DOCTORATE IN TRANSPORTATION AND INFRASTRUCTURES
END OF THE SECOND YEAR EXAMINATION

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Cycle: XXXIV

Curriculum: Transportation and Land-Use Planning

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SAPIENZA UNIVERSITÀ DI ROMA
Department of Civil, Construction and Environmental Engineering
Academic year 2019/2020

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
AfDB	African Development Bank
ANRAM	The Australian National Risk Assessment Model
ARSAP	Africa Road Safety Action Plan
ATC	Australian Transport Council
AU	African Union
AusRAP	Australian Road Assessment Program
BCRs	Benefit-Cost Ratios
BIR	Branch Index Risk
CMF	Crash Modification Factor
CTL	Research Center for Transport and Logistics
EAT	Efficiency Assessment Tools
EB	Empirical Bayes
EC	European Commission
EU	European Union
EuroRAP	European Road Assessment Program
EUROSTAT	European Statistical Office
GDP	Gross Domestic Product
HES	Hospital Episodes Statistics
HMI	Human Machine Interface
HRS	High Risk Sites
HSM	Highway Safety Manual
IC	Information Centre
iRAP	International Road Assessment Program
IRF	International Road Federation
IRR	Infrastructure Risk Rating
IRTAD	International Road Traffic Accident Database
ITF	International Transport Forum
LMICs	Low- and Middle-Income Countries
OECD	Organization for Economic Co-operation and Development
PDO	Property Damage Only
PFI	Potential for a Safety Improvement Index
NDCs	National Data Coordinators
NHS	Information Centre of the National Health Service
NO	Network Operation
NSR	Network Safety Ranking
NTSA	National Transport and Safety Authority
NZTA	The New Zealand Transport Agency
PIARC	World Road Association
RAPs	Road Assessment Programmes
RIA	Road Safety Impact Assessment
RCA	Road Controlling Authority
RFI	Risk Factor Index

RISA	Road Infrastructure Safety Assessment
RISM	Road Infrastructure Safety Management
RPS	Road Protection Score
RSA	Road Safety Audit
RSI	Road Safety Inspections
RSO	Road Safety Observatory
RTCs	Road Traffic Crashes
SCOTI	Standing Council on Transport and Infrastructure
SI	Safety Index
SIR	Section Index Risk
SPF	Safety Performance Function
SPIs	Safety Performance Indicators
UNECA	United Nations Economic Commission for Africa
UNECE	United Nations Economic Commission for Europe
usRAP	United States Road Assessment Program
VRUs	Vulnerable Road Users
WB	The World Bank
WRS	World Roads Statistics
WHO	World Health Organization

1 SECTION A: DOCTORAL RESEARCH

1.1 Additional preliminary knowledge acquired

The additional preliminary knowledge acquired within this second year comprise of the following:

1.1.1 Courses, Seminars and conferences attended

- **99th Annual Meeting of Transportation Research Board**, Washington, DC. January 12-16, 2020.
- **World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium-WMCAUS**, Prague. September 1-5, 2020.
- **Leveraging Urban Mobility Disruptions to Create Better Cities.** Online course. MITx, 40 Hr., 2020.
- **BIGRS IndiaRAP Webinar: World Bank and iRAP helping save lives on Indian roads.** Online course. BIGRS and IndiaRAP, 16 Hr., 2020.
- **Webinars** related to transport issues from different international organizations. World Bank, International Transport Forum, Transportation Research Board, C2 Smart, Transport and Accessibility in Low Income Communities – Latin America Chapter (INTALInC-LAC), among others.

1.1.2 Books and software packages exploited

Books:

- Bliss, T., & Breen, J. (2009). Country guidelines for the conduct of road safety management capacity reviews and the specification of lead agency reforms, investment strategies and safe system projects.
- Bliss, T., & Breen, J. (2013). “Road Safety Management Capacity Reviews and Safe System Projects Guidelines” Global Road Safety Facility. Washington, DC.
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- International Transport Forum. (2008). Towards Zero. Ambitious Road Safety Targets and the Safe System Approach. OECD. Paris.
- International Transport Forum. (2016). Zero road deaths and serious injuries: Leading a paradigm shift to a safe system. OECD. Paris.
- Muhlrad, N. (2009). Road safety management systems, a comprehensive diagnosis method adaptable to low- and middle-income countries. Synthèse INRETS.
- World Health Organization. (2018). Global status report on road safety 2018.
- World Health Organization. (2010). Data systems: a road safety manual for decision-makers and practitioners.

Software packages

- **Safety Manager**, for manage data relating to traffic, infrastructure and road traffic crashes.
- **Sfinge,** for manage and analyze road accident data.
- **TransCAD,** for store, display, manage, and analyze transportation data.
- **QGIS,** for viewing and editing GIS data.

1.2 Bibliography collected related to the research topic

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12. Chhanabhai, V., Beer, K., & Johnson, M. (2017). Calibrating Infrastructure Risk Rating (IRR) for Victorian Roads. In *Australasian Road Safety Conference* (pp. 10–12).
13. De Pauw, E., Daniels, S., Brijs, T., Wets, G., & Hermans, E. (2013). The magnitude of the regression to the mean effect in traffic crashes. Transportation Research Board.
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Safety in National Highways in Sudan. *American Journal of Civil Engineering*, *4*(6), 276. https://doi.org/10.11648/j.ajce.20160406.12
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1.3 Status report of scientific reference framework, in relation to the proposed research topic

See detailed information attached (SECTION 4, 5 and 6).

1.4 Identification of ongoing similar research activities at national and international level

A number of methodologies mostly based on the physical characteristics of a road have been proposed over the last 15 years by researchers from around the world, especially from Italy and New Zealand, so far to assess the safety performance of road infrastructures. Probably, the most known methodology is the international Road Assessment Program (iRAP).

iRAP is the umbrella organisation for EuroRAP, AusRAP, usRAP, and KiwiRAP. iRAP is based on four standardised protocols that together provide consistent safety ratings of roads across borders. Nationally, they enable the identification of the most dangerous roads, tracking performance over time, and therefore where the action is appropriate. Internationally, they enable comparisons of risk within and between countries. Standard protocols for iRAP are:

- Risk Mapping: based on real crash and traffic data, colour-coded maps show a road's safety performance by measuring and mapping the rate at which people are killed or seriously injured. Different maps can be produced depending on the target audience.
- Performance Tracking: identifies whether fewer people are being killed or seriously injured on individual routes or road networks over time, and importantly, through consultation with road authorities, identifies the countermeasures that are most effective.
- Star Rating: using drive-through inspections of routes in specially equipped vehicles. Ratings show the likelihood of a crash occurring and how well the road would protect against death or serious injury in the event of a crash.
- Safer Roads Investment Plans: Following road inspections and coding, in addition to detailed reporting, a Safer Roads Investment Plan can be developed, considering over 70 proven road improvement options.

iRAP consisting of a number of evaluation tools; among them, the most relevant to this project is the Road Protection Score (RPS). The RPS module assigns a road infrastructure safety level basing on how effectively the infrastructure prevents crashes and protects users involved in crashes. Based on the calculated RPS the road section is classified according to a five-level ranking (Star Rating).

iRAP methodology is the inspection of the road network in order to define the level of safety inherent the road design: five-star roads (green) are the safest, and one-star (black) are the least safe. Star Ratings can be completed without reference to detailed accident data, which is often unavailable in low- and middle-income countries. Using specially equipped vehicles, software and trained analysts, RAP inspections focus on more than 30 different road design features that are known to influence the likelihood of a crash and its severity. These features include intersection design, road cross-section and markings, roadside hazards, footpaths, and bicycle lanes.

Two types of road inspections are available, drive-through inspections and video-based inspections, with video-based inspections being the most common.

Drive-through inspections require inspectors to record road design data as they drive along the road using a specialised data tablet. The process is technical and requires accredited RAP inspectors. Drive-through inspections are typically used where the length of the road network being surveyed is short or relatively simple (such as rural roads with no adjacent development). The drive-through inspection equipment includes a video camera, touch-sensitive laptop, and a GPS antenna. The inspections are followed by a period of data analysis and quality checking.

Video-based inspections are undertaken in two stages. Firstly, a specially equipped survey vehicle records images of the road as it travels along. The video is later viewed by analysts, or coders, and assessed according to RAP protocols. The survey vehicle can record digital images of the road (generally at intervals of 5-10 metres) using an array of cameras aligned to pick up panoramic views of the road (forward, left-side and right-side). The main forward view is calibrated to allow measurements such as lane width, shoulder width, and distance to roadside hazards. The vehicles can drive along the road at almost normal speed while collecting the information.

Following the completion of the video-based inspection, each relevant design feature is measured and rated according to RAP protocols. The process involves streaming the video images together to form a video of the road network. Coders then undertake desktop inspections by conducting a virtual drive-through of the road network, at posted speed or on a frame-by-frame basis, depending on the complexity of the road. The software used by the coders enables accurate measurements of elements such as lane widths, shoulder widths, and distance between the road edge and fixed hazards, such as trees or poles. To support the process a detailed road inspection manual is available. At the completion of the rating process, it is possible to produce a detailed condition report of the road that forms the basis for Star Ratings and the Safer Roads Investment Plan. A colour coded map illustrating the level of safety inherent the road design and features is produced and can be used to make drivers aware of the risk of different roads or networks (OECD/ITF, 2015).

1.5 Research proposal

Title: Development of Simplified Road Assessment Programme Methodology.

1.5.1 Introduction

Road safety is one of the most critical problems of human life. In fact, around 1.35 million people die and 50 million are injured in road crashes every year (World Health Organization, 2018). Road traffic crashes are estimated to be the ninth leading cause of death and projections reveal that it will be the third leading cause of death by 2020 (Peden et al., 2004). In addition, 90% of the related deaths resulting from road traffic crashes (RTCs) occur in Low- and Middle-Income Countries (LMICs) (World Health Organization, 2018). At the same time, LMICs have not fully established crash databases reducing their ability to identify and measure road safety problems (World Road Association, 2015). Indeed, the fewer the accident data, the less the information accidents can give about accidents to be prevented (Montella, 2005).

The cost associated with deaths and injuries is estimated to be in the range between 1.3 and 3.2% of the GDP per annum for many countries (Elvik, 2000). To this regard, traffic accident prevention has been a consensus all the time around the World and in the last several years a large amount of money has been spent on traffic accident prevention. Reduction of social and economic costs also associated with accidents and collisions in road transportation (Hasmukhrai, Ganeshbabu, & Gundaliya, 2016).

A road traffic crash results from a combination of several factors, in particular, the accident risk, in terms of repeatability, localization, and severity, is related to three concurrent factors: infrastructure, vehicle, and human factors (Elvik, Vaa, Hoye, & Sorensen, 2009). In this way, road and roadside characteristics are a pivotal factor in the number of fatalities and serious injuries (Chhanabhai, Beer, & Johnson, 2017).

However, progress has been made by some countries in mitigating the number and severity of road accidents (Adminaite, 2016), but the situation in most low- and middle-income countries is alarming and even getting worse (Bliss & Breen, 2012). Efforts are being made towards ameliorating the situation but the efforts are often non-systematic, fragmented and not knowledge-based or data-led resulting in unsuccessful actions. Nevertheless, successful road safety actions need to be conducted within the framework of a functional road safety management system to yield expected results (Papadimitriou & Yannis, 2013).

Road Infrastructure Safety Management (RISM) refers to a set of procedures that support a road authority in decision-making related to improving the road safety of a road network. RISM procedures are effective and efficient tools to help road authorities reduce the number of accidents and casualties, because design standards alone cannot guarantee road safety in all conditions. Yet successful implementation of RISM procedures requires an adequate level of investment, supporting regulation, availability of relevant road safety data and adequate institutional management capacity (OECD/ITF, 2015).

A number of methodologies mostly based on the physical characteristics of a road have been proposed by road safety research so far to assess the safety performance of road infrastructures (Appleton, 2009).

Probably, the most known methodology is the international Road Assessment Program (iRAP) consisting of a number of evaluation tools; among them the most relevant to this research is the Road Protection Score (RPS). The RPS module assigns a road infrastructure safety level basing on how effectively the infrastructure prevents crashes and protects users involved in crashes (iRAP, 2009). Based on the calculated RPS the road section is classified according to a five-level ranking (Star Rating). The iRAP methodology is complex, it includes many variables and there are no convincing studies that validate it.

To support the assessment of road safety risks on different roads, the research seeks to develop and pilot a new simplified methodology to quickly identify critical sections and at low cost even without sufficient crash database. The simplified methodology developed will be tested and validated through a pilot road safety assessment of highways in Italy, Mozambique and Liberia.

1.5.2 Objectives

The general objective of this research consists in developing and piloting a new simplified methodology for road infrastructures' safety assessment. The underpinning idea is to be able to recognize road safety issues connected with road infrastructure characteristics, rapidly, at a low cost, and without the specific need for road traffic crash data. The simplified methodology proposed will be tested and validated through a pilot road assessment of highways in Italy, Mozambique and Liberia.

To achieve this objective, the following scientific and technical objectives are considered:

- Reviewing of the knowledge from available research on the most important road attributes, including the impact of the geometry and operational variables of the roads on road safety risk.
- Choose a set of the attributes to be utilized for the simplified methodology, considering impact on road safety risk, and feasibility of automated image analysis.
- Establishing a methodology for simplified road assessment based on the analysis of road infrastructure attributes (i.e. on their contribution to the risk of road traffic crashes).
- Assist to development of a standard of video filming for data collection and analysis of road safety risk.
- Support the development of a simplified road assessment software using an automated image analysis and coding tool based on the proposed methodology.
- Conducting a pilot assessment of national highways in Italy, Mozambique and Liberia.
- Evaluate the relationship between the simplified methodology proposed and road traffic crashes data.

1.6 Work plan

ANNUAL WORK PLAN

Nº	TASK	YEAR 1 (2018/2019)												YEAR 2 (2019/2020)												YEAR 3 (2020/2021)											
		N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
1	Data source and systems identification	■	■	■	■	■																															
2	Study of the context of road safety knowledge and data (literature review)	■	■	■	■	■	■	■	■	■	■	■	■																								
3	Prepare of one article to be published in international journals/conferences										■	■	■	■	■	■																					
4	Choose a set of the attributes to be utilized for the simplified methodology													■	■	■	■	■																			
5	Establishing a methodology for simplified road assessment																		■	■	■	■	■	■	■												
6	Assist to development of a standard of video filming for data collection and analysis of road safety risk																	■	■	■																	
7	Support the development of a simplified road assessment software using an automated image analysis																	■	■	■	■	■	■	■	■												
8	Data collection on national highways in Mozambique																				■	■															
9	Data collection on national highways in Liberia																						■	■													
10	Prepare of one article to be published in international journals/conferences																						■	■	■	■	■	■									
11	Data collection on national highways in Italy																									■	■										
12	Analysis of the data																									■	■	■	■	■	■	■					
13	Prepare of one article to be published in international journals/conferences																													■	■	■	■	■	■		
14	Writing of thesis																															■	■	■	■	■	■

2 SECTION B: COLLABORATION AND SUPPORT ACTIVITIES

2.1 Teaching support (second year)

- **Teaching Assistant** to Prof. Luca Persia, Road Safety (Graduate), Sapieza Università di Roma, Italy, Spring 2020. Lectures:
    - **Exercises 1:** Road accident data analysis
    - **Exercises 2:** Road accident data descriptive analysis
    - **Exercises 3:** Analysis of a high crash intersection
    - **Module 1.3:** Main factors affecting probability of accidents and injuries
    - **Module 1.4:** The five pillars of road safety
    - **Module 5.4:** Road Assessment Programs (RAP)

- **Teaching Assistant** to Prof. Luca Persia, Transport Policies (Graduate), Sapieza Università di Roma, Italy, Spring 2020. Lectures:
    - **Module 3.1d:** Classification of transport policies: Dissemination of information
    - **Module 3.1e:** Classification of transport policies: Infrastructural measures
    - **Module 3.1f:** Classification of transport policies: Infrastructure management

2.2 Collaboration with research and projects (second year)

Italian National Road Safety Plan – Horizon 2030
Sep. 2020- current
Road Safety Specialist
The study seeks to prepare the National Road Safety Plan of Italy for the decade 2021-2030. Based on the results of the National Road Safety Plan Horizon 2020 and the policy orientations on road safety of the European Commission, the objective is to review and update the strategies and objectives in terms of road safety at the national level with a long-term horizon.
Funding entity: Ministry of Infrastructure and Transport of Italy.
Duration: Sep. 2020-Dec. 2020

Study on the Implications of the African Continental Free Trade Area for Demand of Transport Infrastructure and Services
Jun. 2020- current
Transport Modeller
The objectives of the project are: Forecast of demand for different modes of transport as a result of AfCFTA; estimates of infrastructure investment requirements for different modes of transport; estimates of the impact of improvements in transport infrastructure and services on the volume of intra-African trade; and forecast of the demand of equipment for

different modes of transport - road (trucks), railway (rolling stock), air (aircraft), and maritime (ships).
Funding entity: United Nations Economic Commission for Africa (UNECA).
Duration: Jun. 2020-Mar. 2021

Mobility Management and Optimization Plan for the Regional Road Network Managed by ASTRAL
Mar. 2020- current
Transport Engineer
The project seeks to design and develop procedures that are capable of defining: a supply model (transport characterization of the geo-referenced road graph), representative of the main road network of Lazio; a mobility demand model, with reference to the zoning level defined for the Lazio road network; a reconstruction of the O / D matrix and calibration of the transport model through the interrelation between supply and demand; a hierarchical classification of roads and sections in relation to their functional importance and service level; creation of specific integrated software for data transformation and simulation, with map representations of dedicated layers and graphs for the representation of all the different analyzes and related results of the project.
Funding entity: Azienda Strade Lazio (ASTRAL).
Duration: Mar. 2020-Feb. 2021

ESRA
Sep. 2019- current
Researcher
E-Survey of Road user's Attitudes. Aim of the project is to provide scientific support to road safety policy making at the national and international levels. By using a uniform sampling method and an identical questionnaire, comparability of results across all participating countries is assured.
Funding entity: Joint international initiative of research organizations and road safety institutes.
Duration: Jun. 2015-current

Pilot Study to Collect More Robust Accident Data for Sierra Leone
Jan. 2020- Mar. 2020
Road Safety Engineer
The study aims to set up a methodology for road traffic crash data collection using sample data on a pilot basis, and to develop and implement an electronic data management system for road traffic crash data storage, analysis and retrieval for Low Volume Roads.
Funding entity: ReCAP – Ukaid.
Duration: Feb. 2018-Aug. 2018 / Jan. 2020 – Mar. 2020

3 SECTION C: INFORMATION

3.1 Information

1) Scholarship holder provided by Sapienza - University of Rome…..…YES ☑ NO
2) Nationality………………………………………………………….COLOMBIAN
3) Doctorate in co-tutorship…………………………………………...YES NO ☑
   (if yes, indicate the co-author)
4) Double degree doctorate……………………………………………YES NO ☑
5) Scholarship with external funding……………………………………..YES NO ☑
6) University of origin…………………..UNIVERSIDAD DE IBAGUÉ, COLOMBIA
7) Number of monthly research fees spent in a foreign research facility…………NONE
8) Funding within international research training networks……………....YES NO ☑
9) Publications and other products of the last 3 years

Below are the publications, in the framework of the research work developed within this first and second year:

3.1.1 Journal Publications

1. **González-Hernández, B.,** Usami, D. S., Prasolenko, O., Burko, D., Galkin, A., Lobashov, O., & Persia, L. (2020). The driver's visual perception research to analyze pedestrian safety at twilight. *Transportation Research Procedia*, 45, 827-834.

