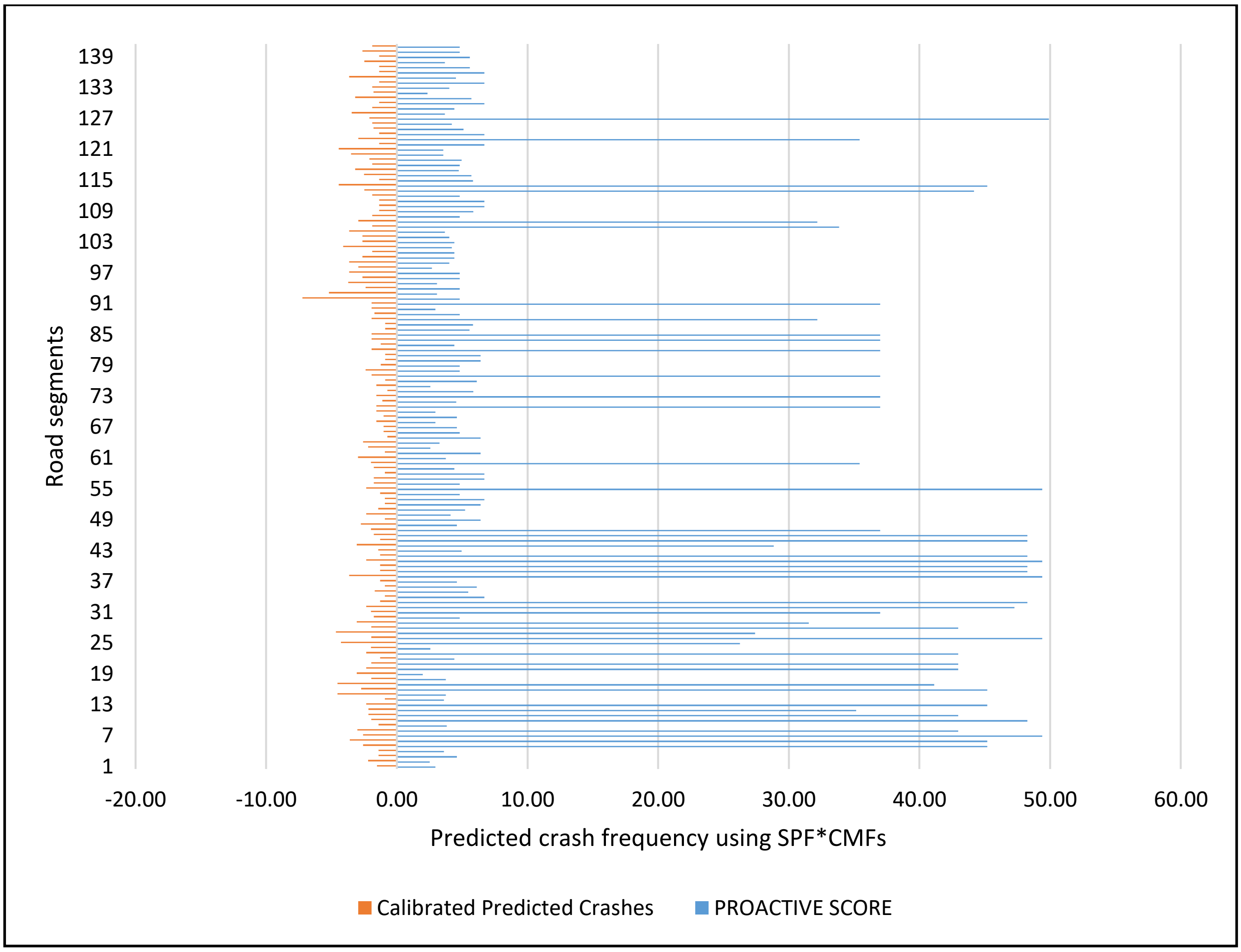


***Figure 5-3**: Comparison between Proactive score and Predicted crashes for all high risks segment*

5.4.2. Comparison between the rankings for Method I

The Spearman's ranked correlation coefficient was evaluated considering all 415 road sections. The correlation coefficient obtained, r was 0.49, which indicated that the rankings between the PS and predicted crashes are moderately significant. This means that the rankings between PS values and crash history do agree at approximately a half of the time. Therefore, the PS index could be potentially suitable for ranking the safety performance levels of road sections for typical highways in Sub-Saharan Africa.

5.4.3. Comparing Proactive Score value with the Expected Crash frequency (Method II)

Proactive Scores (PSs) analysis

Based on the two aggregation methods, the following PS values for the different indicators were obtained, as shown in Table 5-11.

Table 5-*11* *Proactive score aggregated values*

Section	Municipality	Length of section (km)	Number of segments	PS_{sim}	PS_{min}
1	Dibamba	13.00	26	22.95	2.34
2	Dibamba	8.50	17	40.38	3.57
3	Dibamba	5.50	11	48.23	4.81
4	Dizangue	0.50	01	5.85	5.85
5	Edea II	3.50	07	53.59	4.81
6	Edea II	8.50	17	72.14	57.97
7	Edea II	5.00	10	38.20	3.67
8	Edea I	7.00	14	19.43	2.68
9	Edea I	3.50	07	56.26	2.94
10	Edea I	4.50	09	60.42	4.81
11	Ngwei	17.00	34	66.05	5.57
12	Ngwei	7.00	14	63.73	6.40
13	Ngwei	4.50	09	57.55	4.81
14	Pouma	8.50	17	50.27	2.56
15	Pouma	6.00	12	63.88	50.43
16	Pouma	8.50	17	58.77	4.54
17	Dibang	4.50	09	64.19	37.01
18	Dibang	8.50	17	59.60	2.94
19	Dibang	5.00	10	68.26	4.81
20	Ngog Mapubi	5.00	10	38.04	2.56
21	Ngog Mapubi	2.50	05	69.47	57.97
22	Ngog Mapubi	8.00	16	59.14	4.40
23	Matomb	13.00	26	46.98	4.10
24	Matomb	6.50	13	57.70	37.01
25	Matomb	17.50	35	50.74	4.81
26	Mbamkomo	16.50	33	57.91	2.56
27	Mbamkomo	4.50	09	61.74	42.97
28	Mbamkomo	7.00	14	35.96	1.99
29	Yaounde III	2.00	04	37.92	3.83
30	Yaounde III	3.50	07	23.10	2.51

Expected crash frequency

i) Model Parameters

Considering the model form, the dependent variable (in this case, observed crashes), and the following covariates, AADT and segment length, the calibration of the model was carried out in Python, and the model parameters together with the goodness-of-fit measures were obtained as illustrated in Table 5-12.

Table 5-*12 Model parameters and goodness-of-fit measures*

Parameter	Estimate	Standard Error	Z-value	K	AIC	Log likelihood
a_0	- 4.823	0.614	-7.86			
a_1(AADT)	0.674	0.146	4.62	2.688	204.43	-98.215
a_2(Length)	0.926	0.116	7.99			

ii) Expected crashes

Applying the model coefficients based on the model form chosen, the predicted crashes were estimated. These crashes were subjected to the EB technique and the expected crashes obtained.