2. **González-Hernández, B.,** Llopis-Castelló, D., & García, A. (2020). Operating speed models for heavy vehicles on tangents of two-lane rural roads. *Advances in Transportation Studies*, 50, 5-18.

3. Persia, L., **González-Hernandez, B.**, Carroccia, R., Saporito, M. R. and Shingo Usami, D. (2019). Lo sviluppo dei sistemi di trasporto stradale e dell'incidentalità nei paesi a basso e medio reddito [Development of road transport systems and road traffic crashes rates in developing countries]. *Methodology & Education for Clinical Innovation*, 27(2), 81-87.

4. Llopis-Castelló, D., **González-Hernández, B.**, Pérez-Zuriaga, A.M., & García, A. (2018). Speed prediction models for trucks on horizontal curves of two-lane rural roads. *Transportation Research Record*, 2672(17), 72-82.

3.1.2 Conference Papers

1. **González-Hernández, B.,** Usami, D. S., & Persia, L. (2020). Road safety issues addressed by Africa Road Safety Plan: Are still relevant? *World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium-WMCAUS,* Prague. September 1-5, 2020.

2. Usami, D.S., **González-Hernández, B.,** Persia, L., Kunsoa, N. B., Meta, E., Saporito, M. R., Schermers, G., Carnis, L., Yerpez, J., Bouhamed, N., Cardoso, J., Kluppels, L., & Vandemeulebroek, F. (2020). Defining suitable Safe System Projects in Africa. *World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium-WMCAUS,* Prague. September 1-5, 2020.

3. **González-Hernández, B.**, Meta, E., Persia, L., Usami, D.S., & Cardoso, J. Identifying barriers to the potential implementation of road safety good practices in Africa. *99th Annual Meeting of Transportation Research Board*, Washington, DC. January 12-16, 2020.

4. Usami, D.S., Kunsoa, N. B., Persia, L., **González-Hernández, B.**, Meta, E., Saporito, M. R., Schermers, G., Carnis, L., Yerpez, J., Bouhamed, N., Cardoso, J., Kluppels, L., & Vandemeulebroek, F. Developing Safe System Projects in Africa. *26th World Road Congress - PIARC*, Abu Dhabi, UAE. October 6-10, 2019.

5. **González-Hernández, B.**, Llopis-Castelló, D. & García, A. Operating Speed models for heavy vehicles on tangents of Spanish two-lane rural roads. *98th Annual Meeting of Transportation Research Board*, Washington, DC. January 13-17, 2019.

6. Llopis-Castelló, D., **González-Hernández, B.**, Pérez-Zuriaga, A.M. & García, A. Speed prediction models for trucks on horizontal curves of two-lane rural roads. *97th Annual Meeting of Transportation Research Board*, Washington, DC. January 7-11, 2018.

3.1.3 Books and chapters

1. Sicurezza dei Trasporto Stradale. Sistemi Informativi di Supporto (*Safety in Road Transport. Support Information Systems*) (2019). Chapter authors: Persia, L., & **González-Hernández, B.** In Sicurezza nei Trasporti. Teoria e gestione (*Safety in Transportation. Theory and management*). Editor(s): Malavasi, G. Egaf Edizioni. ISBN: 978-88-8482-971-9.

3.1.4 Technical Reports

2020

1. Robibaro M., **González-Hernández B.**, Usami D.S., Centro di ricerca per il Trasporto e la Logistica - FRED Engineering S.r.l. *Pilot study to collect more robust accident data for Sierra Leone, Training Report, SLE2129A*. London: ReCAP for DFID.

2019

1. Usami, D. S., & **González-Hernández, B.** Deliverable 8.15: Report about Crowdsourcing on road safety in Africa. *SaferAfrica project.*

2. Deliverable 7.8: Identification of potential local projects. Welsh, R., Kourantidis, K., Cardoso, J., Meta, E., & **González-Hernández, B.** *SaferAfrica project.*

3. Meta, E., Usami, D. S., **González-Hernández, B.**, Kluppels, L., Viera-Gomes, S., Nkeng, G. E., & Wounba, F. Deliverable 6.5: Report on twinning program in Cameroon. *SaferAfrica project.*

4. Fava, A. & **González-Hernández, B.** Deliverable 2.7: Network expansion report 2. *SaferAfrica project.*

5. Goldenbeld, C., Kluppels, L., Carnis, L., Cardoso, J., **González-Hernández, B.**, Mignot, D., Usami, D. S., & Schermers, G. Deliverable 3.3: Road Safety and Traffic Management Initiatives. *SaferAfrica project.*

6. Fava, A. & **González-Hernández, B**. Deliverable 2.5: Activities Report 4. *SaferAfrica project.*

7. Tripodi, A., **González-Hernández, B.** & Shevchenko, A. Final Report. *Development of a new simplified methodology for road infrastructures' safety assessment based on the automated analysis of video images.*

8. Goldenbeld, C., Carnis, L., Kluppels, L., Usami, D. S., **González-Hernández, B.**, & Schermers, G. Deliverable 3.2: Road Safety Policy Initiatives. *SaferAfrica project.*

9. **González-Hernández, B**. Deliverable 8.13: Report about Crowdsourcing - SaferAfrica Webinars.

10. Meta, E., **González-Hernández, B.**, Cardoso, J. & Welsh, R. Deliverable 7.2: Transferability Audit. *SaferAfrica project.*

2018

1. Usami, D.S. & **González-Hernández, B**. Deliverable 2.3: Activities Report 2. SaferAfrica project.

3.1.5 Invited Presentations

1. Simplified Road Safety Methodology for Infrastructure Risk Assessment. *2nd Annual Training Seminar on SmaLog Issues*, Lviv, Ukraine. July 30-31, 2019.

2. Results of Risks Assessment on National Highways in Liberia. *Workshop and Training on road safety risk assessment tool*, Monrovia, Liberia. May 24, 2019.

3. Results of Risks Assessment on National Highways in Mozambique. *Workshop and Training on road safety risk assessment tool*, Maputo, Mozambique. May 21, 2019.

4. Modal Choice in a Multimodal Transport System. *Research Center for Transport and Logistics (CTL) Workshop*, Rome, Italy. May 15, 2019.

5. WP6: Capacity building. Task 6.4 Twining project. *EU project SaferAfrica meeting*, Brussels, Belgium. May 3-4, 2019.

6. WP3: Fostering dialogue on road safety and traffic management - Task 3.2 and 3.3 in Central Africa. *EU project SaferAfrica meeting*, Brussels. Belgium. February 12-13, 2019.

3.1.6 Refereeing

- **Journal Peer Reviewer**, Transportation Research Record (TRR); Advances in Transportation Studies (ATS)
- **Conference Peer Reviewer**, Transportation Research Board (TRB)
- **Reviewer**, Drive to the Future project's deliverables

4 LITERATURE REVIEW

4.1 Road Safety

Road safety is one of the most critical problems of human life. In fact, around 1.35 million people die and 50 million are injured in road crashes every year (World Health Organization, 2018). Road traffic crashes are estimated to be the ninth leading cause of death and projections reveal that it will be the third leading cause of death by 2020 (Peden et al., 2004).

Road traffic crashes (RTCs) in the Member States of the European Union claim about 25.600 lives and leave more than 1,4 million people injured in 2016 (European Commission, 2018). In addition, 90% of the related deaths resulting from road traffic crashes (RTCs) occur in Low- and Middle-Income Countries (LMICs) (World Health Organization, 2018). At the same time, LMIC's have not fully established crash databases reducing their ability to identify and measure road safety problems (World Road Association, 2015). Indeed, the fewer the accident data, the less the information accidents can give about accidents to be prevented (Montella, 2005).

Besides the human live cost, economic consequences are also very important. The cost associated with deaths and injuries is estimated to be in the range between 1.3 and 3.2% of the Gross Domestic Product (GDP) per annum for many countries (Elvik, 2000). The socio-economic costs of road crashes for the European Union are estimated at least above EUR 500 billion 3% of the EU's GDP. Most of these costs are related to serious injuries (OECD/ITF, 2018). To this regard, traffic accident prevention has been a consensus all the time around the World and in the last several years a large amount of money has been spent on traffic accident prevention. Reduction of social and economic costs also associated with accidents and collisions in road transportation (Hasmukhrai, Ganeshbabu, & Gundaliya, 2016).

Kopits & Cropper (2003) observed an inverse U-shaped relationship between the capita GDP and road fatality. Thus, road fatality firstly increases as the economy of a country does, and therefore decreases when the country becomes developed. The initial growth may be due to the rapid mobility increase of the country, not in accordance to the road safety knowledge development. This is typical for developing countries. Developed countries have better vehicles, infrastructure, knowledge and higher mobility, so the road safety rate decreases again. This problem reveals as very important if we consider that the number of developing countries is about to increase during the incoming years.

An accident is defined as an unforeseeable event that alters normal behavior of things and causes some damage. Thus, a road accident can be defined as an accident in which a moving vehicle is implied and takes place in the public road network. Accidents are not completely random. Thus, it is necessary to know and understand their causes, circumstances and consequences in order to be able to prevent them or, at least, reduce their severity.

Accidents can be classified considering several factors, but the most common are severity and typology.

According to the damage caused to the people implied in a road accident, victims can be classified as:

- Fatality. Person who dies instantly or within 30 days after the road accident takes place.
- Injury victim. Person who has been injured as a result of the road accident, but not resulting in a fatality. We distinguish two types:
  - Severe injury. Injury victim who needs to be hospitalized more than 24 h due to the road accident.
  - Slight injury. Victim who needs to be hospitalized less than 24 h.

The severity of a road accident is determined as the highest severity level of the people implied. Therefore, road accidents can be classified as:

- Accident with victims. Accident with at least one victim.
- Fatal accident. Accident with at least one fatality.
- Property Damage Only Accident. Accident with no victims.

The severity of an accident is influenced by several factors, such as the type or road users, the collision angle and the speed of the vehicles (Laureshyn, Svensson, & Hydén, 2010).

Road accidents can also be classified according to their typology:

- Run off the road accident. The vehicle abandons the platform. The severity of the accident is highly dependent on the roadside configuration. This is normally a single-vehicle accident.
- Rear end accident. At least two vehicles are involved, depending this number on the traffic conditions. The vehicles drive in the same direction and collide because of the speed dispersion. This accident is very frequent in low-light conditions, traffic congestion or sudden speed reduction of the preceding vehicle.
- Head-on accident. Two vehicles driving in opposite directions collide. The cause of the accident might be diverse. The severity of this accident is normally maximum, due to the relative speed difference.
- Lateral accident. This accident normally takes place at intersections or curves. Two vehicles who drive in different (not opposite) directions collide. Its severity will be determined by the energy dissipated in the collision, as well as the vehicles type and location of the impact.

A collision implies a sudden kinetic energy release, causing a deformation of the vehicle(s). Kinetic energy (E_k) is determined, depending on the mass (m) of the object and its speed (v), according to Equation (1).

$$E_k = \frac{1}{2} \cdot m \cdot v^2 \qquad (1)$$

Rear-end collisions usually present low severity, since the relative speed differential is low. On the other hand, head on accidents present the highest relative speed difference, and therefore the highest severity.

4.1.1 Concurrent factors

A road traffic crash results from a combination of several factors, in particular, the accident risk, in terms of repeatability, localization, and severity, is related to three concurrent factors: infrastructure, vehicle, and human factors (Elvik, Vaa, Hoye, & Sorensen, 2009). Other researchers distinguish other two of less importance factors: Traffic and environmental.

- Infrastructure factor. This factor is related to road design. Road infrastructure must be designed according to drivers' expectations. The zones that not meet the aforementioned condition might present higher crash rates. Some researchers estimate that this factor is behind over 30% of road accidents, on its own or combined with human factor. Hence the importance of its consideration and correct treatment (Treat et al., 1979).
- Human factor. This is the most important concurrent factor, since it is estimated to be behind over 90% of all road accidents. This factor focuses on the human being, analyzing both its physical and psychical aspects while performing the driving task. Its interaction with the infrastructure factor reveals as very important too.
- Vehicle factor. It focuses on how the vehicle can be involved in the generation of an accident. It gathers all possible issues with vehicle malfunctions, low maintenance issues, etc. As the technology develops, this factor reveals as less important.
- Traffic factor. This is a less important factor than the previous three. Traffic conditions do also have an effect on road crashes. One example is how the accident type changes depending on the different traffic states (congested or free-flow conditions).
- Environmental factor. This is not an important concurrent factor too. It includes all external factors that may affect the likelihood of having an accident. One example is weather conditions.

Depending on the factors involved in a road accident, very different solutions may arise. For instance, some problems related to human factor like drunk driving can be treated with psychological actions. On the other hand, consistency-related issues should be addressed through a road redesign. Industrial engineering deals with the vehicle factor. In addition, in most cases a road accident can be explained through the combination of several concurrent factors. Hence the importance of multidisciplinary teams to understand road safety. Figure 3 1 shows the three most important concurrent factors, as well as their relative importance to road accident likelihood. These factors are also related to the accident severity.

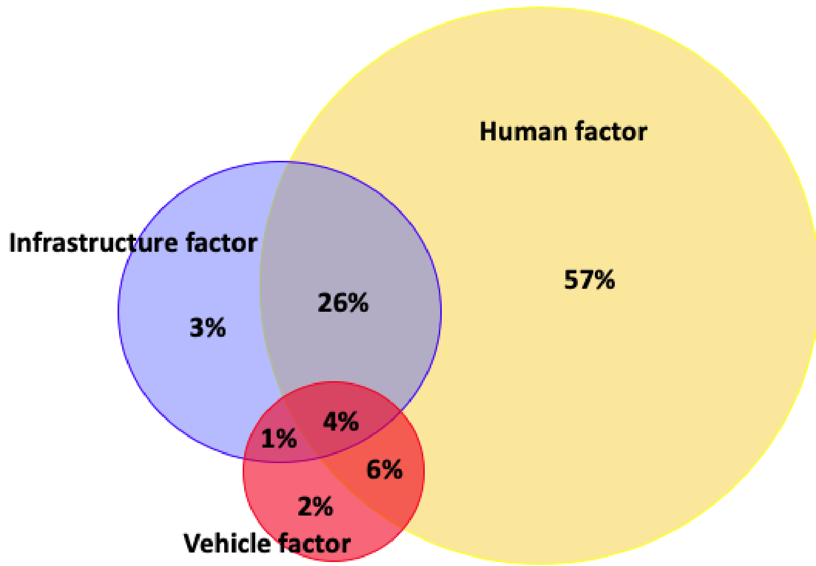


Figure 4-1 Road Safety main concurrent factors (adapted from Elvik et al. 2009).

4.1.1.1 Infrastructure factor

Infrastructure plays a major role in accident causation. In fact, this is why accidents tend to concentrate in certain locations, instead of dispersing randomly through the road network.

Most research focus on the horizontal alignment. Complex alignments are normally related to higher accident rates. Shankar, Mannering, & Barfield (1996) found that the increased number of horizontal curves per kilometer increased the severity of the accidents. Milton & Mannering (1998) found that short road sections were less likely to experience accidents than longer sections.

Some other researchers found that a higher curvature is linked to a lower accident rate, which is counter-intuitive (Wang, Quddus, & Ison, 2012). However, this might be because of the way the curvature was analyzed in that research. The difficulty at analyzing the paper of the road infrastructure on crashes is that it is normally linked to the human factor. This is why sometimes road users drive more carefully at more complex alignments.

Some of the most important aspects related to the infrastructure factor are:

- Road type and design-related parameters (design speed, etc.).
- Horizontal alignment.
- Vertical alignment.
- Combined horizontal and vertical alignment, paying special attention to sight distance and road perception.
- Cross-sectional parameters. Particularly important are the lane and shoulder widths, since they are highly connected to operating speed.
- Road margins.
- Road marking and signs.
- Pavement conditions.

4.1.1.2 Human factor

Human factor considers the issues related to driver reactions and behavior. This factor is highly related to human psychology, perception, reaction and learning processes. This is a complex area, so there exist several theories that try to explain them. These theories allow researchers to detect which level is more likely to be the cause of a road accident, and hence actuate on it.

Each driver presents different characteristics, abilities and limitations. They are also influenced by their particular circumstances, which may be related to the environment or not. Environment conditions affect all drivers at the same level, whereas personal circumstances obviously not. Some examples of environment-related circumstances are weather conditions, urban planning, orography, light conditions and more. Some driver-related circumstances are stress level, fatigue or alcohol consumption.

Hence, all those circumstances result in a high variability of the responses for the same road layout. This is the reason why the human-road interaction has to be deeply analyzed. This would allow engineers to design safer roads for everybody, foreseeing drivers' reactions.

4.1.1.3 Vehicle factor

This factor becomes less and less important in developed countries, due to the technological development of vehicles. In fact, vehicle related accidents are mostly due to a poor maintenance, punctures, blowouts, etc. Nevertheless, it remains as a very important contributing factor in developing countries, since passive and active safety measures are not embedded in their vehicles.

4.1.1.4 Traffic factor

Accidents occur when traffic moves. These traffic characteristics affect road safety through both engineering and behavioral effects. We can distinguish four traffic related parameters: speed, traffic flow, density and congestion (Wang et al., 2012).

It seems clear that the speed has an influence on road safety. A higher speed implies more kinetic energy, more distance travelled during the perception and reaction time, and a narrower vision field. The higher kinetic energy implies a higher severity once the accident has occurred. However, it is not clear how the speed affects the probability of having an accident.

The extreme variability between operating speed and crash rates can be explained through the driver-road interaction. From a physical point of view, a higher speed is linked to a higher accident risk: there is less time to react, the vision field is reduced, and maneuvers take more distance to be completed. However, the human factor compensates this, increasing the attention level and the workload demand. They also are more aware of the surrounding traffic and leave more distance from the preceding vehicle. The infrastructure effect is not negligible: the roads with higher design standards are normally those which present higher speeds.

Although it is not clear whether the average operating speed plays an important role on the generation of road accidents, it seems clearer that the operating speed dispersion does. A higher operating speed dispersion implies more interactions between vehicles, increasing the probability of having a crash.

Traffic volume is also related to accidents, especially to accident type. As it will be later indicated, exposure plays a major role in accident estimation. Ceder & Livneh (1982) analyzed crash rates for different traffic conditions and found that single and multiple crash rates behaved in different ways according to the traffic conditions.

Himes, Donnell, & Porter (2010) examined the influence of the hourly traffic volume on the mean speed and its dispersion. They examined 79 sites of 8 roads in Pennsylvania and Virginia, finding that the hourly traffic volume was strongly correlated to the speed dispersion. An increase of 100 vph is associated with a decrease in speed deviation by 1.2 mph. Therefore, a higher traffic volume was found to produce a more uniform flow.

The effect of traffic density on road safety still remains almost unknown. The reason can be the difficulty of accurately estimating traffic density. Ivan, Wang, & Bernardo (2000) noticed that single-vehicle accident rate increased as the ratio volume/capacity did, following a negative binomial distribution. The accident rate was the highest at a low volume/capacity ratio.

The proportion of heavy traffic also affects crash rates. One of the underlying reasons is the higher speed dispersion, as well as the more amount of passing maneuvers, being a higher conflict exposure to head-on crashes.

4.1.1.5 Environment factor

The environment factor covers some other aspects not considered previously, such as weather conditions, urban planning development, orography, etc. The affection is mostly due to an impairment by drivers (for instance, sun glares or low visibility).

Shankar et al. (1996) found that rain may increase the possibility of injury rear-end crashes, if compared with PDO crashes. Abdel-Aty (2003) found that darker periods often lead to a higher accident severity.

4.1.2 Road Safety theories

Road safety theories try to determine why an accident has occurred. The better knowledge about the underlying phenomena would let researchers and practitioners to develop more suitable methods and policies for improving safety.

Figure 4-2 represents the most basic approach to understand how a road safety measure influences the final outcome of road accidents. A certain road safety measure affects several risk factors, producing a change in the final outcome, in terms of number of accidents or their severity.

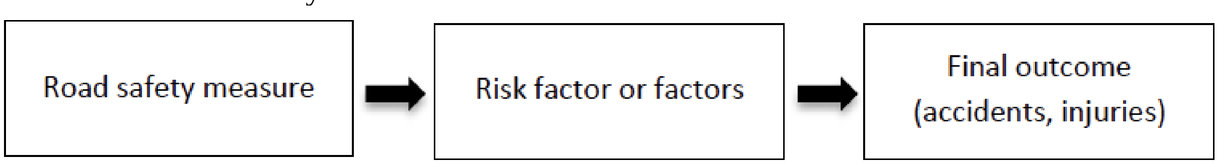


Figure 4-2 Influence of a road safety measure (Elvik, 2004).

This simple model presents three important problems:

- The number of risk factors that should be considered is very large. Some of them remain even unknown or unmeasurable.
- Many of the road safety evaluation studies do not clearly identify and/or measure the risk factors influenced by the countermeasure.

- Some road safety measures present user behavioral adaptation, i.e., users get adapted to the countermeasure by changing their attitudes and behavior. Thus, the safety measure could indeed be counter-productive.

Evans (1991) suggested a two casual chain model that includes this phenomenon (Figure 4-3).

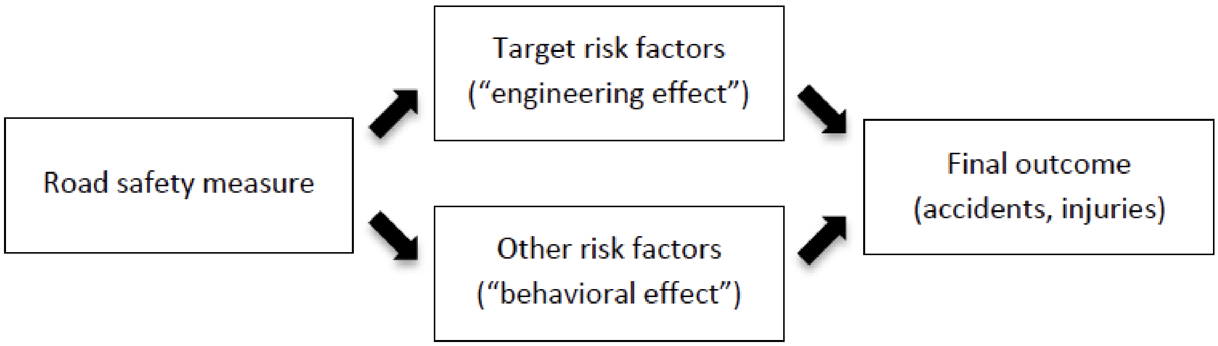


Figure 4-3 Casual chain model (Evans, 1991).

This duality is the reason why road safety lacks of a solid theoretical ground, on the contrary to several other mature disciplines (Wang et al., 2012). Instead, there exist some groups of theories that try to explain the user-road-crashes interaction. We can distinguish two ways of approaching to road safety:

- By means of the infrastructure factor. Several objective relationships can be established between some geometric or environmental parameters and road crashes.
- Analysis of the human factor. This approach cannot estimate the number of road accidents. Instead, a better knowledge of the process is achieved.

There are some other theories that try to combine the best part of both approaches. Some of them try to explain driver's attitudes and behavioral change after a certain countermeasure is applied. Some others establish a general framework for driver behavioral adaptation due to infrastructure changes.

Elvik (2004) proposed a conceptual framework based on Evans' model (Figure 4-3). He proposed the following risk factors to be considered, as well as the behavioral adaptation:

- Kinetic energy. This is not a risk factor per se, since it does not cause harm as long as it is controlled. If a collision takes place, this energy is released, affecting the severity.
- Friction. This factor is related to the control and stability of the vehicle.
- Visibility. The more sight distance, the more time drivers have to process the information, hence reducing the likelihood of surprises.
- Compatibility. It refers to the difference that exists between different types of vehicles in terms of speed, mass, performance, etc.
- Complexity. It refers to the amount of information that a user has to process per unit of time.

- Predictability. It denotes the reliability at which the occurrence of a risk factor can be predicted in a given situation.
- Individual rationality. Individual users normally try to behave looking for their maximum benefit, i.e., satisfying their preferences.
- Individual vulnerability. When an accident occurs, some individuals are more exposed than others.
- System forgiveness. Some elements of the road should be designed in order to prevent accidents or reduce their severity. Some examples are clear margins, rumble strips, road lighting, and others.

In order to prevent counterproductive responses, Amundsen & Bjørnskau (2003) suggested to analyze the following factors, which already include the behavioral adaptation effect:

- How easily a certain countermeasure is noticed. Drivers are continuously scanning the road. When they notice a safety countermeasure, behavioral adaptation might occur. Thus, the best solution is to act without leaving them to know (obviously, this is not always possible).
- Historical antecedent of behavioral adaptation to basic risk factors. There is a higher probability of behavioral adaptation if it already took place before.
- Size of the engineering effect on generic risk factors. Large changes are more likely to be noticed by users.
- Whether or not a measure primarily reduces injury severity. Measures that reduce injury severity are less likely to lead to behavioral adaptation than measures that mostly act on reducing the likelihood of an accident.
- The likely size of the material damage incurred in an accident. Road users prefer the material damage in an accident to be as small as possible.
- Whether or not additional utility can be gained. Users try to maximize utility of the trip. For some road safety measures, it is difficult to see how road users could gain any benefit by changing their behavior.

Considering all these parameters, Elvik (2006) proposed a revised causal chain model that incorporated the relationships between road safety measures and driver behavior, through behavioral adaptation (Figure 4-4). The result is termed as behavioral safety margin, indicating how road users assess their safety margin when travelling.

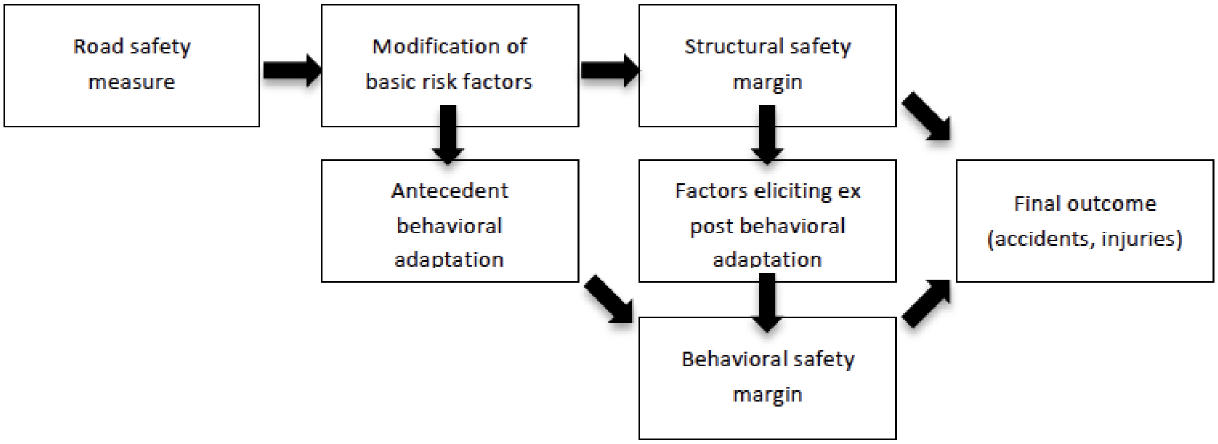


Figure 4-4 Elvik's revised casual chain model.

According to Elvik (2006), accidents may be explained according to a few general statistical regularities that determine the relationship between risk factors and accident occurrence. These regularities are called "laws of accident causation". He proposed the following laws:

- Universal law of learning. The ability to foresee undesirable traffic situations increases uniformly as the amount of travel (or conflicts) increases. This law also implies that the accident rate per unit of exposure decreases as the exposure increases.
- The law of rare events. The rarer a certain risk factor is encountered, the larger its effect results on accident rate. Moreover, its rareness makes this event more difficult to be learnt.
- The law of complexity. The more information rates the road user must attend to, the higher the probability of committing an error.
- The law of cognitive capacity. As the cognitive capacity of a road user approaches to their limits, the higher the probability of having an accident.

4.1.3 Statistical methods to estimate and assess road safety

There exist some specific tools for estimating or analyzing crashes. Some of them allow the designers to estimate the number of accidents depending on some factors. Some others are useful for determining whether a road countermeasure has been effective or not.

4.1.3.1 Safety Performance Functions

A Safety Performance Function (SPF) is an expression that allows us to estimate the number of crashes in a certain roadway entity depending on some factors. The factors include some design and/or environmental features, as well as the exposure. The exposure may have an influence on the output or not. Those functions are normally calibrated considering a Negative Binomial distribution.

Their common functional form is shown in Equation (2) (intersections) and Equation (3) (road segments). AADT and length are normally given in vpd and km, respectively.

$$\lambda_i = E(y_i) = \beta_0 \cdot AADT_i^{\beta_1} \cdot e^{\sum_{j=2}^{k} \beta_j \cdot X_{ij}} \qquad (2)$$

$$\lambda_i = E(y_i) = \beta_0 \cdot AADT_i^{\beta_1} \cdot L_i^{\beta_2} \cdot e^{\sum_{j=2}^{k} \beta_j \cdot X_{ij}} \quad (3)$$

X_{ij} represents the different parameters that are considered by the SPF, while β_{ij} are the corresponding estimates. The exposure is normally introduced in terms of elasticity. This is the functional form that produces the best adjustments (Oh et al., 2003).

The exposure is very important in those models. In fact, it explains most of the accident variability. However, the way to consider it has been very controversial. Some researchers support that the exposure does not affect the crash generation process, and so assuming $\beta_1 = \beta_2 = 1$. In recent years, most researchers assume that the AADT has a true effect on how accidents are generating, thus not enforcing $\beta_1 = 1$.

According to the AADT estimate, there are four possibilities:

- $\beta_1 = 0$. The number of crashes is not influenced by the traffic volume. Obviously, this is not true.
- $\beta_1 = 1$. The crash rate is the same regardless of the traffic volume. The number of crashes is proportional to AADT.
- $\beta_1 > 1$. The crash rate becomes higher as the traffic increases.
- $\beta_1 < 1$. The crash rate becomes lower as the traffic volume increases. This is the most common outcome for the AADT estimate, according to most safety performance functions.

The consideration of the segment length has remained more controversial. Some researchers include it in the analysis, obtaining a calibrated estimate. Some others do not, fixing it to 1 but performing a negative binomial regression, which may also be correct. In the last case, researchers assume that the road segment length does not have an influence on the crash rate. Some researchers indicate that it behaves in the opposite direction than AADT: a longer road segment leads to a higher crash rate. Some others, like Miaou, Song, & Mallick (2003) and Lord, Manar, & Vizioli (2005) affirm that road length does not affect crash rates.

Obviously, the length of the road segment might only be relevant if homogeneous road segments are considered. Thus, road segmentation becomes a very important issue. (Resende & Benekohal, 1997) indicated that only homogeneous road segments should be considered, based on traffic flow and geometric characteristics.

4.1.3.2 Before/After studies

Before/After studies are widely considered to be the most appropriate method to execute the evaluation of the effectiveness of traffic safety measures (De Pauw, Daniels, Brijs, Wets, & Hermans, 2013). It consists on comparing the number of accidents before and after the application of the countermeasure.

Although this may seem a simple approach, there are some problems due to the nature of road accidents. De Pauw et al. (2013) distinguished the following issues:

- Regression to the mean.
- Long-term trends affecting the number of crashes or injured road users.
- General changes in the number of crashes.
- Changes in traffic volumes.

- Any other specific events introduced at the same time as the road safety measure.

Due to the high variability of road crashes, the actual number of accidents at a certain location can never be known. However, the more years of data we have, the more precision about the outcome. When comparing the number of accidents before and after a countermeasure has been applied, at least 3-5 years before and after are suggested to use. Figure 4-5 shows how the accident randomness affects the results.

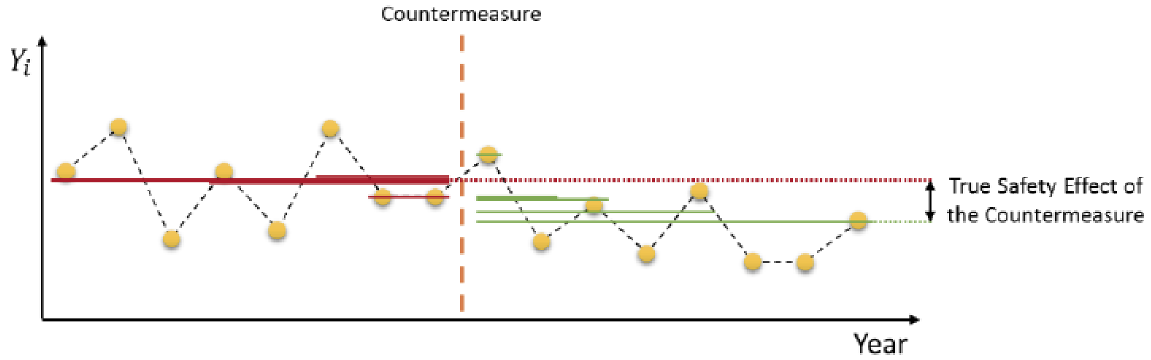


Figure 4-5 Variation of the estimated before/after effect depending on the number of years considered.

Several researchers have stated that the distribution of the expected mean of a Poisson-distributed count parameter follows a Gamma distribution. Considering this assumption, we cannot perfectly estimate the expected number of accidents, but we can determine a range that includes it with a certain probability.

According to it, we can use the properties of the Gamma distribution to estimate the range within the actual expected number of accidents is located. Figure 4-6 represents the variation of the lower and upper bound of the range for an estimation of three crashes/year. One can notice how the uncertainty is extreme for 1-2 years, but it is quite stable for more than 5 years. This is why at least 3 to 5 years are recommended to be used for before/after analyses. This is due to the Regression to the Mean (RTM) bias (De Pauw et al., 2013). If short periods of time are considered, the Empirical Bayes Method is suggested as a good tool to reduce this bias. If long periods of time are considered, there is no need to use an additional technique.

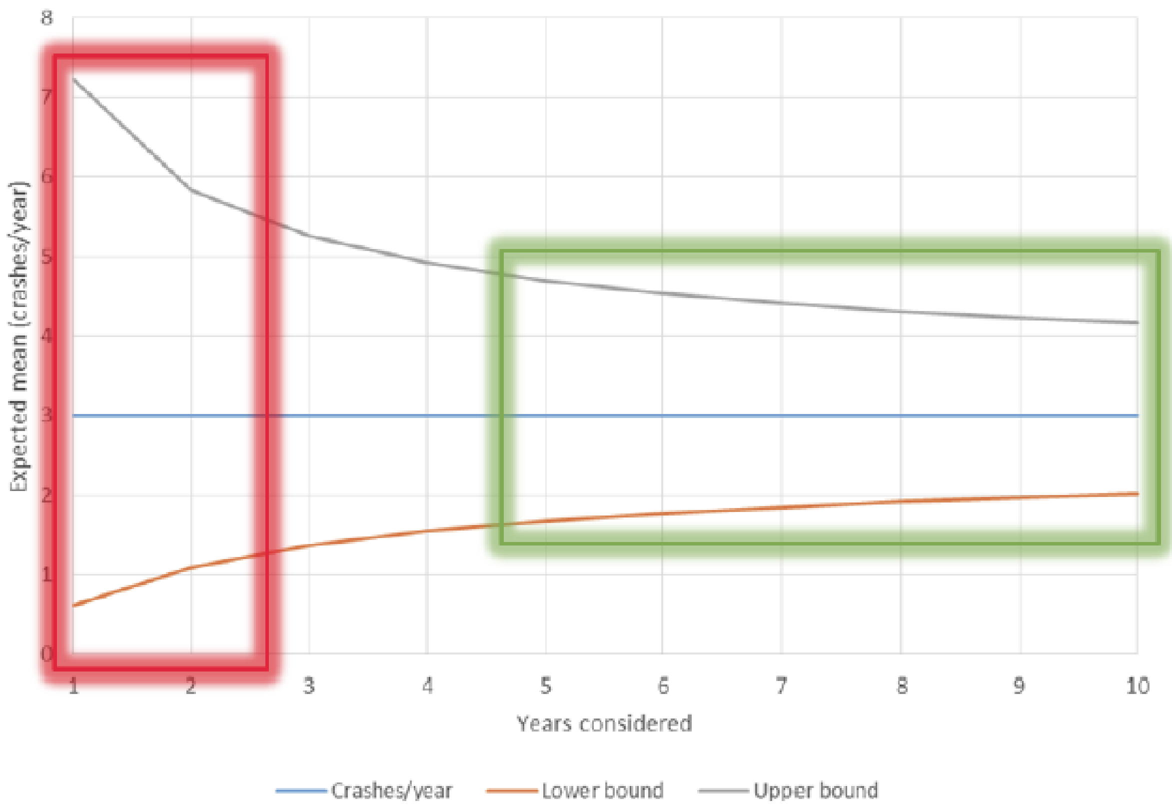


Figure 4-6 Confidence intervals for a gamma distribution depending on the number of years considered.

The accident outcome after the application of the countermeasure can also be affected by some other factors. Some examples are social awareness, traffic volume variations, etc. Those factors cannot be directly measured but they do exist. Thus, the effect of those other factors should be deducted in order to estimate the actual effect of the safety measure. We can do this by examining the crash variation in a control group. A control group is a set of similar roadway entities in which the countermeasure has not been applied. Thus, the variation of the number of crashes is only due to these general factors. Their comparison will let us to determine the true effect of the countermeasure.

4.1.3.3 Crash Modification Factors

A Crash Modification Factor (CMF) is a coefficient that lets us rapidly estimate the variation of the crash outcome due to a certain countermeasure. Considering y_0 the initial number of accidents of the roadway entity i, the number of accidents after the countermeasure is applied (y_0) can be calculated as shown in Equation (4).

$$y_f = y_i \cdot CMF_{0 \to f} \tag{4}$$

$CMF_{0 \to f}$ is the crash modification factor that let us go from the initial to the final condition. Is worth pointing out that CMFs are normally not considered in terms of before-after situations, but referred to a base condition. The CMF is 1.0 for the base condition.

Some CMFs refer to all accidents, while others refer to a certain subgroup (type of accident or severity).

Crash modification factors are a very simple and powerful tool, but they have to be handled with care. They were calibrated based on several Before/After analysis, considering certain conditions, such as traffic volume, cross-section, visibility, etc. A variation of those parameters might affect the outcome of crashes. Therefore, CMFs should only be applied when these additional conditions are satisfied.