5.4.4. Comparison between the rankings for Method II

i) Correlation between the Proactive Scores and Expected Crashes

To verify the relationship that exists between the different aggregated PS values and the expected crashes, comparisons were carried out between PS values and the expected crash frequencies as shown in Figures 5-4 and 5-5.

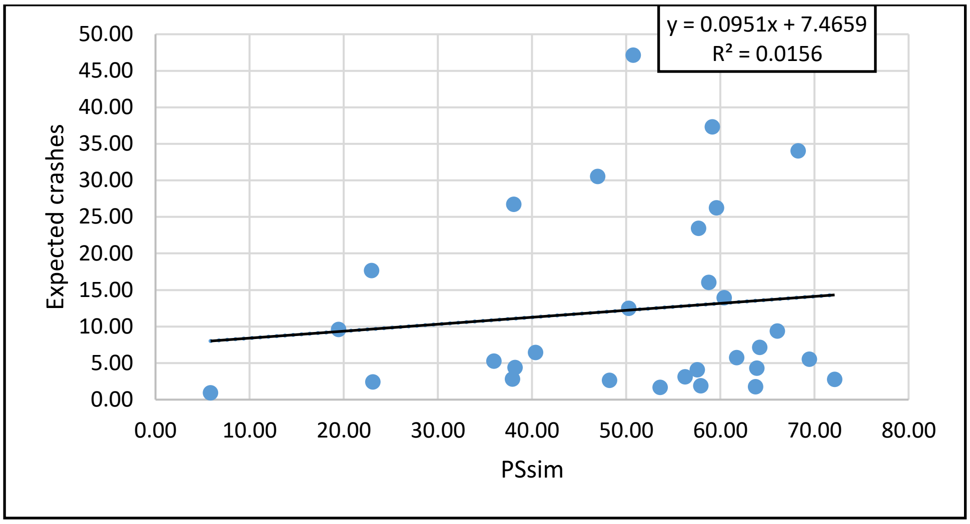


Figure 5-4 *Correlation between PS_{sim} and expected crash frequency*

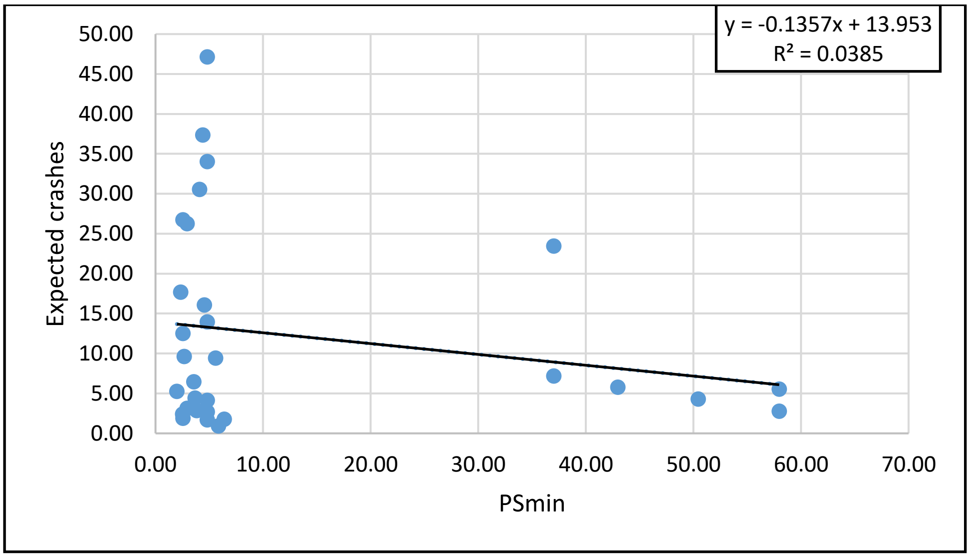


Figure 5-5 *Correlation between PS_{min} and expected crash frequency*

The results showed that the correlation between the expected crash frequencies and PS_{sim} or PS_{min} is highly insignificant, with only 1.56 and 3.35% of the variation in the expected crashes explained by the PS values. This means that the linear correlation between PS and crash history for the road under study is very insignificant.

ii) Comparison between the rankings of PSs and Expected crash frequencies

Since one of the objectives of the procedure is to use the PSs as a ranking criterion, in this c, it is important to compare the rankings obtained based on the PS values and rankings based on expected crashes. Again, Spearman's rank correlation was used for the comparison. Comparison of rankings is also carried out in terms of variation per kilometer by dividing the PS and expected crashes by their respective section lengths (that is, PS/L and EB/L). The results from this analysis are shown in Table 5-13.

Table 5-*13* *Comparison between ranking criteria*

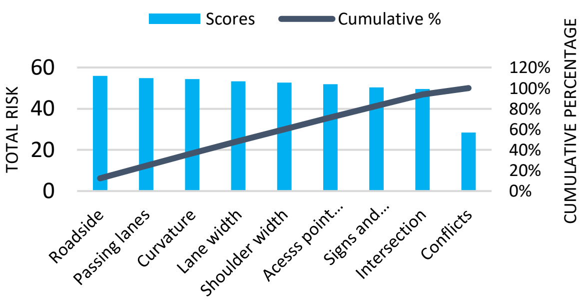
	Rankings between Proactive scores and expected crashes			Proactive scores and expected crashes / length of sections			Ranking between Proactive scores and expected crashes / length of sections		
Section	PS_{sim} Rank	PS_{min} Rank	Expected crashes - Rank	PSsim/ L	PSmin/ L	Expected crashes /L	PS_{sim}/ L Rank	PS_{min}/ L Rank	Expected crashes /L -Rank
1	22.95	2.34	17.65	1.77	0.18	1.36	1	1	15
2	40.38	3.57	6.44	4.75	0.42	0.76	3	1	9
3	48.23	4.81	2.65	8.77	0.87	0.48	3	5	3
4	5.85	5.85	0.91	11.70	11.70	1.82	1	7	1
5	53.59	4.81	1.67	15.31	1.37	0.48	3	5	1
6	72.14	57.97	2.76	8.49	6.82	0.32	21	21	1
7	38.20	3.67	4.38	7.64	0.73	0.88	2	2	3
8	19.43	2.68	9.60	2.78	0.38	1.37	1	1	5
9	56.26	2.94	3.13	16.07	0.84	0.89	1	1	2
10	60.42	4.81	13.94	13.43	1.07	3.10	3	3	5
11	66.05	5.57	9.40	3.89	0.33	0.55	9	4	4
12	63.73	6.40	1.75	9.10	0.91	0.25	5	5	1
13	57.55	4.81	4.10	12.79	1.07	0.91	2	5	1
14	50.27	2.56	12.48	5.91	0.30	1.47	1	1	2
15	63.88	50.43	4.28	10.65	8.41	0.71	4	10	1
16	58.77	4.54	16.04	6.91	0.53	1.89	2	3	1