There are many situations in which more than one CMF needs to be used. This is not a problem, as long as all conditions are satisfied. The uncertainty about the outcome also increases, as further discussed. A general formulation is given in Equation (5) (Wu, Donnell, Himes, & Sasidharan, 2013). y_{rs} is the predicted number of crashes per year on a roadway element. y_{br} is the predicted number of crashes for the base conditions. CMF_j are all the crash modification factors to apply. Finally, C_r is a calibration factor for the highway element for local conditions.

$$y_{rs} = y_{br} \cdot C_r \cdot \prod_{j=1}^{n} CMF_j \qquad (5)$$

The calibration factor for local conditions covers social, climatic and other aspects that vary across regions and have a certain effect on the number of accidents.

Sometimes, the CMF is not a single value but a function (Crash Modification Function). They are basically managed in the same way as crash modification factors.

CMFs are normally calibrated considering several Before/After analyses. Thus, there exist a certain degree of uncertainty, which is reflected in the variance of the CMF. This allows us to get an idea about their performance and the validity of the outcome. Of course, the more CMFs we use in our analysis, the more uncertain the result becomes.

CMFs can be used together with safety performance functions for a better estimation of the number of crashes, according to the following steps:

1. Estimation of the number of accidents on a road geometric element for the base conditions. This can be done by means of a safety performance function (y_{br}).
2. Adjustment of the previous quantity for the local conditions, applying the CMFs and the geographical parameter (C_r). The estimated number of crashes is y_{rs}.
3. If some information about actual crashes is available, the Empirical Bayes method can be applied (further explained).

There are tons of crash modification factors available for designers. The AASTHO's Highway Safety Manual contains several of them, including their variance, accuracy and feasibility. All those CMFs covered by the part C of the Highway Safety Manual (HSM) present a standard error less than 0.1, whereas CMFs that appear on part D present a standard error lower than 0.3. To identify appropriate CMFs to be applied, a good database can be found on the web page: www.roadsafety-dss.eu. Finally, CMFs should be handled with care. No risk exposure is considered, as well as interaction among the different parameters is not covered.

4.1.3.4 Empirical Bayes Method

The Empirical Bayes Method assumes that accident counts are not the only clue to the safety of a roadway entity. The other clue is how similar roadway entities behave. For instance, if we know that a certain roundabout presents 0 accidents in a year, but on average roundabouts present 0.56 accidents in a year, it would not be correct to assume that our roundabout is completely safe. In the same way, we already know that our roundabout behaves slightly better than the average roundabout. Hence, the actual crash probability of our roundabout should be within those values.

According to (Hauer, Harwood, Council, & Griffith, 2002), the Empirical Bayes Method addresses two safety estimation issues:

- It increases the precision of estimates beyond what is possible when the available data is limited.
- It corrects the regression to the mean bias.

The Empirical Bayes Method considers both observed and estimated data. The expected number of accidents is calculated as shown in Equation (6).

$$E\left(\frac{\lambda}{r}\right) = \alpha \cdot \lambda + (1 - \alpha) \cdot r \qquad (6)$$

$E\left(\frac{\lambda}{r}\right)$ represents the estimated number of accidents. λ is the expected number of accidents, according to the SPF estimation. r is the observed number of accidents. α is a weight parameter, that gives more importance to the estimated or the observed accidents, according to the reliability of the SPF. This parameter is calculated as Equation (7) shows, being μ the over dispersion parameter of the SPF.

$$\alpha = \frac{1}{1+\lambda \cdot \mu} \qquad (7)$$

Depending on the over dispersion parameter of the safety performance function, the estimated number of accidents will be closer to the SPF estimation or the observed accidents (Figure 4-7).

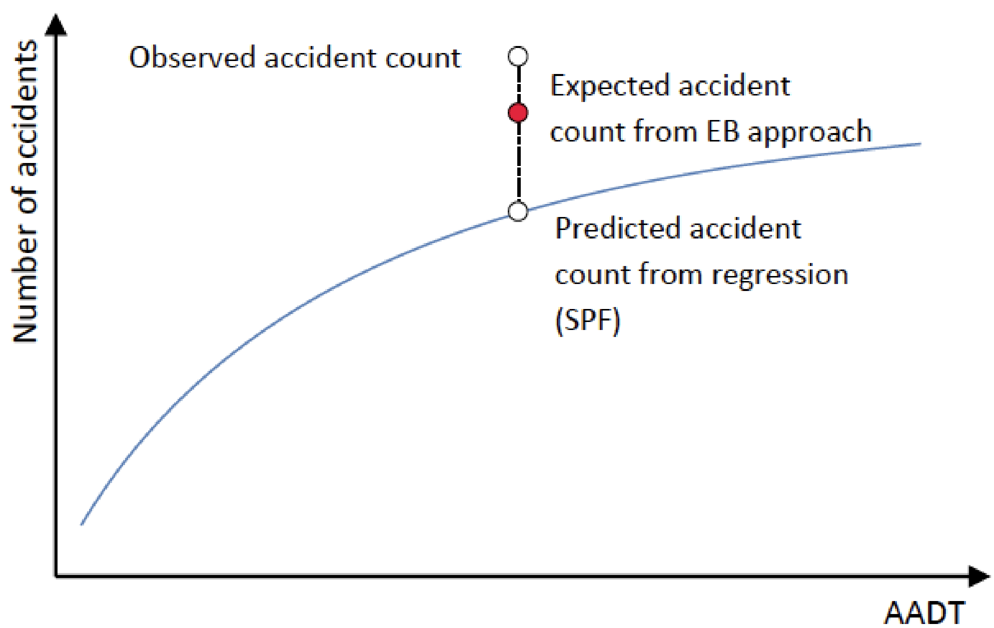


Figure 4-7 Graphical estimation of the expected accident through the EBM.

Harwood, Council, Hauer, Hughes, & Vogt (2000) recommend to apply the Empirical Bayes procedure in the following cases:

- For estimating the number of accidents for the "do-nothing" alternative.
- Projects where the roadway cross-section is changed but the basic number of lanes remains the same. This includes, for instance, shoulder or lane widening projects.
- Projects with minor changes in the alignment.
- Projects in which a passing lane or a short four-lane section is added to increase passing opportunities.
- Any combination of the above.

On the contrary, the Empirical Bayes procedure is not applicable in the following cases:

- Projects where there is an important change in the alignment layout.
- Intersections where the number of legs is changed.

4.2 Road Traffic Crashes data

Reliable and consistent road accident data are a valuable and necessary prerequisite for the support of decision making aimed at the improvement of road safety. Based on the report on Data Systems (World Health Organization, 2011), some steps are given in order to strengthen an existing road accident system or design and implement a new one. The basic targets are considered similar when designing a common data collection system based on the national existing ones. These steps are the following:

1. Establishing a working group, which will review and discuss the road safety goals set already by the national lead agency in terms of data requirements for monitoring and achieving each one.
2. Choosing a course of action, which is a range of strategies aiming to strengthen road safety systems depending on the different needs and characteristics of each region or country. The main strategies concern:
    - the improvement of data quality and system performance of road accident systems coming from police data
    - the improvement of health facility-based data on road injuries.
    - the improvement of the vital registration system and particularly the death registration system
    - the combination of existing data sources in order to obtain more accurate estimates on the magnitude and effects of road injuries
3. Defining the recommended minimum data elements and definitions, based on specific selection criteria.

The recommendation for a common accident data collection system consists of a minimum set of standardized data elements, which allows international comparisons to be made.

For the development of a common data collection system, a two-step approach is most commonly recommended:

a. improvement and harmonization of existing data and methods

b. collection of new harmonized data

The common dataset composed of minimum data elements (variables) will be a key tool for ensuring the appropriate data are captured to enable analysis, and for maximizing consistency and compatibility of data collected across different jurisdictions/ countries. Uniformity of accident data is especially important when combining sub-national datasets and for international comparisons.

4.2.1 Data definitions and standards

One of the greatest limitations when examining international comparisons of road accident figures is the incompatibility of data, which is due to either different collection procedures or different definitions of the variables and values used.

Concerning *road fatalities,* the uniform international definition of persons killed in road accidents is defined as "*the persons who died within 30 days from the day of the accident".* At present this definition is used by a number of developing countries and is suggested to be adopted by the remaining ones. On that purpose, some countries have to modify the data collection process and develop appropriate conversion factors, for the conversion of the number of road accident fatalities prior to the adoption of the common definition.

On the other hand, definitions of *injury severity* may present important differences among countries. Furthermore, the minimum injury for which an accident is recorded by the Police is different in each country. Especially, the distinction between seriously and slightly injured persons presents important differences among countries.

One of the main problems of each national road accident data file is that not all injury accidents are recorded. *Underreporting* is an issue of general concern in developing countries and affects the degree to which the statistical output of a country's data system reveals the actual situation of road safety. Thus, underreporting delivers a biased database in terms of fatalities and serious injuries. Road accident databases that link Police and hospital data may serve as a potential solution to the underreporting issue.

However, additional inaccuracies in reporting the various variables and values contained in the national road accident data collection form may exist. Such vagueness, which are inherent to the nature of these variables and values, result from the conditions under which the primary information is collected by the police officer as well as the way this information is filled-in later on. Such inaccuracies may also raise due to inadequate training of the Police force collecting the information.

Moreover, two main sources of data incompatibility can be identified and should be handled:

- incompatibilities due to missing or incomplete national definitions (e.g. for weather conditions)
- incompatibilities due to different definitions in different countries (e.g. for road types).

The establishment of international rules for road accident data variables, values, structure and definitions has been recommended by several international research projects and some efforts for harmonizing accident data at international level have already taken place (e.g. CARE system). The data structure, definitions and formats for the most common variables in road safety analyses is presented in the following sections.

However, it should be noted that when planning the introduction of new variables or modifying the existing ones, changes to the definitions and values of existing data elements should be minimized, as these can create problems with the consistency and comparability of data over time. On the other hand, if definition or data element changes are made, then the date of change should be clearly noted in official records, allowing for some misclassification during the transition period.

4.2.1.1 Accident data elements

The accident data elements describe the overall characteristics of the accident.

A1. Accident ID

Definition: The accident identification number is a number which will allow the accident record to be cross-referenced to road, traffic unit and person records. It consists of three distinct fields, the country code, the year and the accident number.
Obligation: Mandatory
Data type: Numeric or character string
Comments: This value is usually assigned by the police as they are responsible at the accident scene. Other systems may reference the incident using this number.

A2. Accident date

Definition: The date (day, month and year), on which the accident occurred.
Obligation: Mandatory
Data type: Numeric (DDMMYYYY)
Comments: If a part of the accident date is unknown, the respective places are filled in with 99 (for day and month). Absence of year should result in an edit check. Important for seasonal comparisons, time series analyses, management/administration, evaluation and linkage.

A3. Accident time

Definition: The time at which the accident occurred, using the 24 hour-clock format (00.00-23:59).
Obligation: Mandatory
Data type: Numeric (HH:MM)
Comments: Midnight is defined as 00:00 and represents the beginning of a new day. Variable allows for analyses of different time periods.

A4. Accident municipality and region

Definition: The municipality and county or equivalent entity in which the accident occurred.
Obligation: Mandatory
Data type: Character string
Comments: Important for analyses of local and regional programmes and critical for linkage of the accident file to other local/regional data files (hospital, roadway, etc.). Also important for inter-regional comparisons.

A5. Accident location

Definition: The exact location where the accident occurred. Optimum definition is route name and GPS/GIS coordinates if there is a linear referencing system (LRS), or other mechanism that can relate geographic coordinates to specific locations in road inventory and other files. The minimum requirement for documentation of accident location is the street name, the reference point, the distance from the reference point and direction from the reference point.
Obligation: Mandatory
Data type: Character string, to support latitude/longitude coordinates, linear referencing method, or link node system.
Comments: Critical for problem identification, prevention programmes, engineering evaluations, mapping and linkage purposes.

A6. Accident type
Definition: The accident type is characterized by the first injury or damage-producing event of the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Accident with a pedestrian: Accident between a vehicle and at least one pedestrian.
2. Accident with a parked vehicle: Accident between a moving vehicle and a parked vehicle. A vehicle with a driver that is just stopped is not considered as parked.
3. Accident with a fixed obstacle: Accident with a stationary object (i.e. tree, post, barrier, fence, etc.).
4. Non-fixed obstacle: Accident with a non-fixed object or lost load.
5. Animal: Accident between a moving vehicle and an animal.
6. Single vehicle accident /non-collision: Accident in which only one vehicle is involved and no object was hit. Includes vehicle leaving the road, vehicle rollover, cyclists falling etc.
7. Accident with two or more vehicles: Accident Accidents where two or more moving vehicles are involved.
8. Other accident: Other accident types not described above.

Comments: If the road accident includes more than one event, the first should be recorded, through this variable. If more than one value is applicable, only the one that corresponds best to the first event should be selected. Important for understanding accident causation, identifying accident avoidance countermeasures.

A7. Impact type
Definition: Indicates the manner in which the road motor vehicles involved initially collided with each other. The variable refers to the first impact of the accident, if that impact was between two road motor vehicles.
Obligation: Mandatory
Data type: Numeric
Data values:

1. No impact between motor vehicles: There was no impact between road motor vehicles. Refers to single vehicle accident, collisions with pedestrians, animals or objects.
2. Rear end impact: The front side of the first vehicle collided with the rear side of the second vehicle.
3. Head on impact: The front sides of both vehicles collided with each other.
4. Angle impact – same direction: Angle impact where the front of the first vehicle collides with the side of the second vehicle.
5. Angle impact – opposite direction: Angle impact where the front of the first vehicle collides with the side of the second vehicle.
6. Angle impact – right angle: Angle impact where the front of the first vehicle collides with the side of the second vehicle.
7. Angle impact – direction not specified: Angle impact where the front of the first vehicle collides with the side of the second vehicle.
8. Side by side impact – same direction: The vehicles collided side by side while travelling in the same direction.
9. Side by side impact – opposite direction: The vehicles collided side by side while travelling in opposite directions.
10. Rear to side impact: The rear end of the first vehicle collided with the side of the second vehicle.
11. Rear to rear impact: The rear ends of both vehicles collided with each other.

Comments: Useful for identifying structural defects in vehicles.

A8. Weather conditions

Definition: Prevailing atmospheric conditions at the accident location, at the time of the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Clear (No hindrance from weather, neither condensation nor intense movement of air. Clear and cloudy sky included)
2. Rain (heavy or light)
3. Fog, mist or smoke
4. Sleet, hail
5. Severe winds (Presence of winds deemed to have an adverse effect on driving conditions)
6. Other weather condition
7. Unknown weather condition

Comments: Allows for the identification of the impact of weather conditions on road safety. Important for engineering evaluations and prevention programmes.

A9. Light conditions
Definition: The level of natural and artificial light at the accident location, at the time of the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Daylight: Natural lighting during daytime.
2. Twilight: Natural lighting during dusk or dawn. Residual category covering cases where daylight conditions were very poor.
3. Darkness: No natural lighting, no artificial lighting
4. Dark with street lights unlit: Street lights exist at the accident location but are unlit.
5. Dark with street lights lit: Street lights exist at the accident location and are lit.
6. Unknown: Light conditions at time of accident are unknown.

Comments: Information about the presence of lighting is an important element in analysis of spot location or in network analysis. Additionally, important for determining the effects of road illumination on night-time accident accidents to guide relevant future measures.

4.2.1.2 Accident data elements derived from collected data

AD1. Accident severity
Definition: Describes the severity of the road accident, based on the most severe injury of any person involved.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Fatal: At least one person was killed immediately or died within 30 days as a result of the road accident.
2. Serious/severe injury: At least one person was hospitalized for at least 24 hours because of injuries sustained in the accident, while no one was killed.
3. Slight/minor injury: At least one of the participants of the accident was hospitalized less than 24 hours or not hospitalized, while no participant was seriously injured or killed.

Comments: Provides a quick reference to the accident severity, summarizing the data given by the individual personal injury records of the accident. Facilitates analysis by accident severity level.

4.2.1.3 Road data elements

The road related data elements describe the characteristics of the road and associated infrastructure at the place and time of the accident.

R1. Type of roadway
Definition: Describes the type of road, whether the road has two directions of travel, and whether the carriageway is physically divided. For accident occurring at junctions, where

the accident cannot be clearly allocated in one road, the road where the vehicle with priority was moving is indicated.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Motorway/freeway: Road with separate carriageways for traffic in two directions, physically separated by a dividing strip not intended for traffic. Road has no crossings at the same level with any other road, railway or tramway track, or footpath. Specially sign-posted as a motorway and reserved for specified categories of motor vehicles.
2. Express road: Road with traffic in two directions, carriageways not normally separated. Accessible only from interchanges or controlled junctions. Specially sign-posted as an express road and reserved for specified categories of motor vehicles. Stopping and parking on the running carriageway are prohibited.
3. Urban road, two-way: Road within the boundaries of a built-up area (an area with sign-posted entries and exits). Single, undivided street with traffic in two directions, relatively lower speeds (often up to 50 km/h), unrestricted traffic, with one or more lanes which may or may not be marked.
4. Urban road, one-way: Road within the boundaries of a built-up area, with entries and exits sign-posted as such. A single, undivided street with traffic in one direction, relatively lower speeds (often up to 50 km/h).
5. Road outside a built-up area: Road outside the boundaries of a built-up area (an area with sign-posted entries and exits).
6. Restricted road: A roadway with restricted access to public traffic. Includes cul-de-sacs, driveways, lanes, private roads.
7. Other: Roadway of a type other than those listed above.
8. Unknown: Not known where the incident occurred.

Comments: Important for comparing accident rates of roads with similar design characteristics, and for conducting comparative analyses between motorway and non-motorway roads.

R2. Road functional class
Definition: Describes the character of service or function of the road where the first harmful event took place. For accident occurring at junctions, where the accident cannot be clearly allocated in one road, the road where the vehicle with priority was moving is indicated.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Principal arterial: Roads serving long distance and mainly interurban movements. Includes motorways (urban or rural) and express roads. Principal arterials may cross through urban areas, serving suburban movements. The traffic is characterized by high speeds and full or partial access control (interchanges or junctions controlled by

traffic lights). Other roads leading to a principal arterial are connected to it through side collector roads.

2. Secondary arterial: Arterial roads connected to principal arterials through interchanges or traffic light-controlled junctions supporting and completing the urban arterial network. Serving middle distance movements but not crossing through neighborhoods. Full or partial access control is not mandatory.
3. Collector: Unlike arterials, collectors' cross urban areas (neighborhoods) and collect or distribute the traffic to/from local roads. Collectors also distribute traffic leading to secondary or principal arterials.
4. Local: Roads used for direct access to the various land uses (private property, commercial areas etc.). Low service speeds not designed to serve interstate or suburban movements.

R3. Speed limit
Definition: The legal speed limit at the location of the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. nnn: The legal speed limit as provided by road signs or by the country's traffic laws for each road category, in kilometers per hour (km/h).
2. 999 (unknowns): The speed limit at the accident location is unknown.

Comments: For accident occurring at junctions, where the accident cannot be clearly allocated in one road, the speed limit for the road where the vehicle with priority was moving is indicated.

R4. Road obstacles
Definition: The presence of any person or object which obstructed the movement of the vehicles on the road. Includes any animal standing or moving (either hit or not), and any object not meant to be on the road. Does not include vehicles (parked or moving vehicles, pedestrians) or obstacles on the side of the carriageway (e.g. poles, trees).
Obligation: Mandatory
Data type: Numeric
Data values:

1. Yes: Road obstacle(s) present at the accident site.
2. No: No road obstacle(s) present at the accident site.
3. Unknown: Unknown presence of any road obstacle(s) at the accident site.

R5. Road surface conditions
Definition: The condition of the road surface at the time and place of the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Dry: Dry and clean road surface.

2. Slippery: Slippery road surface due to existence of sand, gravel, mud, leaves, oil on the road. Does not include snow, frost, ice or wet road surface.
3. Wet, damp: Wet road surface. Does not include flooding.
4. Flood: Still or moving water on the road.
5. Other: Other road surface conditions not mentioned above.
6. Unknown: The road surface conditions were unknown.

Comments: Important for identification of high wet-surface accident locations, for engineering evaluation and prevention measures.

R6. Junction
Definition: Indicates whether the accident occurred at a junction (two or more roads intersecting) and defines the type of the junction. In at-grade junctions all roads intersect at the same level. In not-at-grade junctions' roads do not intersect at the same level.
Obligation: Mandatory
Data type: Numeric
Data values:

1. At-grade, crossroad: Road intersection with four arms.
2. At-grade, roundabout: Circular road.
3. At-grade, T or staggered junction: Road intersection with three arms. Includes T intersections and intersections with an acute angle.
4. At-grade, multiple junction: A junction with more than four arms (excluding roundabouts).
5. At-grade, other: Other at-grade junction type not described above.
6. Not at grade: The junction includes roads that do not intersect at the same level.
7. Not at junction: The accident has occurred at a distance greater than 20 meters from a junction.
8. Unknown: The accident location relative to a junction is unknown.

Comments: Accident occurring within 20 meters of a junction are considered as accident accidents at a junction. Important for site-specific studies and identification of appropriate engineering countermeasures.

R7. Traffic control at junction
Definition: Type of traffic control at the junction where accident occurred. Applies only to accident accidents that occur at a junction.
Obligation: Mandatory if accident occurred at a junction (R6)
Data type: Numeric
Data values:

1. Authorized person: Police officer or traffic warden at intersection controls the traffic. Applicable even if traffic signals or other junction control systems are present.
2. Stop signs: Priority is determined by stop sign(s).
3. Give-way sign or markings: Priority is determined by give-way sign(s) or markings.

4. Other traffic signs: Priority is determined by traffic sign(s) other than ‘stop’, ‘give way’ or markings.
5. Automatic traffic signal (working): Priority is determined by a traffic signal that was working at the time of the accident.
6. Automatic traffic signal (out of order): A traffic signal is present but out of order at time of accident.
7. Uncontrolled: The junction is not controlled by an authorized person, traffic signs, markings, automatic traffic signals or other means.
8. Other: The junction is controlled by means other than an authorized person, signs, markings or automatic traffic signals.

Comments: If more than one value is applicable (e.g. traffic signs and automatic traffic signals) record all that apply.

R8. Road curve
Definition: Indicates whether the accident occurred inside a curve, and what type of curve.
Obligation: Mandatory
Data type: Numeric
Data values:
1. Tight curve: The accident occurred inside a road curve that was tight (based on the judgment of the police officer).
2. Open curve: The accident occurred inside a road curve that was open (based on the judgment of the police officer).
3. No curve: The accident did not occur inside a road curve.
4. Unknown: It is not defined whether the accident occurred inside a road curve.

Comments: Useful for identification and diagnosis of high-accident locations, and for guiding changes to road design, speed limits, etc.

R9. Road segment grade
Definition: Indicates whether the accident occurred on a road segment with a steep gradient.
Obligation: Mandatory
Data type: Numeric
Data values:
1. Yes: The accident occurred at a road segment with a high grade.
2. No: The accident did not occur at a road segment with a high grade.
3. Unknown: It is not defined whether the accident occurred at a road segment with a high grade.

Comments: Useful for identification and diagnosis of high-accident locations, and for guiding changes to road design, speed limits, etc.

4.2.1.4 *Vehicle data elements*

The vehicle data elements describe the characteristics and events of the vehicle(s) involved in the accident.

V1. Vehicle number

Definition: Unique vehicle number assigned to identify each vehicle involved in the accident.
Obligation: Mandatory
Data type: Numeric, sequential two-digit number
Comments: Allows the vehicle record to be cross-referenced to the accident record and person records.

V2. Vehicle type

Definition: The type of vehicle involved in the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Bicycle: Road vehicle with two or more wheels, generally propelled solely by the energy of the person on the vehicle, in particular by means of a pedal system, lever or handle.
2. Other non-motor vehicle: Another vehicle without engine not included in the list above.
3. Two/three-wheel motor vehicle: Two or three-wheeled road motor vehicle (includes mopeds, motorcycles, tricycles and all-terrain vehicles).
4. Passenger car: Road motor vehicle other than a two or three-wheeled vehicle, intended for the carriage of passengers and designed to seat no more than nine (driver included).
5. Bus/coach/trolley: Passenger-carrying vehicle, most commonly used for public transport, inter-urban movements and tourist trips, seating more than nine persons. Includes vehicles connected to electric conductors and which are not rail-borne.
6. Light goods vehicle (<3.5 t): Smaller (by weight) motor vehicle designed exclusively or primarily for the transport of goods.
7. Heavy goods vehicle (≥3.5 t): Larger (by weight) motor vehicle designed exclusively or primarily for the transport of goods.
8. Other motor vehicle: Other vehicle not powered by an engine and not included in the two previous lists of values.
9. Unknown: The type of the vehicle is unknown or it was not stated.

Comments: Allows for analysis of accident risk by vehicle type and road user type (in combination with Type of road user, P20). Important for evaluation of countermeasures designed for specific vehicles or to protect specific road users.

V3. Vehicle makes

Definition: Indicate the make (distinctive name) assigned by motor vehicle manufacturer.

Obligation: Mandatory if the vehicle is a motorized vehicle. Not applicable to bicycles, tricycles, rickshaws and animal-powered vehicles.
Data type: Character string. Alternatively, a list of motor vehicle makes can be composed, with a code corresponding to each. Such a list allows for more consistent and reliable recording, as well as for easier interpretation of the data.
Comments: Allows for accident analyses related to the various motor vehicle makes.

V4. Vehicle model
Definition: The code assigned by the manufacturer to denote a family of motor vehicles (within a make) that have a degree of similarity in construction.
Obligation: Mandatory if the vehicle is a motorized vehicle. Not applicable to bicycles, tricycles, rickshaws and animal-powered vehicles
Data type: Character string. Alternatively, a list of motor vehicle models can be composed, with a code corresponding to each. Such a list allows for more consistent and reliable recording, as well as for easier interpretation of the data.
Comments: Record the name of the model as referred to in the country in which the accident occurred. Allows for accident analyses related to the various motor vehicle models.

V5. Vehicle model year
Definition: The year assigned to a motor vehicle by the manufacturer.
Obligation: Mandatory if the vehicle is a motorized vehicle. Not applicable to bicycles, tricycles, rickshaws and animal-powered vehicles
Data type: Numeric (YYYY)
Comments: Can be obtained from vehicle registration. Important for use in identifying motor vehicle model year for evaluation, research, and accident comparison purposes.

V6. Engine size
Definition: The size of the vehicle's engine is recorded in cubic centimeters (cc).
Obligation: Mandatory, if vehicle is motorized. Not applicable to bicycles, tricycles, rickshaws and animal-powered vehicles.
Data type: Numeric
Data values:

1. nnnn: Size of engine
2. 9999: Unknown engine size

Comments: Important for identifying the impact of motor vehicle power on accident risk.

V7. Vehicle special function
Definition: The type of special function being served by this vehicle regardless of whether the function is marked on the vehicle.
Obligation: Mandatory, if vehicle is motorized. Not applicable to bicycles, tricycles, rickshaws and animal-powered vehicles.
Data type: Numeric
Data values:

1. No special function: No special function of the vehicle.

2. Taxi: Licensed passenger car for hire with driver, without predetermined routes.
3. Vehicle used as bus: Passenger road motor vehicle used for the transport of people.
4. Police / military: Motor vehicle used for police / military purposes.
5. Emergency vehicle: Motor vehicle used for emergency purposes (includes ambulances, fire service vehicles etc.).
6. Other: Other special functions, not mentioned above.
7. Unknown: It was not possible to record a special function.

Comments: Important to evaluate the accident involvement of vehicles used for special uses.

V8. Vehicle maneuvers
Definition: The controlled maneuver for this motor vehicle prior to the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Reversing: The vehicle was reversing.
2. Parked: Vehicle was parked and stationary.
3. Entering or leaving a parking position: The vehicle was entering or leaving a parking position
4. Slowing or stopping: The vehicle was slowing or stopping
5. Moving off: The vehicle was still and started moving. Does not include vehicle leaving or entering a parking position.
6. Waiting to turn: The vehicle was stationary, waiting to turn.
7. Turning: The vehicle was turning (includes U-turns).
8. Changing lane: The vehicle was changing lane.
9. Avoidance maneuvers: The vehicle changed its course in order to avoid an object on the carriageway (including another vehicle or pedestrian).
10. Overtaking vehicle: The vehicle was overtaking another vehicle.
11. Straight forward / normal driving: The vehicle was moving ahead away from any bend.
12. Other
13. Unknown

4.2.1.5 Person data elements

The person data elements describe the characteristics, actions, and consequences relating to the people involved in the accident. These elements are to be completed for every person injured in the accident, and also for the drivers of all vehicles (motorized and non-motorized) involved in the accident.

P1. Person number
Definition: Number assigned to uniquely identify each person involved in the accident.
Obligation: Mandatory

Data type: Numeric (two-digit number, nn)
Comments: The persons related to the first (presumed liable) vehicle will be recorded first. Within a specific vehicle, the driver will be recorded first, followed by the passengers. Allows the person record to be cross-referenced to accident, road and vehicle records to establish a unique linkage with the Accident ID (A1) and the Vehicle number (V1).

P2. Occupant's vehicle number
Definition: The unique number assigned for this accident to the motor vehicle in which the person was an occupant (V1).
Obligation: Mandatory
Data type: Numeric (two-digit number, nn)
Comments: Allows the person record to be cross-referenced to the vehicle records, linking the person to the motor vehicle in which they were travelling.

P3. Pedestrian's linked vehicle number
Definition: The unique number assigned for this accident to the motor vehicle which collided with this person (V1). The vehicle number assigned under (V1) to the motor vehicle which collided with this person.
Obligation: Mandatory
Data type: Numeric (two-digit number, nn, from V1)
Comments: Allows the person record to be cross-referenced to the vehicle records, linking the person to the motor vehicle that struck them.

P4. Date of birth
Definition: Indicates the date of birth of the person involved in the accident.
Obligation: Mandatory
Data type: Numeric (date format – dd/mm/yyyy, 99/99/9999 if birth date unknown)
Comments: Allows calculation of person's age. Important for analysis of accident risk by age group, and assessing effectiveness of occupant protection systems by age group. Key variable for linkage with records in other databases.

P5. Gender
Definition: Indicates the gender of the person involved in the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Male: On the basis of identification documents / personal ID number or determined by the police.
2. Female: On the basis of identification documents / personal ID number or determined by the police.
3. Unknown: Sex could not be determined (police unable to trace person, not specified).

Comments: Important for analysis of accident risk by sex. Important for evaluation of the effect of sex of the person involved on occupant protection systems and motor vehicle design characteristics.

P6. Type of road user
Definition: This variable indicates the role of each person at the time of the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Driver: Driver or operator of motorized or non-motorized vehicle. Includes cyclists, persons pulling a rickshaw or riding an animal.
2. Passenger: Person riding on or in a vehicle, who is not the driver. Includes person in the act of boarding, alighting from a vehicle or sitting/stranding.
3. Pedestrian: Person on foot, pushing or holding a bicycle, pram or a pushchair, leading or herding an animal, riding a toy cycle, on roller skates, skateboard or skis. Excludes persons in the act of boarding or alighting from a vehicle.
4. Other: Person involved in the accident who is not of any type listed above.
5. Unknown: It is not known what role the person played in the accident.

Comments: Allows for analysis of accident risk by road user type (in combination with Vehicle type, V2). Important for evaluation of countermeasures designed to protect specific road users.

P7. Seating position
Definition: The location of the person in the vehicle at the time of the accident.
Obligation: Mandatory for all vehicle occupants
Data type: Numeric
Subfield: Row
Data values:

1. Front
2. Rear
3. Not applicable (e.g. riding on motor vehicle exterior)
4. Other
5. Unknown

Subfield: Seat
Data values:

1. Left
2. Middle
3. Right
4. Not applicable (e.g. riding on motor vehicle exterior)
5. Other
6. Unknown

Comments: Important for full evaluation of occupant protection programmes.

P8. Injury severity
Definition: The injury severity level for a person involved in the accident.
Obligation: Mandatory
Data type: Numeric
Data values:

1. Fatal injury: Person was killed immediately or died within 30 days, as a result of the accident.
2. Serious/severe injury: Person was hospitalized for at least 24 hours because of injuries sustained in the accident.
3. Slight/minor injury: Person was injured and hospitalized for less than 24 hours or not hospitalized.
4. No injury: Person was not injured.
5. Unknown: Injury severity was not recorded or is unknown.

Comment: Important for injury outcome analysis and evaluation and appropriate classification of accident severity (PD1). Important element for linkage with records in other databases.

P9. Safety equipment
Definition: Describes the use of occupant restraints, or helmet use by a motorcyclist or bicyclist.
Obligation: Mandatory
Data type: Numeric
Subfield: Occupant restraints
Data values:

1. Seat-belt available, used
2. Seat-belt available, not used
3. Seat-belt not available
4. Child restraint system available, used
5. Child restraint system available, not used
6. Child restraint system not available
7. Not applicable: No occupant restraints could be used on the specific vehicle (e.g. agricultural tractors).
8. Other restraints used
9. Unknown: Not known if occupant restraints were in use at the time of the accident.
10. No restraints used

Subfield: Helmet use
Data values:

1. Helmet worn
2. Helmet not worn
3. Not applicable (e.g. person was pedestrian or car occupant)
4. Unknown

Comments: Information on the availability and use of occupant restraint systems and helmets is important for evaluating the effect of such safety equipment on injury outcomes.

P10. Pedestrian maneuvers
Definition: The action of the pedestrian immediately prior to the accident.
Obligation: Mandatory
Data type: Numeric
Data values

1. Crossing: The pedestrian was crossing the road.
2. Walking on the carriageway: The pedestrian was walking across the carriageway facing or not facing traffic.
3. Standing on the carriageway: The pedestrian was on the carriageway and was stationary (standing, sitting, lying etc.).
4. Not on the carriageway: The pedestrian was standing or moving on the sidewalk or at any point beside the carriageway.
5. Other: The vehicle or the pedestrian was performing a maneuver not included in the list of the previous values.
6. Unknown: The maneuvers performed by the vehicle or the pedestrian was not recorded or it was unknown.

Comments: Provides useful information for the development of effective road design and operation, education and enforcement measures to accommodate pedestrians.

P11. Alcohol use suspected
Definition: Law enforcement officer suspects that person involved in the accident has consumed alcohol.
Obligation: Mandatory for all drivers of motorized vehicles, recommended for all non-motorists (pedestrians and cyclists).
Data type: Numeric
Data values:

1. No
2. Yes
3. Not applicable (e.g. if person is not driver of motorized vehicle)
4. Unknown

P12. Alcohol test
Definition: Describes alcohol test status, type and result.
Obligation: Conditional (mandatory if alcohol use suspected, P25)
Data type: Numeric
Subfield: Test status
Data values:

1. Test not given
2. Test refused
3. Test given
4. Unknown if tested

Subfield: Test type
Data values:

1. Blood
2. Breath
3. Urine
4. Other
5. Test type unknown

Subfield: Test result
Data values

1. Value
2. Pending
3. Result unknown

Comments: Alcohol-related accidents are a major road safety problem. Information on alcohol involvement in accident facilitates evaluation of programmes to reduce drink-driving.

P13. Drug use
Definition: Indication of suspicion or evidence that person involved in the accident has consumed illicit drugs.
Obligation: Mandatory for all drivers of motorized vehicles, recommended for all non-motorists (pedestrians and cyclists).
Data type: Numeric
Data values:

1. No suspicion or evidence of drug use
2. Suspicion of drug use
3. Evidence of drug use (further subfields can specify test type and values)
4. Not applicable (e.g. if person is not driver of motorized vehicle)
5. Unknown

P14. Driving license issue date
Definition: Indicates the date (month and year) of issue of the person's first driving license, provisional or full, pertaining to the vehicle they were driving.
Obligation: Mandatory for all drivers of motorized vehicles
Data type: Numeric (MMYYYY)
Data values:

1. Value (MMYYYY)
2. Never issued a driving license
3. Date of issue of first license unknown

Comments: Allows calculation of number of years' driving experience at the time of accident.

4.2.2 Data collection and storage process

There are three primary methods by which accident data can be collected; police reports, hospital reports and in-depth investigations.

4.2.2.1 Police reports

In most countries, the Police play a key role in the accident data collection process since they are the first to arrive at the accident scene and record the needed data and are the last to update the related data. The Police are also responsible for providing the authorities with the collected data. Relevant authorities such as the police, ministries or governmental departments are then responsible for maintaining the National accident data files and publishing related statistics.

When called to an accident with casualties, the Police have to carry out an on-site investigation and sometimes fill in an autopsy report as well as a part of the accident data collection form. This form will be completed later at the police headquarters. When the 30-days definition of fatalities is in place, the accident data forms have to be kept in the police headquarters for at least one month and be finalized with the necessary updates for any killed road users.

When the national road accident data are finalized, the Police are in charge of forwarding the data to the body responsible for the national accident data file, e.g. the National Statistical Office, the Ministry of Transport etc.

The main tool for accident data collection is the data collection form, hence the central national authority responsible for the national accident file has to carry out the initial development and the revisions later on, with the aim to cover not only the national needs but also the international requirements.

The accident data collection form has to be coupled with clear instructions for filling in, as well as for the data transmission process to the national data file. The national road accident data form has to be revised regularly (at least once every ten years) in order to better cope with the new needs of road accident analysis at national and international level, while attention should be given to compatibility issues before and after the modifications.

The road accident data collection form should also include detailed information on the accident type and conditions, the road infrastructure and the road and traffic environment. Moreover, it should include detailed information on each vehicle involved in the accident and on each road user (driver, passenger or pedestrian) affected by the accident.

Consequently, the national accident data collection form should be simple and self-explaining in its structure. Moreover, the related instructions should be precise and detailed, in order to provide clear and complete data definitions. It is also recommended that all existing standardized international definitions of variables and values are adopted by the national authorities when developing or revising their accident data collection forms.

Once the road accident data collection form is finalized by the Police, the form is forwarded to the national authority responsible for maintaining the national road accident data file. The necessary data quality control should then be undertaken within

Then, the data should be coded and introduced in the electronic national road accident data file. Data coding includes the attribution of identification numbers to all accidents, vehicles and persons involved, as well as the attribution of numerical codes to all data values. It is also suggested to use different coding (i.e. groups of values) for the same variable, in order to allow for different levels of detail to be directly available for the data users. For example, it is common to code person age both in years and in age group classifications.

The structure of the national data file should be in accordance with the structure of the accident data collection form. The use of sub-files, with each of them referring to the accident, person and vehicle, would be efficient due to the hierarchical relationships of the accident components. The different sub-files should be linked by means of the accident, vehicle, road and person identification numbers, so that combined information on all accident components can be easily retrieved. Thus, the national accident data file will include disaggregate data for all accidents components, which can be retrieved by means of queries.

4.2.2.2 Hospital data

Data can be collected concerning road accident casualties who attend/are admitted to hospital as a consequence of their accident. This provides the potential for the formation of a database relating to Hospital Episodes.