17	64.19	37.01	7.15	14.26	8.22	1.59	4	6	1
18	59.60	2.94	26.24	7.01	0.35	3.09	3	1	1
19	68.26	4.81	34.03	13.65	0.96	6.81	5	2	4
20	38.04	2.56	26.74	7.61	0.51	5.35	1	1	3
21	69.47	57.97	5.54	27.79	23.19	2.21	7	7	1
22	59.14	4.40	37.34	7.39	0.55	4.67	4	1	2
23	46.98	4.10	30.55	3.61	0.32	2.35	1	1	2
24	57.70	37.01	23.42	8.88	5.69	3.60	1	3	2
25	50.74	4.81	47.12	2.90	0.27	2.69	1	3	3
26	57.91	2.56	1.88	3.51	0.16	0.11	1	1	1
27	61.74	42.97	5.76	13.72	9.55	1.28	2	2	2
28	35.96	1.99	5.25	5.14	0.28	0.75	1	1	2
29	37.92	3.83	2.82	18.96	1.92	1.41	1	1	2
30	23.10	2.51	2.40	6.60	0.72	0.69	1	1	1
	$\dot{\rho}_s = 0.63$	$\dot{\rho}_s = 0.46$					$\dot{\rho}_s = 0.83$	$\dot{\rho}_s = 0.79$	

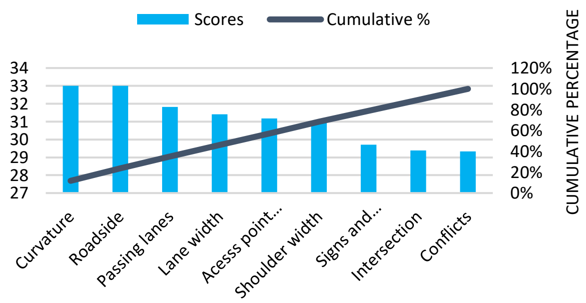
In terms of rankings, the results showed that the rankings moderately agree between the PS_{sim} and expected crash frequency, and the level of agreement between the PS_{min} and expected crash frequency is slightly below average. In terms of ranking variation per kilometer, the results from the Spearman's rank correlation showed that the rankings between expected crash frequency and PS_{sim}/L or PS_{min}/L , agree at 83% and 79% respectively. This means that the PS values in terms of ranking do agree with the rankings from historical crash occurrences.

5.4.5. Identification of main safety problems

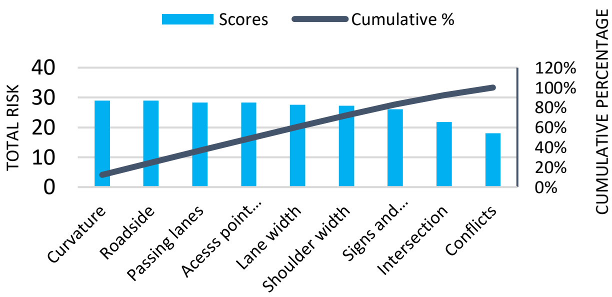
The main outcome of NWA is a list of proposed future actions that can be indertaken to improve the safety levels of the road infrastructure. These future actions include different types of RSIs recommended based on the priority class of the road section. The three types of RSIs include: (i) Immediate RSIs, which are recommended for all road sections that are of high risk; (ii) Periodic RSIs every three years, which are recommended for all the road sections that are of intermediate risks; and (iii) Periodic RSIs every five years recommended for all the road sections that are of low risk. Since such actions require the expertise of accredited Road Safety Inspectors, who are scarce in Africa, this study resorted to identifying the main risk attributes that contribute the most within each road section passing through the respective municipalities. This action would enable future actions to be taken at the level of the municipal authorities. To do this, Pareto charts were used to identify the main risk attributes. The Pareto principle are based on an empirical relationship in which 20 percent of the causes generate 80 percent of the effects (Wilkenson, 2006). Thus, once 20 percent of the most common causes are identified, it is possible to effectively improve these attributes. In this study, it is assumed that by improving the 20 percent high risk attributes, would contribute to eradicating 80 percent of the road traffic crashes within each section. Figure 5-6, illustrates the set of Pareto charts obtained for each of the road sections.



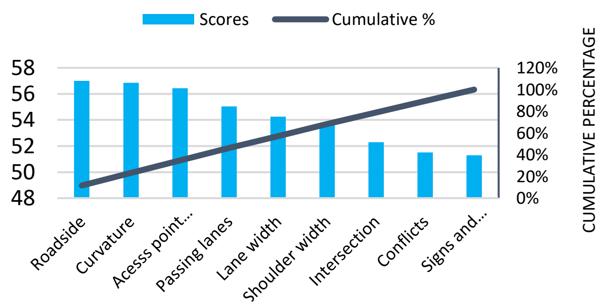
a) *Road section passing through **Dibamba** Municipality*



b) *Road section passing through **Edea 2** Municipality*

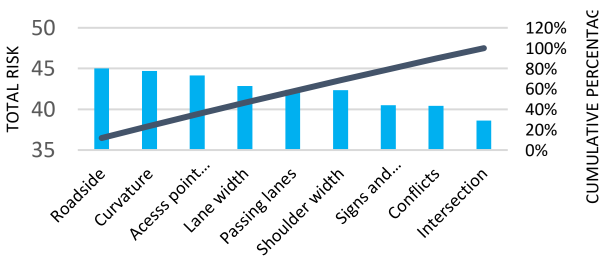


d) *Road section passing through **Edea 1** Municipality*

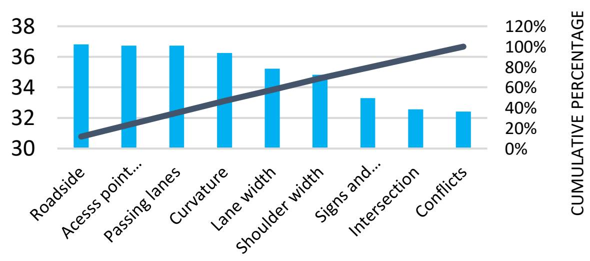


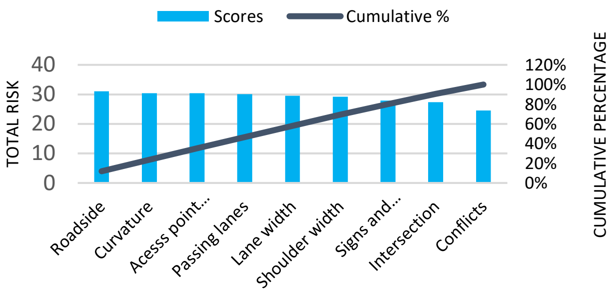
c) *Road section passing through **Ngwei***