For example, information on casualties admitted to hospital as in-patients in England is contained in the Hospital Episodes Statistics (HES) database owned by the Information Centre of the National Health Service (NHS). It is compiled by the Information Centre (IC) from over 300 NHS Trusts in England. Casualties treated in Accident and Emergency departments who are not subsequently admitted to a hospital are not included in the HES database. However, all casualties admitted to a bed in a hospital in England should be recorded in the data even if the admission did not require an overnight stay. International standard diagnostic classifications are used in the health records (ICD-10). These include transport accident codes which allow for the identification of road transport accident casualties. More specifically, they allow the identification of road user type and casualty class (e.g. casualty being a passenger of a motorcycle).

For this method, the hospital admissions records are based on periods of care (episodes) under a particular consultant. So, a single patient may have more than one episode of care arising from a single accident (e.g. if they transfer to another consultant). Therefore, some data cleaning (de-duplication) needs to be carried out to identify records relating to the same patient and same accident.

As with the Police data, clear guidelines for the collection and coding of variables to be included in Hospital data are required. Identifiers should be put in place that allow matching of hospital and police data in the event that both sources are collected within a country. This enables a rich database to be developed that benefits from both the on-scene report from the police and also the detailed injury outcome from the hospital.

4.2.2.3 In-depth accident investigations

In-depth accident data, sometimes termed microscopic data, is an ideal method to identify and evaluate human factor issues related to real world accidents and potential Human Machine Interface (HMI) issues faced by road users. The advantage of this data source is the high level of detail known about each accident and how this can be related to a number of outcomes. Microscopic data is usually collected by independent research teams with a strict methodology collecting key variables pertaining to the accident, vehicle, road user, injury data, interview information, road infrastructure and scene information, accident reconstructions and accident causation analysis all of which is collected and analyzed by experienced investigators.

The data collected by the in-depth collection activities is independent and transparent, as opposed to the national reporting systems which are generally based on judicial investigations, although these will be impartial investigations they will often be collected with “vehicle to blame” in mind. In-depth accident data collected by the researchers is aimed at the cause of the accident, not who was to blame (Hagstroem et al., 2010).

Accident investigations are undertaken in two ways; at the scene or retrospectively. These are achieved by collecting data from accidents wither within minutes of their occurrence, where a specialist investigation team attend the scene along with the emergency services; or by retrospectively undertaking in-depth examinations of the vehicles and recording their damage characteristics and assessing their crashworthiness.

The information gathered at the scene or retrospectively is enhanced with follow up data including injury outcomes and causes for casualties who attend hospital and via questionnaires sent to those involved in the accident along with any available witness statements.

The data from in-depth accident investigations, whilst generally funded by a governmental body, tend to be managed, stored and analyzed by research institutes contracted by the government.

4.2.2.4 Representivity of accident data

When setting up accident data collection protocols at a country level, it is essential that consideration be given to harmonization of these protocols across countries so that cross-country comparative analyses can be made as robustly as possible. This has been considered at a European level within several projects including DaCoTA where a common protocol for European in-depth investigations was established (Atalar, Talbot, & Hill, 2012).

Once common national methods are in place, accident data from Police and Hospital sources potentially provide the national picture in terms of the accident population and resulting injury outcomes and therefore also have the potential to be fully representative of the accident constellation.

For in-depth accident investigations, requiring specialist teams, sampling needs to be taken into consideration in order to build a data base that is fit for the required analysis purpose. To establish true representivity an ideal sampling plan would involve randomly sampling accidents 24-7 all year round from regions that are nationally representative. This however is not generally feasible due to practical and financial implications.

The DaCoTA project outlined the following principles for achieving a pan-European representative accident sample for in-depth accidents (Hagstroem et al., 2010):

- Determine a sampling area which is representative of the national picture
- Within the sampling area, random sampling is considered a necessary precondition to have broadly representative results.
- Stratification reduces the sample variance and still guarantees representativeness of the sample.

- Multiple selection criteria (e.g. stratification according to different variables such as road user type, accident severity) are possible provided the source of information is reliable.
- Different strategies for sampling across regions / countries can be accommodated provided they are undertaken consistently and transparently and as long as no (large) biases in the sample are introduced.

4.3 Exposure data

Exposure indicators are considered indispensable in risk studies and international comparisons. Multiple linkages of databases as well as systematic surveys of road user behavior could facilitate the identification of relevant exposure data. However, for the purposes of international comparisons and priority settings, efforts should be targeted in defining exposure indicators as well as their compatibility to the accident data.
The exposure measures can be classified into two groups:

- Road traffic estimates: road length, vehicle kilometers and vehicle fleet.
- Road user at risk estimates: person kilometers, population, number of trips, time in traffic and driver population.

Among these measures, vehicle fleet, driver population and road length are useful alternative exposure measures in many countries worldwide, since the related data are recorded systematically by most countries. However, the definitions used for the variables and values are often not compatible.
Some basic requirements for the collection of such exposure measures are the following:

- Travel/mobility surveys for the collection of vehicles- or persons kilometers data should be in the form required for accident risk analysis.
- Traffic counts systems have to be established on the national and main interurban road network and at a later stage urban and rural areas to be included.
- A common vehicle classification should be considered by all countries.
- A common method for calculating vehicle-kilometers from the traffic counts should be adopted.

The collection exposure data should be performed under a common framework in order to obtain comparable indicators at international level. In this way, in the EU funded research project SafetyNet the two-step methodology was developed for the EU countries. The methodology includes:

1. harmonization of existing data and methods, including common transformation rules for all countries and all exposure indicators, in order to improve their national collection methods
2. collection of new harmonized data, including data collection at African level with common definitions and methods.

The data needed for the estimation of the exposure indicators are the following:

- Road length data by road type, area type and region
- Vehicle fleet data by vehicle type and vehicle age

- Driver population data by driver age and gender
- Vehicle-kilometers by vehicle type, age, road type, area type
- Person-kilometers by person class, age and gender

Once these indicators have been harmonized and collected, additional data needs may be tackled, such as:

- Vehicle fleet by engine type
- Driver population by nationality and experience
- Vehicle-kilometers by engine size
- Person-kilometers by nationality and experience
- Number of trips by person class, age, gender and vehicle type
- Time spent in traffic by person class, age, gender and vehicle type

4.3.1 Population

Population is a common exposure indicator used in road safety analyses due to the availability of the related data. Three variables are useful when assessing accident risk at a population level: person age, gender and nationality. In addition, population at regional level would be important for calculating respective risks.

All variables and values (in particular person age, gender and nationality) included in the population registers should have a straightforward meaning. Therefore, their definitions and their compatibility should be assessed and used for any risk calculation in matching with population-based road safety variables and values in the accident data base.

All countries have to collect population data in national registers and update them on a regular basis by conducting nation-wide censuses. Considering that most censuses are carried out on a regular basis (e.g. every 10 years), data for the intermediate years are estimations, which are used for the annual updates of the registers.

Attention should be given to the character of population data. In general, international databases provide average population data or population as of the 1st of January of every year. To avoid misleading results, population data with the same characteristic should be used.

However, for international comparisons risk calculations based on population data are not sufficient, especially in the case of large differences of motorization level, traffic density etc. among the countries. Therefore, additional exposure data have to be collected for risk assessment.

4.3.2 Driver population

The best source for driver population data is usually the national driver licenses databases. However, differences may exist among the countries concerning the registration of licensed drivers in total or for specific vehicle types. In addition, errors or failure to update systematically the register may lead to wrong estimations of the number of drivers. For example, when individuals who have died or who are no longer licensed are not marked or removed from the register there is an overestimation of the number of drivers.

Consequently, the following information should be available in the national registers on an annual basis:

- the total number of active drivers' licenses
- the number of drivers licenses by license group and by age group of the driver.

4.3.3 Road length

Road length data is a practical exposure variable for the estimation of traffic risk at the network level. The variables selected have to be compatible with the respective accident data concerning road. Thus, type of road, area type and region/municipality are regarded as useful variables.

Information on road length by area type or region may be available in local authorities, while for the main road network data may be available in national authorities. In order to aggregate the existing information, the cooperation of several authorities responsible for the operation and maintenance of road network is needed, while procedures such as national questionnaires could be developed on that purpose.

If relevant data are not available, national authorities should carry out the required activities for collecting this information. Road length data may be collected on-site, using vehicles equipped with odometers, or with maps. In both cases, care must be taken in order to adequately handle intersection areas and avoid double measuring their length.

4.3.4 Vehicle fleet

While the best estimation of exposure can be given by the number of vehicle-kilometers, such data are not always available and are very expensive to collect. In the case that these data are available, they are not always reliable. Therefore, the second-best exposure indicator is considered to be the vehicle fleet, due to its correlation with the level of motorization.

Considering that the fatality risk is entirely different depending on the type of the vehicle (e.g. bus, car, or bike) it is necessary to make the comparisons in the respect of different vehicle categories. Consequently, the following information should be available in the national registers on an annual basis:

- total number of registered vehicles
- number of vehicles by vehicle type and by age group of the vehicle.

4.3.5 Vehicle kilometers

As mentioned before, the number of vehicle-kilometers is probably the most appropriate exposure indicator for the estimation of accident risk. Vehicle kilometers are a direct measure of traffic volume and can be available in a significant level of disaggregation, i.e. time, vehicle type, road type, driver characteristics etc.

However, in practice, the availability and the level of disaggregation of vehicle kilometers varies significantly and is strongly dependent on the type and features of the collection method used in each country. Moreover, the calculation of the exposure estimate is not consistent throughout countries resulting in a low overall compatibility. Vehicle kilometers are estimated by several methods, most of which include data collection by surveys and traffic counts. Furthermore, estimations are also carried out by the use of statistical models and combinations of methods.

In order to obtain a common and compatible risk exposure measurement unit, the definition of the indicator should be uniform between all countries. In the Glossary of Transport Statistics (Eurostat, 2003) a definition of vehicle kilometer is proposed, which could form the basis for a common definition:

> *"Vehicle kilometer - Unit of measurement representing the movement of a road motor vehicle over one kilometer. The distance to be considered is the distance actually run. It includes movements of empty road motor vehicles. Units made up of a tractor and a semi-trailer or a lorry and a trailer are counted as one vehicle*".

Vehicle kilometer data are most useful for traffic risk analyses related to the vehicle and the road network. For the estimation of traffic risk at vehicle level, the vehicle type, vehicle age, vehicle engine size and road type are the most important variables, while the vehicle type, area type, road type and region variables are most important for the estimation of traffic risk at network level.

4.3.6 Person kilometers

Person kilometers can be collected either by travel surveys or by traffic counts and occupancy rate estimates. Travel surveys provide more detailed data than other methods. Moreover, data on person kilometers for non-motorized road users (bicycles and pedestrians) as well as cross tabulated data for age/gender groups of road users (both motorized and non-motorized) can be obtained only through surveys.

Person-kilometer data estimated by surveys are more usable for the variables: person class, person age and person gender and less usable for the vehicle type and the year. However, data are collected through surveys based on all these indicators.

Travel surveys are currently the most promising method available in order to have adequate data on person kilometers distributed by age/gender/road user. Thus, it is important to design the surveys in ways that allow for relevant risk calculations to be made. It is therefore recommended that travel surveys are conducted as follows:

- For risk exposure purposes travel surveys ought to be nationwide. Travel surveys in particular areas are less suitable because it is difficult to know how representative the area is, what the exact area covered is and it may be difficult to have precise correspondence between exposure data and accident data.
- Travel surveys ought to have sub samples distributed over a whole year (for instance sub samples every day) in order to account for seasonal travel variations.
- Travel surveys ought to include data also for professional drivers and travels conducted as part of work in addition to private travels.
- Travel surveys based on person samples often lack data for children. A possible way to obtain some data for children is to ask car drivers about age and gender of passengers.
- It is important to distinguish between travel made in a road traffic environment and travel made outside the road network. For pedestrians and cyclists this is particularly relevant.
- In order to reduce the problems with inaccurate reporting of distances and time, one should adopt tests of logic and reason to check answers.
- In addition to distance travelled one ought to try to register travel time as well.

4.4 Road Safe Performance Indicators

Safety performance indicators (SPIs) are measures (indicators), reflecting those operational conditions of the road traffic system, which influence the system's safety performance. SPIs are aimed to serve as tools in assessing the current safety conditions of a road traffic system, monitoring the progress, measuring impacts of various safety interventions and making comparisons.
The performance indicators can be divided into four pillars - problem areas: road, vehicle, road user and post-accident care. Indicative indicators on these four pillars consist of:

- road: number and length of road safety audits conducted, number of identified high risk sites and related interventions
- vehicles: mean age of vehicle fleet, number of technical inspections
- road user: seat-belt use rates, helmet use rates, speeding, drink-driving and use of mobile phone while driving
- post-accident care: number of staffs working on it, number of ambulances.

The present section presents the definitions of variables and values for producing national SPIs in certain areas of the aforementioned pillars.

4.4.1 SPIs on drink-driving

Alcohol use by road users and especially by drivers of motor vehicles increases the road accident risk considerably. Consequently, most countries ban the use of alcohol among drivers, or set low legal limits for blood alcohol concentrations. Nevertheless, a high proportion of fatal accidents involve drink-driving in most countries. Road safety policy makers need information about the state of this problem in their countries.

A SPI reflecting the alcohol related road toll is the *percentage of drivers under the influence of alcohol*.

Another more comparable indicator, which, however, seems to be out of line with the basic idea of SPIs, is suggested in the SafetyNet project and is based on accident data. The proposed SPI is the *percentage of severe and fatal injuries resulting from road accidents involving at least one active road user under the influence of alcohol*.

In order to estimate the first indicator a sampling frame has to be defined, while for the second one a national system has to be set up. Medically trained persons should take the blood specimen and provide the respective results. It is also noted that amendments of the road traffic law may be needed in countries where alcohol testing of drivers involved in fatal accidents is not mandatory. The police should ensure that blood or breath samples are taken from all drivers involved in road accidents and should report the results to the agency responsible for national road accident statistics.

4.4.2 SPIs on the use of protection systems

The non-use of protection systems is associated with severe injuries and fatalities. Such systems are the seat-belts for vehicle occupants, the helmets for riders of powered two-wheelers and cyclists and the child restraint systems. The assessment of the use of protection systems in traffic allows for identifying the magnitude of the problem and preventing fatal injuries in road traffic.
The SPIs examined in this section are the following:

- wearing rates of seat belts, in front seats (passenger cars + vans /under 3.5 tons), in rear seats (passenger cars + vans /under 3.5 tons), by children under 12 years old (restraint systems use in passenger cars), and in front seats (HGV + coaches /above 3.5 tons)
- usage rates of safety helmets by cyclists, moped riders and motorcyclists.

The SPIs are estimated by conducting a national observational survey, where the measurements should be classified by type of road, such as motorways, rural roads and urban roads. The values for major road types are then aggregated into one indicator (of each type) for the country. It is important that the assessment is conducted on a regular basis (preferably annual).

4.4.3 SPIs on vehicles

The SPIs on vehicles are related to the level of protection afforded by the vehicles which constitute the fleet in a country. When accidents occur, the potential of the vehicle itself to prevent injuries can determine whether the outcome is a fatality or something less serious. Thus, improvements in passive safety do not affect the occurrence of accidents, but help to minimize the consequences when accidents happen. Unsafe operational conditions could be defined as the presence within the fleet of a number of vehicles:

1. that will not protect the occupant well in a collision (accident worthiness)
2. with an increased capacity to inflict injury (compatibility).

The vehicles (passive safety) area differs from the other SPI areas, since the estimation of the indicators is not based on surveys, but the necessary data are taken from national databases. The minimum information which is required to produce some calculations of vehicle age (as a proxy for vehicle accident worthiness) and fleet composition (as a measure of compatibility), are total number of vehicles listed by:

- year of manufacture (or year of first registration)
- vehicle type (using definitions compatible with accident database).

4.5 Road Infrastructure Safety Management

Road Infrastructure Safety Management (RISM) refers to a set of procedures that support a road authority in decision making related to road safety improvement of a road network. These procedures are aimed at enhancing road safety at the different stages of a road infrastructure life cycle (Figure 4-8). Some of them can be applied to existing infrastructures, thus enabling a more reactive approach (e.g. by fixing the safety issues identified on the infrastructure); while others are used in the early stages (i.e. planning and design) allowing a more proactive approach (OECD/ITF, 2015).

Figure 4-8 Life cycle stages of a road infrastructure (OECD/ITF, 2015)

Several RISM procedures have been proposed in the last decades, some of them are very popular (e.g. treatment of high-risk sites) and some are less known. In some cases, they have similar characteristics. According to OECD/ITF (2015), the following are the most consolidated RISM procedures:

- *Road Safety Impact Assessment* (RIA). A strategic comparative analysis of the impact of a new road or a substantial modification to the existing network on the safety performance of the road network. It is carried out at the initial planning stage before the infrastructure project is approved. The purpose is to demonstrate, on a strategic level, the implications on road safety of different planning alternatives of an infrastructure project and these should play an important role when routes are selected.
- *Efficiency Assessment Tools* (EAT). Budgets for transport in general and for road safety in particular should be spent as optimally as possible. Efficiency assessment tools (e.g. cost benefits analysis) determine the effects for society of an investment, for instance of an investment in road safety, in order to prioritise investment alternatives.
- *Road Safety Audit* (RSA). An independent detailed systematic and technical safety check relating to the design characteristics of a road infrastructure project and covering all stages, from planning to early operation, in order to identify and detail unsafe features of a road infrastructure project.
- *Network Operation* (NO). This relates to daily management of the infrastructure of a road network, with particular reference to maintaining road serviceability and safety.
- *Road Infrastructure Safety Performance Indicators* (SPIs). Safety performance indicators (SPIs) are seen as any measurement that is causally related to crashes or

injuries and is used in addition to the figures of accidents or injuries, in order to indicate safety performance or understand the process that leads to accidents. Road Infrastructure Safety Performance Indicators aim to assess the safety hazards by infrastructure layout and design (e.g. percentage of road network not satisfying safety design standards).

- *Network Safety Ranking* (NSR). A method for identifying, analysing and classifying parts of the existing road network according to their potential for safety development and accident cost savings.
- *Road Assessment Programmes* (RAPs). These methods involve the collection of road characteristics data which are then used to identify safety deficits or determine how well the road environment protects the user from death or disabling injury when a crash occurs.
- *Road Safety Inspection* (RSI). A preventive tool consisting of a regular, systematic, on-site inspection of existing roads. The inspections cover the whole road network and are carried out by trained safety expert teams. They result in in a formal report on road hazards and safety issues found and which require a formal response by the relevant road authority.
- *High Risk Sites* (HRS). A method to identify, analyse and rank sections of the road network which have been in operation for more than three years and upon which a large number of fatal accidents in proportion to the traffic flow have occurred.
- *In-depth Investigation*. In-depth Investigation is the acquisition of all relevant information and the identification of one or several of the following: a) the cause (or causes) of the accident; b) injuries, injury mechanisms and injury outcomes; c) how the accident and injuries could have been prevented.

Why do we use RISM? Because as the time goes by, road infrastructure could change in terms of performance and use. For instance, road conditions can change because of the weather which worsen the status of pavements and so on. Road could also change in terms of use: for instance, in terms of traffic volume (and we know road accidents change according to traffic volume) or in terms of different road users.

Beyond the application to specific stages, other differences may appear when looking at the type of road, the dimension of the tackled road safety problem (e.g. the entire road network or a single road site) and the specific needs of the country using RISM procedures. RISM procedures can be applied to every type of road, i.e. motorways, rural and urban roads. However, some differences exist relating to "how" a procedure is carried out on a certain type of road network, and the extent of the road network involved in the procedure (e.g. a target site, a group of sites with similar characteristics or an area) (OECD/ITF, 2015).