f) *Road section passing through **Pouma** Municipality*

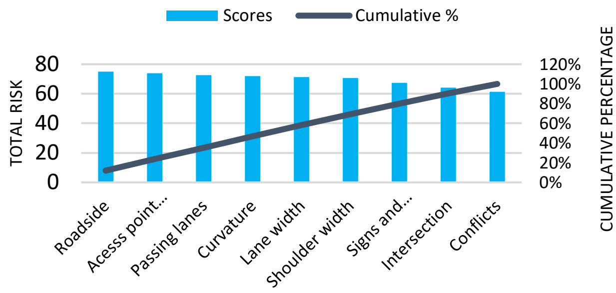


e) *Road section passing through **Dibang** Municipality*

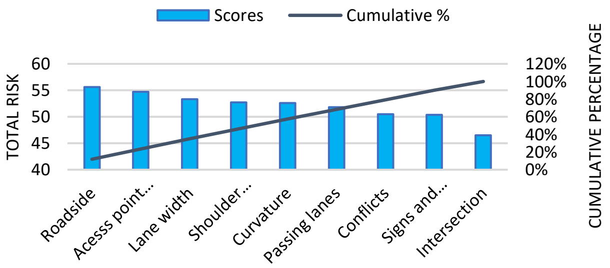




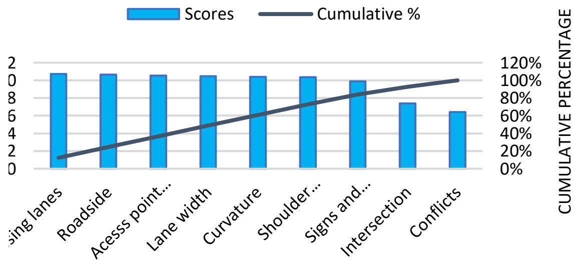
*h) Road section passing through **Ngog Mapubi** Municipality*



*g) Road section passing through **Matomb** Municipality*



*j) Road section passing through **Mbamkomo** Municipality*



*i) Road section passing through **Yaounde 3** Municipality*

Figure 5-6: *Pareto charts for all the road sections passing through the municipalities*

The bars in the graphs indicate, in descending order, the percentage of total risks obtained during the inspection for each road attribute. Their cumulative impact is represented by the line. According to these graphs, the main risk factors that are responsible for 80% of the accidents on this highway are: conflicts, intersections, signs and markings. The risk attribute "Conflicts" appeared on all the road sections passing through the municipalities. Conflicts do exist only between the drivers, pedestrians, and power two-wheel users, since they were no bicyclists on this road. The "conflict" parameter recorded the highest risks, especially in urban areas. This can be attributed to the fact that there are no pedestrian infrastructures, such as pedestrian crossings, pedestrian fencing, anywhere on this road that could enable road users' traverse safely. The next main risk attribute was the "intersections". Many of the intersections suffers from issues such as inadequate sight distance, no lighting, absence of vertical signs, no turn-lanes and channelization, no pedestrian crossings (Madanu et al., 2010; Montella

& Mauriello, 2012). Lastly, the next risk factor was "signs and markings", which were inadequate and in poor state.

5.5. Discussion

The overall results for the transferability of the European NWA Proactive assessment in Sub-Saharan Africa indicated that in terms of linear correlation between the PS values and crash history, there is a very low relationship that exist between them, both in the first and second method applied for the analysis. In other words, the study found that the PS index was not able to explain the variation in the estimated number of crashes on this road. Nevertheless, in terms of ranking the safety performance levels of the road sections, the PS and the estimated crashes rankings highly agree in the second method of analysis. In the first method of analysis, both rankings agreed at approximately 50%. As such, in terms of road safety rankings, the study found that the PS index have the potentials to be applied for identifying probable crash locations on Sub-Saharan Africa highways, in the absence of crash data. Also, in terms of data availability, most of the road design characteristic data recommended by the European NWA procedure were easy to find on Sub Saharan African highways. In addition, the proactive assessment results were used to identify the top 20% risk attributes for each road section that causes 80% of the crashes. The result was provided at the level of the municipalities through which the highway under study traverses. Such decentralization of safety assessment results can be used in prioritizing future interventions after such analysis is performed. The most frequent issues identified across the road sections using the Pareto charts included intersections, conflicts, signs and markings. The same risk attributes are similar to those identified in previous road safety studies conducted on this road network (Padison & Tiafack, 2022; Wounba et al., 2020, 2023). The findings of the study are very important to the local road safety agencies and also to road projects funding organizations in Sub-Saharan Africa such as the European Commission, World Bank, International Monetary Funds, African Development Bank etc. They can recommend the use of NWA Proactive assessment on all the roads funded with budgets from their respective organizations to ensure safe roads are constructed, as such, indirectly contributing to the reduction of road fatalities in the world. Several limitations were identified in the study. First, the road traffic crash data were poorly recorded with missing information such as GPS locations of crash locations or kilometers points to indicate where the crashes occurred. This affected the analysis resulting to the use of predicted crashes based on the HSM SPFs, and the aggregation of PS values to facilitate comparison with crash history. Thus, future work could be directed to upgrading the local crash data collection form, and the development of local crash prediction models to boost the safety assessment of roads in this part of the world.

5.6. Conclusion

The main objective of this chapter was to test the applicability of the European NWA Proactive methodology in Sub-Saharan Africa. A typical highway in this part of Africa usually consists of a two-lane, two-way road of mixed traffic flow and serving two or more cities. In this investigation, the Yaounde – Douala highway in Cameroon was selected as the road fulfilled the characteristics of a typical highway in Sub-Saharan Africa as indicated above. Two different methods were used for the analysis; the first method involved the comparison of the PS values obtained through safety inspections of the current state of the road network to the predicted crash history for the road obtained by calibrating the HSM SPFs to the local conditions. The second method compared the PS values obtained through safety inspections to the estimated expected crashes obtained by calibrating the four years observed crashes that occurred on this road. Both methods showed that the linear relationship between the PS index and the crash history is very low, but in terms of rankings, the PS index showed that the index had the potential to be used for identifying crash locations on this type of roads. With such potentials, the NWA Proactive assessment methodology can be highly recommended for ranking the safety performance of road networks in Sub-Saharan Africa, and assisting the decision makers on where to invest their safety budgets, which are often inadequate.

CHAPTER 6. Conclusion

6.1. Main achievements

This thesis had four primary objectives, and all of them have been met as indicated in the following paragraphs.

The first primary objective of this thesis focused on identifying and critically analyzing existing road safety assessment procedures to establish an understanding of the current state-of-practice. To accomplish this, the systematic literature review method was adopted and carried out following the principles and guidelines provided by the Joana Briggs Institute (JBI) and the Preferred Reporting Items for Systematic Reviews and Meta-analysis Protocols (PRISMA-P). The main research question that guided the review was: "What are the existing road safety assessment procedures currently applied for the safety evaluation of road infrastructures?" Based on this question, several search terms were used and the search was conducted in four different databases including Scopus, Web-of-science, Taylor and Francis online, and Google scholar. The websites of road agencies and international organizations were also searched. The findings identified a total of 44 road safety assessment procedures currently in practice today, and they were classified into three main groups as such:13 reactive assessment procedures, 28 proactive assessment procedures, and 3 integrated procedures. The reactive assessment procedures are those that rely mainly on historical crashes as the primary data source, and they were further subdivided into two groups: 10 crash-based procedures and 3 predictive model-based procedures. Crash-based methods are procedures that depend on the analysis of crashes using basic statistical metrics such as crash rates, crash densities, etc. The predictive model-based are those that rely on crash prediction models or SPFs, which are developed using data from crashes, road geometric characteristics, and traffic flow. The proactive procedures are the methods that are carried out using other primary data sources, except historical crashes. The 28 proactive procedures were further subdivided into three groups as such: 23 procedures are based on safety inspection and scoring of design characteristics for different road elements such as segments, intersections, roundabouts, and interchanges. 3 were based on vehicle operating speed data, and 2 were based on human factors. The integrated assessment procedures are those that combine the results from two different procedures to improve the prioritization of safety interventions. Overall, the following strengths and limitations were identified for the three primary groups: reactive, proactive, and integrated procedures.

The second primary objective was to investigate if the vehicle operating speeds on this road was a significant risk factor on two-lane undivided rural highways in Italy. And if yes, quantify the speed-crash risks by developing a CMF function for speed. Since speed cannot be easily controlled, a before-after method could not be applied. The most feasible approach was a cross-sectional method, which consists of comparing the safety performance of two entities, one entity containing the feature, and the other entity without the feature. The road segments with their corresponding speeds were grouped into categories of vehicle operating speeds. For each speed category, the predicted crashes on all the segments were determined using the updated HSM SPFs, and the observed crashes were identified and summed. Then, the ratios between the observed and predicted crashes for each category of speed were calculated. The results showed that speed was a very significant risk factor since none of the ratios was equal or very close to one. In the next step, all the ratios were plotted against the mid-points of each speed category and a power curve fitted, from which the CMF function was derived for average operating speed and 85^{th} vehicle operating speed. The two CMF functions were validated by comparing the HSM predictions with speed CMF and HSM predictions without speed CMF. The results showed that the predictions considering the CMF function for the average operating speed were closer to the actual crashes than for predictions without CMF speed or predictions with 85^{th} percentile operating speed.

The third primary objective was aimed at improving the predictive performance of the NWA Proactive model by incorporating the safety effects of vehicle operating speeds and investigating the impacts on integrated assessments and different values of operating speeds. To accomplish this, safety inspections were carried out on four different rural highways selected within the Lazio Region in Italy. NWA Proactive assessment with and without speed was then applied for all the selected roads, and the outcomes were compared to the expected crash frequencies estimated. The study found that the proactive assessment with speed matched with the expected crash frequencies better than those without speed in all four rural highways under study. Furthermore, the NWA Reactive assessment was performed in all the selected roads and the results were integrated with those of NWA Proactive assessment with and without speed. The integrated results showed that without considering speed, the majority of the prioritized road sections appeared to be safer than when speed was considered. Since incorporating speed into the model improved the predictions, it is better to apply this model for proactive assessments to avoid inadequate identification of the safety levels of road sections, which may lead to the improper allocation of safety investments.

Finally, the fourth primary objective of this thesis was to investigate the possibility of transferability of the European network-wide methodology to non-European roads. Particular attention was paid to a typical highway in Sub-Saharan Africa, which is a two-lane, undivided road carrying mixed traffic and serving border towns and villages. Due to poor crash data records, only the proactive assessment methodology was applied. Two different methods were selected for this investigation. The first method involved three steps: calculating the predicted crash frequency using calibrated HSM SPFs; calculating the Proactive scores based on safety inspection of the road; and finally comparing the Proactive scores with the predicted crash frequencies. The second method compared the proactive scores obtained through safety inspections to the expected crashes obtained by calibrating the four years observed crashes that occurred on this road. Both methods were applied on the Yaounde-Douala highway in Cameroon, which was selected for the case study because the road fulfilled all the characteristics of a typical highway in Sub-Saharan Africa. The first method found that graphically, more than half of the predicted crashes matched with the Proactive score values obtained through safety inspections. Both methods showed that the linear correlation between the PS index and the crash history is very low, but in terms of rankings, the PS index showed that the index has the potentials to be used for identifying crash locations on this type of roads. Also,most of the road design characteristic data recommended by the European NWA was easily accessible in Africa. Based on the fact that the data was easy to get and because there exist a moderate relationship between the rankings for NWA Proactive Index and crash history, this study concluded that the European NWA Proactive assessment model is highly recommended for ranking the safety performance of road networks in Sub-Saharan Africa.

6.2. Limitations

- **Systematic Review**

- Since studies in languages other than English were excluded, several assessment procedures available in languages such as French, Italian, German etc were therefore not considered. For instance, the SURE method in France, the German blackspot analysis method etc.
- Basic reactive assessment procedures that rely on the number-based system for accident location identification were discarded, for instance, defining a hazardous location as any road section with two or three fatal accidents in the past four years. Such procedures are not adequate enough since they depend solely on accident numbers which are often missing or underreported, and if available, they are faced with issues related to the regression-to-mean bias. Also, identifying a crash location without taking into consideration road geometric and operational characteristics would undermine the quality of the assessment results.
- Several predictive models have been developed at country-levels, but the attention of this review focused on only the three international widely used predictive models, that is, the HSM Predictive models, the European PRACT models, and the ANRAM Predictive models.

- **CMF Development**

- The main limitation of the cross-sectional approach adopted for the development of the CMF function is found in the process of grouping the road segments based on the different operating speeds categories created. This is because the grouping affects the resulting ratios and hence, the developed CMF functions. Also, if very few categories of vehicle operating speed classes are used, for instance creating just three classes, the speed data would be over-deducted and some useful information may be lost. Likewise, too many speed categories would result to small number of road segments within that category, could have an impact on the result. And so far, there are no guidelines for the minimum number of groups to create, or even the minimum sample size for road segments within each group.

- The vehicle operating speed used was obtained from probed vehicles only, which statistics have shown that less than 5% of vehicles have their GPS installed and also effectively use them while traveling. This may have an impact on the overall results especially in the process of classifying segments into the different speed categories defined.

- **Network-wide assessment**

- The ranking criteria in NWA reactive assessment require the calculation of reference populations, that is, the average crash rates and average crash densities of sites with similar characteristics. Nevertheless, for this study, the reference population was not readily available and thus, the study assumed that the total length of the road sections under this study forms the reference population. This means that a section is compared against average statistics estimated across the total length of the four road sections.