Another aspect to take into account is the dimension of the road safety problem examined – whether one is interested in studying a specific road section or intersection, a road corridor or an entire road network. Some RISM procedures are applied to an entire road network or to a part of it (e.g. Network Safety Ranking and High-Risk Sites rank road sections) according to their safety level; therefore, they can be used only at network level (at least two road sections). Other procedures, such as Road Safety Inspections, are applied at section or intersection level. The use can be extended also to an entire road network, but proceeding on a per-section basis (OECD/ITF, 2015). Table 4-1 outlines the road category and extent of application for each RISM procedure.

Table 4-1 Context of application of RISM procedures (OECD/ITF, 2015)

Procedure	Road Category	Road Category
Road Safety Impact Assessment	No specific road category	Part of the road network potentially influenced by a measure
Efficiency assessment tools	No specific road category	Part of the road network potentially influenced by a measure
Road Safety Audit	No specific road category	A designed road infrastructure
Network Operation	No specific road category, however some practices are difficult to perform on an urban network	Generally part or an entire road network managed by a road administration
Road Infrastructure Safety Performance Indicators	Usually performed on a rural and motorway road network	An entire road network
Network Safety Ranking	No specific road category	Generally part or an entire road network managed by a road administration
Road Assessment Programs	Usually performed on a rural/motorway road network	Part or an entire road network.
Road safety inspection	No specific road category	Generally part or all road elements belonging to the same road network
High-Risk Sites	No specific road category	Generally part or an entire road network managed by a road administration
In-depth Investigation	No specific road category	Limited to the area of intervention (e.g. 30 min from accident investigator's base)

Another point to stress is the overlap of RISM procedures, meaning that in some cases, two different procedures could lead to similar results or have some parts in common. This may happen where some procedures have the same purpose, use the same tools or require similar data (Figure 4-9). For example, Road Safety Audits (RSA), Road Assessment Programmes (RAP), Road Safety Inspections (RSI), High-Risk Sites (HRS) and In-depth Accident Investigations have in common a similar purpose: the identification of risk factors related to road design or traffic control that may lead to accidents or make the accidents more severe.

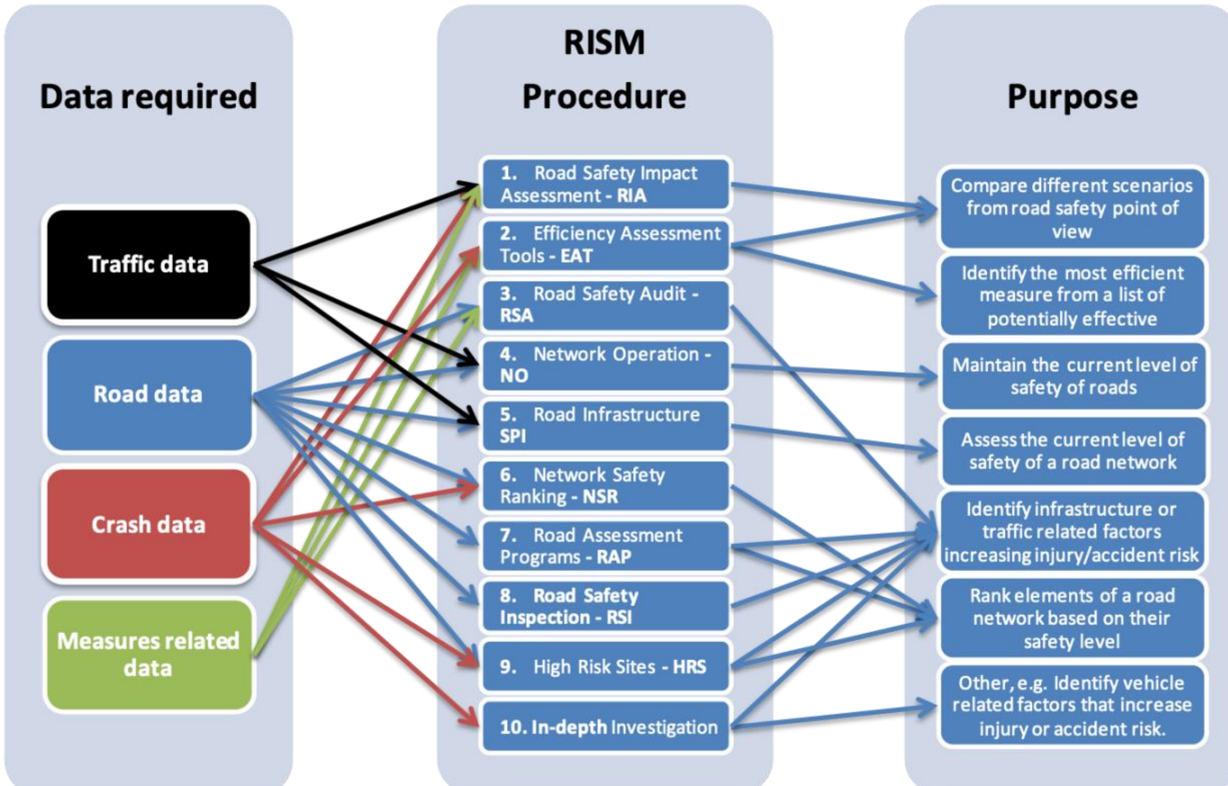


Figure 4-9 Data required and purposes associated to each procedure (OECD/ITF, 2015)

4.6 Road Assessment Programme Methodologies

A number of methodologies mostly based on the physical characteristics of a road have been proposed over the last 15 years by researchers from around the world, especially from Italy and New Zealand, so far to assess the safety performance of road infrastructures (Table 4-2).

Table 4-2 Summary of Road Assessment Programme methodologies

Literature reference	Country	Road Type	Road Element addressed	Risk Index
Montella (2005)	Italy	Rural roads	Segments	Potential for Safety Improvement Index (PFI)
Cafiso et al. (2007); (2011); (2014)	Italy and Poland	Rural roads	Segments	Safety Index (SI)
RANKERS (2008)	Europe	Rural roads	Segments	Road Safety Index
Appleton (2009), RISA	New Zealand	Rural roads	Segments, intersections, road network	Personal Risk, Collective Risk, Network Risk Number
iRAP* (2009)	Worldwide	Rural roads Urban streets	Segments	Star Rating
Habibian et al. (2011)	Iran	Rural roads	Segments, intersections, bridge, Tunnels	Safety Index (SI)

Brodie et al. (2013), Urban KiwiRAP	New Zealand	Urban streets	Segments, intersections	Star Rating
Zumrawi (2016)	Sudan	Rural roads	Segments	Risk Factor Index (RFI)
Chhanabhai et al. (2017) Zia et al. (2019)	New Zealand	Rural roads Urban streets	Segments	Infrastructure Risk Rating (IRR)
Song et al. (2018), FARSA	USA	Rural roads, Urban streets	Segments	Safety Score
Martín-Jiménez et al. (2018)	Spain	Rural roads	Segments	Potential Risk Assessment (PRA)
Demasi et al. (2018)	Italy	Urban streets	Segments	Branch Index Risk (BIR), Section Index Risk (SIR)

Note: *Including: EuroRAP, AusRAP, usRAP, ChinaRAP, IndiaRAP, SARAP, SgRAP, BrazilRAP, and KoRAP

The characteristics of the identified methodologies were compared with respect to the following aspects:

1. Theoretical approach
2. Road segmentation
3. Road users
4. Qualifications of safety personnel
5. Data source and way(s) of data collection
6. Key parameters
7. Method calculation
8. Geographical implementation and validation

These are explained in more details in the following sections.

4.6.1 Theoretical approach

The literature suggested that there are different approaches to calculate a risk index based on the physical characteristics of the road. Seven of the 12 methodologies (Montella, 2005) (Chhanabhai, Beer, & Johnson, 2017) (IRAP, 2009) (Salvatore Cafiso, Cava, & Montella, 2007) (Brodie, Durdin, Fleet, Minnema, & Tate, 2013) (Song et al., 2018) (Demasi, Loprencipe, & Moretti, 2018) considered are based their calculation of the risk on the common definition given by the combination of key factors such as Danger (likelihood that a crash can happen), Vulnerability (risk of injury of road users given a crash occurred) and Exposure (amount of "activity" a user is exposed to a risk).

A rating system is used by three methodologies (Perandones & Ramos, 2008) (Habibian, Mesbah, & Sobhani, 2014) (Mohamed Eltayeb Zumrawi, 2016). This system consists of conducting a survey on the road segments and assigned a score to each item (e.g. road alignment, junctions, overtaking, roadside, etc) according to their availability and conditions.

Benchmarking was another approach identified in one of the methodologies. The risk score is calculated per km of road so that roads of unequal lengths may be compared. The risk scores are relative risks and are called "Personal Risk". A risk of 1.2 means that a person traveling on this road has a 20% higher risk of a crash than when traveling on the benchmark road (Appleton, 2009).

Finally, other approach allows to evaluate road safety from Mobile LiDAR System (MLS) data, taking advantage of the road alignment (geometric consistency indexes) due to its influence on the accident rate. Automation is obtained through an inductive reasoning process based on a decision tree that provides a potential risk assessment (Antonio Martín-Jiménez, Zazo, Arranz Justel, Rodríguez-Gonzálvez, & González-Aguilera, 2018).

4.6.2 Road segmentation

Defining homogeneous road segments is one of the key steps in assessing road safety risk. Road segmentation varies widely between different methodologies, from 100 m to 7 km.

Of the 12 methodologies considered, three calculate the risk index each 100 meters (IRAP, 2009) (Brodie et al., 2013) (Song et al., 2018). While another considers each homogeneous section is 100 m ±20% long. Road branches are considered homogeneous if they have uniform/homogeneous attributes related to physical and operating conditions (i.e., accident rate, geometric layout, composition of cross section, traffic spectrum, average operating speed) (Demasi et al., 2018).

Two methodologies address rural two-lane highways and does not consider junctions. In this case, the road is divided into homogeneous segments of 200 m (Montella, 2005) (Salvatore Cafiso et al., 2007).

Benchmarking approach calculates the risk score per km of road, thus roads of unequal lengths can be compared (Appleton, 2009).

Other methodologies perform the road segmentation into as many segments as necessary according to established parameters. Road segmentation (road length section of 1.5 – 2 km) depends on the road safety auditor. The safety analysis address all types of existing roads: dual-carriageways, motorways, rural and urban roads (Perandones & Ramos, 2008). A road is decomposed to six elements, namely, straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use in two-lane rural roads (Habibian et al., 2014). In 2015 a field survey of the safety conditions was conducted on a total of 3,350 Km of eight national highways in Sudan, the segments varied between 160 to 557 km (Mohamed Eltayeb Zumrawi, 2016). In other case, homogenous sections are those where the speed limit would be the same. Sections to be around 5km in length, though sections between 3km and 7km in length are acceptable. Shorter lengths (around 1km) can be used where necessary but should be avoided where possible. These shorter lengths are typically only expected where there has been a significant change in road stereotype or land use, intersection density or access density (Chhanabhai et al., 2017). Segmentation according to 3D Initial Point cloud, 2D Road mark classification, Road axis (Antonio Martín-Jiménez et al., 2018).

4.6.3 Road users

More than half of global road traffic deaths are amongst pedestrians, cyclists and motorcyclists who are still too often neglected in road traffic system design in many countries (World Health Organization, 2018). Despite this, nine of the 12 methodologies focus on calculating the risk index exclusively for motor vehicle users (Montella, 2005) (Chhanabhai et al., 2017) (Salvatore Cafiso et al., 2007) (Perandones & Ramos, 2008) (Appleton, 2009) (Habibian et al., 2014) (Mohamed Eltayeb Zumrawi, 2016) (Song et al., 2018) (Antonio Martín-Jiménez et al., 2018). Two other methodologies besides calculating the risk index for motor vehicle users, calculates it for motorcyclists, bicyclists and pedestrians (IRAP, 2009) (Brodie et al., 2013). Finally, only one methodology focuses on calculating the risk index exclusively for Vulnerable Road Users (VRUs): pedestrians, cyclists, and motorcyclists (Demasi et al., 2018).

4.6.4 Qualifications of safety personnel

After the segmentation of the road, a necessary step toward in calculating the risk index is to construct an appropriate data set. Data collection constitutes the most time consuming. During this part of the process the experience and skills of the data collectors play an essential role in the process.

Two of the 12 methodologies require road safety experts and / or technical team, but do not indicate how many experts are necessary and their qualifications (Perandones & Ramos, 2008) (Mohamed Eltayeb Zumrawi, 2016).

Another two methodologies (Appleton, 2009) (Habibian et al., 2014) indicate the number of people who are part of the data collection team, but not their qualifications. One methodology requires a team of 3 people and a driver. At present the team collects all the information by a visual inspection of the road. Each person has one survey form to complete. The forms are: cross Section: Lane & shoulder widths and roadside hazards; alignment: Horizontal curves and delineation; and surface & miscellaneous: surface condition, accessways and one lane bridges (Appleton, 2009). The Analytical Hierarchy Process (AHP) method requires five experienced safety auditors as expert panel (Habibian et al., 2014).

The three Italian methodologies (Montella, 2005), (Salvatore Cafiso et al., 2007) , (Demasi et al., 2018) require two road safety auditors according to the procedures defined in the Italian road safety audit guidelines (Public Works Ministry of Italy, 2001), it means auditors must have university-level preparation and demonstrated experience in road highway design, accident analysis, traffic engineering, or other activities related to road safety.

iRAP activities require a particular accreditation (IRAP, 2009). In this way, training courses are delivered face-to-face or online. To be eligible for accreditation, the course should be deliverable by iRAP or an accredited training organization. This type of accreditation is available only to individuals in three activities:

- Road surveys, which involves image, GPS and distance data collection, and speed and flow sampling.
- Road attribute coding, which involves using survey imagery to record road attributes at fixed intervals.
- Analysis and reporting, which involves using road attribute coding data and other supporting data to create road safety Star Ratings and Safer Roads Investment Plans in the iRAP online software, ViDA.

The two methodologies that perform their data collection process automatically do not indicate the qualities of data collectors. In any case, considering their approach, one requires specialists in deep convolutional neural network (CNN) architecture (Song et al., 2018), and the other one in Mobile LiDAR System (MLS) (Antonio Martín-Jiménez et al., 2018).

4.6.5 Data source and way(s) of data collection

Of the 12 methodologies considered, 10 perform data collection manually (Montella, 2005) (Chhanabhai et al., 2017) (IRAP, 2009) (Salvatore Cafiso et al., 2007) (Perandones & Ramos, 2008) (Appleton, 2009) (Habibian et al., 2014) (Brodie et al., 2013) (Mohamed

Eltayeb Zumrawi, 2016) (Demasi et al., 2018). Road features are collected through on-site inspection also called as Road Safety Inspection (RSI), safety review, safety inspection, or safety audit. Other complementary information is also collated: crash data, traffic flow, speed, etc, (see key parameters section).

One methodology considers the design consistency evaluation, where safety criteria evaluation is strictly related to the operating-speed profile. Operating speed can be evaluated by using experimental regression models. Therefore, the horizontal and vertical alignment of the road must be known (Salvatore Cafiso et al., 2007).

Two types of road inspections are available, drive-through inspections and video-based inspections, with video-based inspections being the most common (IRAP, 2009).

Drive-through inspections require inspectors to record road design data as they drive along the road using a specialised data tablet. The process is technical and requires accredited RAP inspectors. Drive-through inspections are typically used where the length of the road network being surveyed is short or relatively simple (such as rural roads with no adjacent development). The drive-through inspection equipment includes a video camera, touch-sensitive laptop, and a GPS antenna.

Video-based inspections are undertaken in two stages. Firstly, a specially equipped survey vehicle records images of the road as it travels along. The video is later viewed by analysts, or coders, and assessed according to RAP protocols. The survey vehicle can record digital images of the road (generally at intervals of 5-10 metres) using an array of cameras aligned to pick up panoramic views of the road (forward, left-side and right-side). The main forward view is calibrated to allow measurements such as lane width, shoulder width, and distance to roadside hazards.

Aerial imagery is useful for gaining an overview of the section to be coded and can be used to code features such as alignment. Existing data sources, such as Road Asset Maintenance Management (RAMM) databases, are useful for coding traffic volume and can be used to code other features such as carriageway width. Coding can also be done using still images, such as Google Street View, but this will likely be slower and less accurate as it is more difficult to get a complete picture of the road corridor (Zia, Harris, & Smith, 2019).

Finally, there are two methodologies that perform data collection automatically (Song et al., 2018) (Antonio Martín-Jiménez et al., 2018). The CNN architecture takes as input a street-level, equirectangular panorama (e.g., from Google Street View) and outputs a categorical distribution over a discrete label space. In this way, road level attributes, including curvature, roadside hazards, and the type of median are estimated (Song et al., 2018).

The other methodology allows to evaluate road safety from Mobile LiDAR System (MLS) data, taking advantage of the road alignment due to its influence on the accident rate. Automation is obtained through an inductive reasoning process based on a decision tree that provides a potential risk assessment. To achieve this, a 3D point cloud is classified by an iterative and incremental algorithm based on a 2.5D and 3D Delaunay triangulation, which apply different algorithms sequentially. Next, an automatic extraction process of road horizontal alignment parameters is developed to obtain geometric consistency indexes, based on a joint triple stability criterion (Antonio Martín-Jiménez et al., 2018).

4.6.6 Key parameters

As previously mentioned, during the data collection process each methodology considers different attributes affecting risk safety on roads. In urban areas the traffic system context is more complex, where a mixed road user environment prevails, therefore, in the urban areas, the risk factor depends to a lesser extent on the characteristics of the infrastructure. In this way, Table 4-3 summarizes the main attributes for rural roads.

Table 4-3 Summary of the main attributes affecting road safety on rural roads

Infrastructure/ Operational Element	**Specific Risk Factor**	**Montella (2005)**	**Cafiso et al. (2007)**	**RANKERS (2008)**	**Appleton (2009)**	**iRAP (2009)**	**Habibian et al. (2011)**	**Zumrawi (2016)**	**Chhanabhai et al. (2017)**	**Martín-Jiménez et al. (2018)**
Exposure	Vehicle flow (AADT)		x		x	x			x	
	Risks associated with traffic composition (risk to VRUs only)					x				
	Risks associated with the distribution of traffic flow over arms at junctions	x				x		x	x	
Speed	Speed limit (general+motorcycle, truck)					x	x			
	Operating speed				x	x		x	x	x
	Mean speed					x				
	Design speed			x						x
Road Surface	Inadequate Friction	x	x	x	x	x		x		x
	Uneven surface	x	x	x	x	x	x	x		x
Alignment - Road Segments	Low Curve Radius	x		x	x	x			x	x
	Alignment deficiencies - High Grade			x	x	x	x		x	x
	Poor sight distance – Horizontal curves	x	x			x	x	x	x	
	Poor sight distance – Vertical curves	x	x				x	x	x	
Cross-Section - Road Segments	Number of lanes					x				x
	Absence of paved shoulders					x				
	Lane width	x	x	x	x	x			x	x
	Shoulder width	x	x	x	x	x	x		x	x
	Undivided Road - Median Type	x	x			x		x		
	Risks associated with safety barriers	x	x			x				
	Sight obstructions (Landscape, Obstacles and Vegetation)		x	x	x	x			x	x
	Absence of guardrails or crash cushions	x	x			x				
	Absence of clear zone					x				
	Missing passing lane	x						x		
	Missing climbing lane	x								
	Drainage						x			
	Vehicle parking									

	Facilities for bicycles									
Traffic control – Road segments	Absence of traffic signs	x	x	x		x	x	x		x
	Absence of road markings	x	x	x		x	x	x		x
	Absence of rumble strips	x				x	x			
Alignment and Traffic Control - Junctions	Risk of different junction types			x		x	x	x		
	At-grade junction deficiencies - Intersection quality		x		x	x	x	x		
	Density of intersection/lateral accesses	x	x	x	x	x		x	x	
	Uncontrolled rail-road crossing	x			x	x				
	Poor junction readability - Absence of road markings and crosswalks	x		x		x	x			
Road lighting	Poor Visibility - Darkness (risk to pedestrians only)					x				
	Poor Visibility - Darkness (risk to all)					x	x			
Presence of workzones	Roadworks					x				
Geometry design consistency	Driver's expectations		x							x

4.6.7 Method calculation

Below are the approaches for calculating the risk index of each methodology.