- **Transferability**

- The absence of GPS locations for the crash data led to the use of longer road sections, and the aggregation of Proactive scores, as such some useful information may have been lost in this process. For example, aggregating scores for over 60 road segments of 500 meters each, may not adequately capture the risks involved within those sections.

6.3. Further research and recommendations

Further research

- Incorporating the safety effects of vehicle operating speed into the NWA Proactive model has shown that the model's predictive accuracy was improved. However, in this study, the CMF function that quantifies these effects was developed only for two-lane undivided rural highways. As such, there is a need to develop CMF functions for the other road types such as multilane undivided highways, urban roads, secondary roads etc.

- The NWA integration approach is very biased towards the proactive component instead, by considering that all the sections identified as high risks by the reactive component is classified as 'high risk' nomatter the result from the proactive component. This indirectly is relegating safety assessment to rely on the number of people killed on the road, which contradicts the 2050 vision zero strategy adopted by the European Commission. Thus, further research to develop a better integration approach is required, as well as reducing the use of reactive assessments in the identification of crashes.

Recommendations

- Since incorporating vehicle operating speed produced better results, it is highly recommended that the modified NWA Proactive model should be used for safety assessment.

- This research also recommended the update of crash data reporting sheets in Sub-Saharan Africa, by integrating the use of GPS co-ordinates in the identification of crash locations. This could enhance future research and quality road safety evaluations.

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Annexes

Annex 1. Publications

1. **Chia Ngwah, E.,** Stephen Kome, F., Steffel Ludivin, F. T., Brayan, G.-H., Davide Shingo, U., & Luca, P. (2026). ***Comparative Analysis of In-built Road Safety Assessment Methodologies***. Traffic Safety Research. DOI: 10.55329/ktxy3871
2. **Chia Ngwah, E.,** Steffel Ludivin, F. T., Stephen Kome, F., Brayan, G. H., Davide Shingo, U., & Luca, P. (2024). ***Urban Road Safety Assessment Methodologies: A Systematic Review.*** IRF World Congress 2024.
3. **Chia Ngwah, E.,** Steffel Ludivin, F. T., Stephen Kome, F., Brayan, G. H., Davide Shingo, U., & Luca, P. (2024). ***Comparative Analysis of Methodologies for In-built Network-wide Road Safety Assessments***. ICTCT 2024 Conference.
4. **Chia Ngwah, E.,** Tevoh, N., Isaac Ndumbe, J. I., Brayan, G.-H., & Davide Shingo, U. (2025, June 3). ***Impact of using rural roads crash modification factors on urban road safety assessments.*** Young Researchers Seminar 2025 – Proceedings of the 12th Young Researchers Seminar. https://doi.org/10.60850/bericht-a53
5. González-Hernández, B., **Chia Ngwah, E.,** Usami, D. S., & Persia, L. (2024). ***In-built network-wide road safety assessment methodologies for rural roads***. Traffic Injury Prevention, *25*(8), 1048–1054. https://doi.org/10.1080/15389588.2024.2361461
6. Japhet Kuma, C., & **Chia Ngwah, E.** (2025). ***Regulating Ride-Sourcing in Africa: Governance Challenges and Policy Lessons from Cameroon*** (1st ed.). Routledge. https://doi.org/10.4324/9781003560074
7. Tezong Feudjio, S. L., Fondzenyuy, S. K., **Chia Ngwah, E.,** Wounba, J. F., Usami, D. S., & Persia, L. (2025). ***Traffic Conflict Approach in Road Safety: A Review of Data Collection Methods.*** Transportation Research Procedia, *90*, 615–622. https://doi.org/10.1016/j.trpro.2025.06.100
8. Steffel Ludivin, F. T., Isaac Ndumbe, **Chia Ngwah, E**., Stephen Kome, F., Tevoh, N., Davide Shingo, U., & Luca, P. (November 2025). ***Exploring the Contribution of Road Infrastructure and Environmental Factors to Crash Severity at Intersections in Mixed Traffic Settings***. Infrastructures. DOI:10.3390/infrastructures10120317

9. Steffel Ludivin, F. T., Isaac Ndumbe, **Chia Ngwah, E**., Stephen Kome, F., Tevoh, N., Davide Shingo, U., & Luca, P. (January 2025). ***Traffic conflict-based crash estimation models: overview and application across various traffic environment***. Transportation Research Procedia 92:241. DOI: 10.1016/j.trpro.2025.12.130
10. Steffel Ludivin, F. T., Isaac Ndumbe, **Chia Ngwah, E**., Stephen Kome, F., Tevoh, N., Davide Shingo, U., & Luca, P. (January 2025). ***Application of extreme value theory models to crossing conflicts in mixed traffic intersection : Evidence from a case study in Yaoundé, Cameroon***. Transportation Research Procedia. DOI: 10.1016/j.trpro.2025.12.129

Annex 2. Traffic volume

FROSINONE PROVINCE

STRADE PROVINCIALI NELLA PROVINCIA DI FROSINONE					
Den. Naz. Str.	DESCRIZIONE	INIZIO (km)	FINE (km)	ESTESA (km)	Classe TGM
SP003	GUGLIETTA VALLEFRATTA	0+000	12+250	12,250	1000-2000
SP020	PIGLIO ARCINAZZO	0+000	10+667	10,667	500-1000
SP023	FERENTINO SUPINO I Tronco	0+000	0+500	0,500	1000-2000
SP023	ROTATORIA FERENTINO	-	-	-	1000-2000
SP023	RAMO PER STRADA CONSORTILE ASI	0+000	0+140	0,140	1000-2000
SP028	TREVI FILETTINO	0+000	16+940	16,940	0-500
SP030	FILETTINO CAPISTRELLO	0+000	10+200	10,200	0-500
SP066	ORTELLA	0+000	9+100	9,100	2000-3000
SP076	DEI SANTI I Tronco	0+950	9+500	8,550	1000-2000
SP076	DEI SANTI II Tronco	9+600	20+493	10,893	1000-2000
SP081	APPIA NUOVA	0+789	9+518	8,729	2000-3000
SP128	CAMPO STAFFI	0+000	2+800	2,800	0-500
SP152	PIEDIMONTE PIGNATARO I Tronco	0+000	2+275	2,275	5000-7500
SP227	PEDEMONTANA MONTI LEPINI I TRATTO	0+000	28+177	28,177	2000-3000
SP227	PEDEMONTANA MONTI LEPINI II TRATTO	0+000	28+177	28,177	0-500
SP227	PEDEMONTANA MONTI LEPINI III TRATTO	0+000	28+177	28,177	2000-3000
SP227	PEDEMONTANA MONTI LEPINI IV TRATTO	0+000	28+177	28,177	1000-2000
SP229	TAVERNA 50	0+000	3+265	3,265	3000-4000
SP237	BORGO VICALVI I e II Tronco	0+000	9+402	9,402	1000-2000
SP257	PONTECORVO S. GIOVANNI INCARICO	0+000	12+000	12,000	1000-2000

STRADE PROVINCIALI NELLA PROVINCIA DI FROSINONE

Den. Naz. Str.	DESCRIZIONE	INIZIO (km)	FINE (km)	ESTESA (km)	Classe TGM
SP275	ALLACCIAMENTO STABILIMENTO FIAT	0+000	3+690	3,690	4000-5000
SP276	STRADA STABILIMENTO FIAT	0+000	1+290	1,290	5000-7500
SP277	ASSE ATTREZZATO FROSINONE	0+000	5+670	5,670	1000-2000
SP278	MARIA	0+000	17+900	17,900	1000-2000
SP279	ASSE ATTREZZATO CECCANO	0+000	2+949	2,949	4000-5000
SP280	COLLEGAMENTO SS 6 STABILIMENTO FIAT	0+000	1+550	1,550	1000-2000
SP281	STRADA PERIMETRALE EST STABILIMENTO FIAT	0+000	1+555	1,555	1000-2000
SP628	LEUCIANA I Tronco	0+000	4+750	4,750	3000-4000
SP628	LEUCIANA II Tronco	8+750	17+000	8,250	3000-4000

STRADE REGIONALI NELLA PROVINCIA DI FROSINONE

Den. Naz. Str.	DESCRIZIONE	INIZIO (km)	FINE (km)	ESTESA (km)	Classe TGM
SR082	DELLA VALLE DEL LIRI	47 + 777	104 + 870	57,093	2000-3000
SR149	DI MONTECASSINO	0 + 000	8 + 738	8,738	1000-2000
SR155	DI FIUGGI	0 + 000	53 + 870	53,870	0-500
SR155racc	DI FIUGGI RACCORDO	0 + 000	18 + 700	18,700	4000-5000
SR156dir	DEI MONTI LEPINI DIRAMAZIONE	0 + 000	5 + 320	5,320	1000-2000
exSR214	MARIA E ISOLA CASAMARI	0 + 000	2 + 440	2,440	1000-2000
SR411	SUBLACENSE	31 + 950	50 + 560	18,610	0-500
SR411dir	DI CAMPOCATINO	0 + 000	18 + 400	18,400	0-500
SR430	DELLA VALLE DEL GARIGLIANO	0 + 000	3 + 660	3,660	5000-7500
SR509	DI FORCA D'ACERO	9 + 680	39 + 500	29,820	500-1000
SR627	DELLA VANDRA	0 + 000	47 + 250	47,250	1000-2000
SR630	AUSONIA	0 + 000	22 + 280	22,280	4000-5000

SR637	DI FROSINONE E DI GAETA	0 + 000	36 + 140	36,140	4000-5000
SR637dir	DI FROSINONE E DI GAETA DIRAMAZIONE	0 + 000	8 + 200	8,200	1000-2000
SR666	DI SORA	0 + 000	17 + 000	17,000	500-1000

LATINA PROVINCE

STRADE PROVINCIALI NELLA PROVINCIA DI LATINA

Den. Naz. Str.	DESCRIZIONE	INIZIO (km)	FINE (km)	ESTESA (km)	Classe TGM
SP001	ARDEA FONTANA DEI PAPI	0+000	10+400	10,400	500-1000
SP002	CISTERNA CAMPOLEONE	1+300	17+000	15,700	0-500
SP003	VELLETRI ANZIO I TRONCO A	5+485	8+454	2,969	0-500
SP003	VELLETRI ANZIO I TRONCO B	9+400	15+000	5,600	4000-5000
SP003	VELLETRI ANZIO I TRONCO C	16+536	23+200	6,664	2000-3000
SP015	VELLETRI ANZIO II	2+200	15+640	13,440	5000-7500
SP038	BORGO PIAVE ACCIARELLA	0+000	10+481	10,481	0-500
SP058	MIGLIARA 47	0+000	7+300	7,300	5000-7500
SP058A	MIGLIARA 47 (BRACCIO APPIA)	0+000	1+570	1,570	5000-7500
SP062	MARITTIMA II (TRONCO A)	0+000	5+335	5,335	5000-7500
SP062	MARITTIMA II (TRONCO B)	7+820	17+200	9,380	5000-7500
SP067	GUGLIETTA VALLEFRATTA	0+000	6+580	6,580	2000-3000
SP077	MIGLIARA 53 (TRONCO A)	0+000	4+900	4,900	5000-7500
SP077	MIGLIARA 53 (TRONCO B)	5+100	9+438	4,338	5000-7500
SP095	AMBRIFI PASTENA	0+000	4+780	4,780	500-1000
SP097	LENOLA	0+000	5+435	5,435	2000-3000
SP125	AUSENTE	2+400	20+750	18,350	3000-4000
SP128	TAVERNA 50	0+000	4+361	4,361	3000-4000
SP209	CIRCOLARE A	146+080	156+080	10,000	5000-7500
SP210	EX SS APPIA	0+000	3+690	3,690	500-1000
SP211	MIGLIARA 47 (BORGO PASUBIO)	0+000	3+725	3,725	5000-7500

STRADE REGIONALI NELLA PROVINCIA DI LATINA					
Den. Naz. Str.	**DESCRIZIONE**	**INIZIO (km)**	**FINE (km)**	**ESTESA (km)**	**Classe TGM**
SR082	DELLA VALLE DEL LIRI	104 + 870	126 + 836	21,966	0-500
SR156	DEI MONTI LEPINI	24 + 150	33 + 800	9,650	4000-5000
SR207	NETTUNENSE	13 + 220*	27 + 840*	9,298*	10000-15000
SR213	VIA FLACCA	0 + 000	36 + 080	36,080	7500-10000
SR609	CARPINETANA	30 + 900	42 + 480	11,580	2000-3000
SR630	AUSONIA	22 + 280	31 + 250	8,970	7500-10000
SR637	DI FROSINONE E DI GAETA	36 + 140	52 + 045	15,905	4000-5000

RIETI PROVINCE

STRADE PROVINCIALI NELLA PROVINCIA DI RIETI					
Den. Naz. Str.	**DESCRIZIONE**	**INIZIO (km)**	**FINE (km)**	**ESTESA (km)**	**Classe TGM**
SP010	TURISTICA DEL TERMINILLO	0+000	21+650	21,650	0-500
SP034	TURANENSE	0+000	40+150	40,150	0-500
SP054	MAGLIANO SABINA (I TRONCO)	0+000	10+000	10,000	500-1000
SP054	MAGLIANO SABINA (II TRONCO)	16+500	25+700	9,200	0-500
SP069	SELVAPIANA	0+000	2+050	2,050	0-500
	RACCORDO SR 657 – CASELLO A1 “SORATTE”	0+000	1+720	1,720	500-1000

Tabella 0-1 Classe TGM delle strade regionali della RVR nella provincia di Rieti

STRADE REGIONALI NELLA PROVINCIA DI RIETI					
Den. Naz. Str.	**DESCRIZIONE**	**INIZIO (km)**	**FINE (km)**	**ESTESA (km)**	**Classe TGM**
SR004bis	DEL TERMINILLO	0 + 000	22 + 000	22,000	0-500
SR079	TERNANA	28 + 015	50 + 083	22,068	1000-2000
SR313	DI PASSO CORESE	0 + 000	45 + 250	45,250	2000-3000
SR314	LICINESE	0 + 000	40 + 470	40,470	500-1000
SR471	DI LEONESSA	39+150	48 + 200	-	0-500
SR521	DI MORRO	0 + 000	24 + 870	24,870	0-500
SR577	DEL LAGO DI CAMPOTOSTO	26 + 400	39 + 650	13,250	0-500
SR657	SABINA	0 + 000	22 + 730	22,730	3000-4000
	BRETELLA SR313-SS 4DIR	0 + 895	1+000	-	2000-3000

STRADE REGIONALI NELLA PROVINCIA DI ROMA					
Den. Naz. Str.	**DESCRIZIONE**	**INIZIO (km)**	**FINE (km)**	**ESTESA (km)**	**Classe TGM**
SR007 dir/a	VIA APPIA	0 + 000	2 + 000	2,000	7500-10000
SR155	DI FIUGGI	53 + 870	74 + 600	20,730	7500-10000
SR207	NETTUNENSE	0 + 000*	37 + 700*	28,403*	20000-30000
SR218	DI ROCCA DI PAPA	5 + 000	14 + 200	9,200	4000-5000
SR313	DI PASSO CORESE	0 + 000	45 + 250	45,250	1000-2000
SR314	LICINESE	0 + 000	40 + 470	40,470	500-1000
SR411	SUBLACENSE	0 + 000	31 + 950	31,950	2000-3000
SR609	CARPINETANA	0 + 000	30 + 900	30,900	5000-7500
	TANGENZIALE DEI CASTELLI	0+000	3+000	-	20000-30000
	BRETELLA SR313-SS 4DIR	0 + 000	0 + 895	0,895	2000-3000

VITERBO PROVINCE

STRADE PROVINCIALI NELLA PROVINCIA DI VITERBO					
Den. Naz. Str.	DESCRIZIONE	INIZIO (km)	FINE (km)	ESTESA (km)	Classe TGM
SP001	CIMINA	1+322	32+690	31,368	5000-7500
SP002	TUSCANESE	2+850	21+404	18,554	10000-15000
SP003	TARQUINIENSE	0+000	4+536	4,536	5000-7500
SP004	DOGANA (1° TRONCO)	0+000	19+072	19,072	1000-2000
SP004	DOGANA (2° TRONCO)	0+000	4+765	4,765	1000-2000
SP008	VERENTANA	2+950	22+190	19,240	15000-20000
SP008	VERENTANA TRATTO SOTTESO MARTA	0+000	2+792	2,792	10000-15000
SP008	VERENTANA TRATTO SOTTESO CAPODIMONTE	0+000	3+200	3,200	10000-15000
SP008	VERENTANA TRATTO SOTTESO VALENTANO	0+000	0+896	0,896	10000-15000
SP011	VETRALLESE	6+150	18+484	12,334	1000-2000
SP141	VARIANTE ALLA SP 1 (RONCIGLIONE)	0+000	2+500	2,500	3000-4000
SP144	MAREMMANA	62+750	77+803	15,053	7500-10000
SP147	CLAUDIA BRACCIANESE	0+000	19+700	19,700	5000-7500
SP149	NEPESINA	0+000	22+315	22,315	7500-10000
SP150	MAGLIANO SABINA	0+000	17+642	17,642	7500-10000
SP151	ORTANA	4+500	30+350	25,850	7500-10000

STRADE REGIONALI NELLA PROVINCIA DI VITERBO					
Den. Naz. Str.	**DESCRIZIONE**	**INIZIO (km)**	**FINE (km)**	**ESTESA (km)**	**Classe TGM**
SR312	CASTRENSE	0 + 000	40 + 568	40,568	10000-15000
SR657	SABINA	22 + 730	23 + 200	0,470	5000-7500
EXSS675	UMBRO LAZIALE	0 + 000	6 + 150	6,150	10000-15000

Annex 3. Crash Modification Factors and Reduction Factors for Network-wide Assessment

Risk factor	Detailed parameters	NWA Proactive score	
		CMF value	**RF value**
1. Lane width (LW)	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
2. Roadside Hazard Rating (RHR)	- CZ > 9.14m Flatter than 1V: 4H	0.875	1.000
	- 6.10m ≤ CZ < 7.62m About 1V: 4H	0.935	1.000
	-CZ ~ 3.05, guardrail > 1.98m About 1V: 4H	1.000	1.000
	-1.52m ≤ CZ < 3.05m, with guardrail offset 1.52m to 1.98m About 1V: 3H or 1V: 4H	1.069	0.935
	-1.52m ≤ CZ < 3.05m, with guardrail offset < 1.52m About 1V: 3H	1.143	0.875
	-CZ ≤ 1.52m About 1V: 2H, exposed to rigid objects	1.222	0.818
	-CZ ≤ 1.52m About 1V: 2H or steeper, exposed to cliff or vertical rock	1.306	0.766
3. Curvature	Radius and operating speed / speed limit	CMF formular	1 / CMF
4. Density of property access points	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	1.312	0.762
5. Junctions	Roundabout	1.000	1.000
	3-leg un-signalized with turn lane	1.130	0.885
	3-leg un-signalized without turn lane	1.391	0.719
	4-leg un-signalized with turn lane	1.515	0.660
	4-leg un-signalized without turn lane	2.178	0.459
6. Conflicts between pedestrians, Bicyclists & Motorized traffic	Grade separated facility	1.00	1.00
	No facility for pedestrian crossing speed limit > 70km/h	16.75	0.060
	No facility for pedestrian crossing speed limit ≤ 70km/h	12.00	0.083
	No pedestrian traffic	1.00	1.00
	Segregated-protected pedestrian path	1.00	1.00
	No facility for pedestrians walking along	20.00	0.05
	No bicycle traffic	1.00	1.00
7. Shoulder type and width	SW ≥ 1.83	1.00 (1.071)	1.00 (0.983)
	1.23 ≤ SW < 1.83	1.063 (1.077)	0.941 (0.929)
	0.91 ≤ SW < 1.23	1.097 (1.106)	0.912 (0.904)
	0.61 ≤ SW < 0.91	1.127 (1.136)	0.887 (0.880)

	0.00 ≤ SW < 0.61	1.211 (1.211)	0.826 (0.826)
8. Passing lanes	Un-divided 2-lane road with slope > 4% for more than 500m – passing lanes in both directions	1.000	1.000
	> 4% for more than 500m – passing lanes in one direction	1.149	0.870
	4% for more than 500m, no passing lanes	1.502	0.666
9. Signs & markings	In place, high quality and in good condition	-	1.00
	In place, medium quality and in poor condition	-	0.95
	Critical markings and signs missing	-	0.90