4.6.7.1 Potential for Safety Improvement Index (PFI)

The potential for safety improvement index (PFI) assessment is based on evaluation of safety items that have a known impact on road safety. On the basis of existing literature, the safety effect of each detailed issue has been estimated. The safety effect is expressed by two indices: ΔA, which represents the estimated relative increase in injury accidents risk caused by the safety issue, and ΔS, which is the estimated relative increase in accident severity. Accident severity is the ratio between fatal accidents and all-injuries accidents. Since some safety features do not affect all accident types, related accidents have been defined for each detailed issue. Length of road affected by each item is expressed by the parameter related effect (Montella, 2005).

Relative risk of the detailed issue j, which represents the global estimated increase in injury accidents risk due to the issue j, is computed by the formula:

$$RR_j = expo_j * \Delta A_j * P_j \quad (8)$$

Where: RR_j = relative risk of the detailed issue *j*; $expo_j$ = exposure of the issue *j*, that is, the proportion of road affected by the issue *j*; ΔA_j = estimated relative increase in injury accidents risk due to the issue *j*; and P_j = proportion of accidents affected by the issue *j*.

Fatal accident RR_j is computed by the formula:

$$RR_{faj} = RR_j * (1 + \Delta S_j) \quad (9)$$

Where: RR_{faj} = fatal accidents relative risk of the detailed issue *j*; and ΔS_j = estimated relative increase in accident severity (fatal and injury accidents) due to the issue *j*.

Relative risk of the general issue *I* is computed by the formula (equal to the formula for fatal accidents):

$$RR_i = \sum_{j=1}^{n} RR_j \quad (10)$$

Where: RR_i = relative risk of the general issue *i*; RR_j = relative risk of the detailed issue j associated with the general issue *i*; and n = number of detailed issues associated with the general issue *i*.

Relative risk of the segment, which represents the global estimated increase in injury accidents risk due to the identified issues, is computed by the formula (equal to the formula for fatal accidents):

$$RR = RR_1 + RR_2 * (1 + RR_1) + RR_3 * (1 + RR_2) * (1 + RR_1) + \cdots \quad (11)$$

Where: RR = relative risk of the segment; and $RR_{1,2,3,\ldots,n}$ = relative risk of the general issues.

PFI represents a measure of the accident increase due to the identified safety items. That is, PFI is a measure of the safety gains that can be obtained by eliminating the safety issues. It depends both on the relative risk and the traffic volume and is equal to:

$$PFI = RR * (AADT)^b \quad (12)$$

Where: $AADT$ = average annual daily traffic [(vehicles per day)/1,000]; and b is the exponent of $AADT$ in the pertinent accident predictive model.

4.6.7.2 Safety Index (SI)

The Safety Index (SI) measures the relative safety performance of a road segment. The SI is formulated by combining three components of risk: the exposure of road users to road hazards (exposure factor), the probability of a vehicle's being involved in an accident (accident frequency factor), and the resulting consequences, should an accident occur (accident severity factor) (Salvatore Cafiso et al., 2007).

The general formulation for the SI is as follows:

*SI = exposure factor * accident frequency factor * accident severity factor* *(13)*

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

*exposure factor = L * AADT*
(14)

The accident frequency factor is obtained by:
*accident frequency factor = RSI AF * GD AF*
(15)

Where: *RSI AF* =road safety inspection accident frequency factor (based on accident modification factors (AMFs)); and *GD AF* = geometric design accident frequency factor.

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

$$accident\ severity\ factor = \left(\frac{V_{85}}{V_{base}}\right) * RSI\ AS_{roadside}$$
(16)

Where: V_{85} = average 85th percentile of speed along segment (weighted to element length); V_{base} = base operating speed for two-lane local rural highways (assumed equal to legal speed limit of 90 km/h); and $RSI\ AS_{roadside}$ = roadside accident severity factor of segment.

4.6.7.3 Ranking for European Road Safety (RANKERS)

A Road Safety Index (RSI) is proposed for the evaluation of road safety in road sections, which assesses the actual status of road infrastructure and its relationship with road safety. The Road Safety Index is separately estimated for in six infrastructure topics: road alignment, junctions, overtaking, roadside, pavement and road layout consistency. The index provides a general safety mark for each road section and six particular road safety marks for each category in each road section (Perandones & Ramos, 2008). The safety marks are provided each 1.5 - 2 km of the road network and are divided in four categories, as follows (1 being the worst and 4 the best):

1. It is urgent to take remedial measures to solve this infrastructure safety topic.
2. There are deficiencies to be solved in a medium-term period.
3. No need of action if maintenance is kept properly.
4. No action is necessary.

For each road infrastructure topic, there are different questions that tackle all that has to be considered within it (i.e.: in road alignment there will be questions for lane width, shoulder width, etc.). Therefore, there will be a mark for each issue. In order to provide an evaluation of the whole topic, an average of the different issues is calculated. Thus, this average will always be comprised between 1 and 4.

4.6.7.4 Road Infrastructure Safety Assessment (RISA)

The New Zealand Transport Agency (NZTA) has developed a procedure called Road Infrastructure Safety Assessment (RISA) (Appleton, 2009), using benchmarking approach. RISA calculates the relative risk of each road assessed. The risk score is calculated per km of road so that roads of unequal lengths may be compared. The risk scores are relative risks and are called “Personal Risk”. A risk of 1.2 means that a person traveling on this road has a 20% higher risk of a crash than when traveling on the benchmark road. As a general rule low volume road have high risk relative to the benchmark road, and higher volume roads have a relative risk closer to the benchmark road. Additionally, the traffic volume is combined with the risk scores to create the “Collective Risk” i.e. the risk to all road users. The Collective risk relates to crash numbers. RISA takes the Collective Risk Scores and data on traffic volumes to scale up these results to the whole network and creates a Network Risk Number. This is an abstract number. It relates to the number of crashes on the network. The basis of RISA is the research that relates infrastructure features to crash rates. Therefore, the RISA Risk Scores, more specifically, the Personal Risk Scores, should relate to the actual crash rates on the roads assessed.

4.6.7.5 International Road Assessment Programme (iRAP) & Urban Road Safety Assessment Programme (KiwiRAP)

iRAP consisting of a number of evaluation tools; among them, the Road Protection Score (RPS). The RPS module assigns a road infrastructure safety level basing on how effectively the infrastructure prevents crashes and protects users involved in crashes. Based on the calculated RPS the road section is classified according to a five-level ranking (Star Rating Score).

Star Ratings Score (SRS) involve an inspection of road infrastructure attributes that are known to have an impact on the likelihood of a crash and its severity. Between 1 and 5-stars are awarded depending on the level of safety which is 'built-in' to the road. The safest roads (4- and 5-star) have road safety attributes that are appropriate for the prevailing traffic speeds. The least safe roads (1- and 2-star) do not have road safety attributes that are appropriate for the prevailing traffic speeds (International Road Assessment Programme (iRAP), 2014).

The SRS represents the relative risk of death and serious injury for an individual road user; and is calculated for each 100-metre segment of road and each of the four road users (vehicle occupant, motorcyclist, bicyclist, and pedestrian), using the following equation (International Road Assessment Programme (iRAP), n.d.):

$$SRS = \sum crash\ type\ scores \quad (17)$$

Where:

$$crash\ type\ scores = likelihood * severity * operating\ speed * external\ flow\ influence * median\ traversability \quad (18)$$

Where: *likelihood* = road attribute risk factors that account for the chance that a crash will be initiated; *severity* = road attribute risk factors that account for the severity of a crash; *operating speed* = factors that account for the degree to which risk changes with speed, *external flow influence* = the degree to which a person's risk of being involved in a crash is a function of another person's use of the road; and *median traversability* = the potential that an errant vehicle will cross a median (only applies to vehicle occupants and motorcyclists run-off and head-on crashes).

An SRS is only produced if a flow of the particular road user is recorded. For example, if no pedestrians are present, then no SRS is produced. SRS are also not produced when major road works are being undertaken.

KiwiRAP is part of an international family of Road Assessment Programmes (RAP) under the umbrella of the International Road Assessment Programme (iRAP). Urban KiwiRAP looks to apply road risk ratings to major urban networks, use the Star Rating system and there are two components of the risk assessment model; an intersection component and a corridor component (Brodie et al., 2013).

4.6.7.6 Safety Index (SI)

Habibian et al. (Habibian et al., 2014) proposed a framework to identify and rank hazardous road locations in two-lane rural roads. In this study, an audit-based framework is proposed to carry out a preliminary assessment of the safety level of a road network. Based on this assessment, the potential hazardous road locations are identified. Thus, the priority of data collection for an elaborated study is determined using the results of the preliminary assessment. The developed framework uses an expert panel investigation and Analytical Hierarchy Process (AHP) method. A road is decomposed to six elements, namely, straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use. For each element, a list of intervening safety factors is also described. The AHP method is used to find out the weight of the elements and factors.

In order to calculate the weight of the categories, a questionnaire was designed. In the designed questionnaire the relative importance of the elements and factors affecting road safety were stated by road safety experts. Later, during the road safety audit, a score is assigned to each factor. The weighted sum of these ranks is used to calculate a Safety Index (SI) for a road segment. Road segments with the lowest values of SI are identified as the most hazardous locations.

4.6.7.7 Risk Factor Index (RFI)

The RFI was established and adapted to measure the safety hazards condition on the selected highways in Sudan (Mohamed Eltayeb Zumrawi, 2016). The rating system consists of identification number for each surveyed item and rating score (from 0 to 10) according to its availability and conditions. The RFI is defined as a numerical indicator which rates the safety hazards condition of the existing road. The RFI provides feedback on road safety performance for validation or improvement of current road design and maintenance procedures. A numerical rating of the RFI ranges from (0) to (10) with (0) being the lowest possible condition and (10) being the highest and worst possible condition.

4.6.7.8 Infrastructure Risk Rating (IRR)

The IRR (Chhanabhai et al., 2017), developed in New Zealand, is a simplified-risk based road assessment methodology, based on fewer features than other road risk tools. IRR scoring is based on the input of ten variables to determine nine road features: Road stereotype; Carriageway width; Land Use; Access Density; Speed; Alignment; Roadside Hazard Risk (Left and right side assessed separately and averaged.); Intersection Density; Traffic Volume. Based on the calculated IRR the homogenous section is classified according to a seven-level ranking (from very low to very high). Homogenous sections with the highest values of IRR are identified as the most hazardous locations.

4.6.7.9 Fully Automated Roadway Safety Assessment (FARSA)

In 2018, Song et al. (Song et al., 2018) proposed a deep convolutional neural network (CNN) architecture for automatic road safety assessment. The process was called: Fully Automated Roadway Safety Assessment (FARSA). From the protocols of the United States Road Assessment Program (usRAP), the CNN architecture directly estimates the star rating from a ground-level panorama. The network also estimates many other road level attributes, including curvature, roadside hazards, and the type of median. To support this, the authors incorporated task specific attention layers so the network can focus on the panorama regions that are most useful for a particular task.

The base CNN architecture takes as input a street-level, equirectangular panorama (e.g., from Google Street View) and outputs a categorical distribution over a discrete label space. The focus is on the roadway safety label space, which is defined by usRAP to have five tiers.

4.6.7.10 Potential Risk Assessment (PRA)

This methodology (Antonio Martín-Jiménez et al., 2018) allows to evaluate road safety from Mobile LiDAR System data, taking advantage of the road alignment due to its influence on the accident rate. Automation is obtained through an inductive reasoning process based on a decision tree that provides a potential risk assessment. To achieve this, a 3D point cloud is classified by an iterative and incremental algorithm based 1on a 2.5D and 3D Delaunay triangulation, which apply different algorithms sequentially. Next, an automatic extraction process of road horizontal alignment parameters is developed to obtain geometric consistency indexes, based on a joint triple stability criterion.

Similarly, through this methodology the potential risk assessment (PRA) was calculated. This index is exclusively derived from a coarse-to-fine approach using point clouds as input data: from the automatic segmentation of roads and the extraction of its horizontal alignment parameters.

4.6.7.11 Branch Index Risk (BIR) & Section Index Risk (SIR)

In 2018, an analytical methodology for the assessment of the accident risk for Vulnerable Road Users (VRUs) (pedestrians, cyclists and motorcyclists) in urban context was proposed (Demasi et al., 2018). This consists of a quantitative approach to assess the Branch Index Risk (BIR) and the Section Index Risk (SIR) of existing urban roads considering their geometry, layout, users, and traffic. The proposal relies on data collected during road safety inspections. From the road inspections, the authors identified nine categories of elements/defects of infrastructure which could cause accidents: geometry; cross-section; private access; pavement; lighting; road signs; intersection; urban furniture; and stopping.

The method depends on the assumed ranges of variables and risk classes, as well as on the values attributed to the variables used for calculating the hazard index of examined homogeneous road sections and branches. Therefore, both SIR and BIR depend on geometric, functional, physical, and environmental defects or elements which are a potential source of road accidents. These factors are then related to the involved vulnerable road users and to existing traffic flows to assess the current levels of risk. The categorization of these values into six levels of risk allows the identification of the most severe conditions and the prioritization of road safety works.

4.6.8 Geographical implementation and Validation

The geographical implementation refers to the country (ies) and total km where the methodologies have been tested. The relationship between indicators based on accidents and indicators based on road infrastructure characteristics has already been investigated in the literature (Persia, Gigli, Azarko, & Usami, 2020). For this review, validation is defined as the relationship between the indicators used within these methodologies and road traffic crash data. In this way, the validation results are expressed with the coefficient of determination (R^2) (Table 4-4).

Table 4-4 Summary of geographical implementation and validation

Literature reference	Geographical implementation	Validation	Validation Results (R^2)
Montella (2005) (Montella, 2005)	406 km in Italy	Yes	0.930
Cafiso et al. (2007) (Salvatore Cafiso et al., 2007) (2011) (Salvatore Cafiso, La Cava, & Montella, 2011) (2014) (S. Cafiso, Kieć, Milazzo, Pappalardo, & Trovato, 2014)	200 km in Italy and 100 km in Poland	Yes	0.870 in Italy and positive correlation in Poland
RANKERS (2008) (Perandones & Ramos, 2008)	44 km in Spain	No	n/a
Appleton (2009), RISA (Appleton, 2009)	Periodic procedure on New Zealand roads	Yes	0.6132
iRAP* (2009) (IRAP, 2009)	Worldwide, over 100 countries	Yes	Positive correlation
Habibian et al. (2011) (Habibian et al., 2014)	Two-lane rural roads in Iran	No	n/a
Brodie et al. (2013), Urban KiwiRAP (Brodie et al., 2013)	Periodic procedure on New Zealand urban roads	Yes	Positive correlation
Zumrawi (2016) (Mohamed Eltayeb Zumrawi, 2016)	3,350 km in Sudan	No	n/a
Chhanabhai et al. (2017) (Chhanabhai et al., 2017)	40 road segments in New Zealand	Yes	0.974
Zia et al. (2019) (Zia et al., 2019)			
Song et al. (2018), FARSA (Song et al., 2018)	Urban and regional regions in USA	No	n/a
Martín-Jiménez et al. (2018) (Antonio Martín-Jiménez et al., 2018)	8,6 km of road segments in Spain	No	n/a
Demasi et al. (2018) (Demasi et al., 2018)	50 km in Italy	Yes	Positive correlation

Regarding the iRAP methodology, different validation studies have been carried out (Persia et al., 2020). Vlakveld & Louwerse (Vlakveld & Louwerse, 2011) found that as the number of stars increases (safer roads), the average serious accidents rate per million vehicle-km decreases. However, they showed a high variance in the accident rate linked to the presence of road sections where no serious accidents occurred. Harwood et al (D. Harwood, Bauer, Gilmore, Souleyrette, & Hans, 2010) have verified that the accident rate decreases in a statistically significant way along with the increase in the number of stars (safer roads). They also investigated the type of accidents involved, finding for instance a significant relationship for run off road accidents on single carriageway two-lane roads and dual carriageway six-lane roads. An Australian study (McInerney et al., 2008) examined the relationship between the number of stars (and RPS) and accident costs per vehicle-km. In this study, road sections have been grouped by number of stars by calculating an average cost per vehicle-km. As the number of stars decreases, the cost per vehicle-km increases. A regression analysis between RPS and cost per vehicle-km was also attempted, however, the wide variability observed in the results discouraged this approach. Persia et al (Persia et al., 2020) found that only in the case of models with accidents as dependent variable, where it was possible to define a functional link between available EuroRAP indicators and related accident frequencies, it was observed that EuroRAP indicators are sufficiently explanatory.

4.7 Road Safety in Developing Countries: Evidence from *SaferAfrica* project

Progress in reducing road traffic deaths over the last few years varies. Significantly between the different regions and countries of the world. There continues to be a strong association between the risk of a road traffic death and the income level of countries. With an average rate of 27.5 deaths per 100,000 population, the risk is more than 3 times higher in low-income countries than in high-income countries where the average rate is 8.3 deaths 100,000 population. As shown in Figure 4-10 the burden of road traffic deaths is disproportionately high among low- and middle-income countries in relation to the size of their populations and the number of motor vehicles in circulation. Although only 1% of the world's motor vehicles are in low-income countries, 13% of deaths occur in these countries (World Health Organization, 2018).

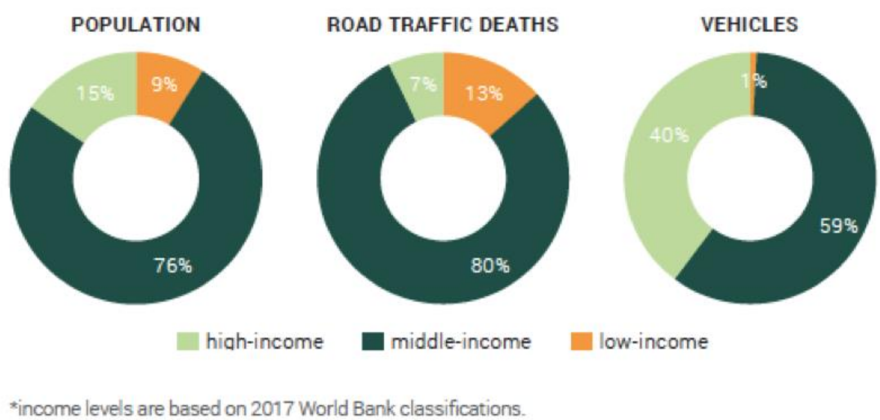


Figure 4-10 Proportion of population, road traffic deaths, and registered motor vehicles by country income category (WHO, 2018)

According to the WHO (2018), countries in the Americas and Europe have the lowest regional rates of 15.6 and 9.3 deaths per 100,000 people respectively. While Africa is the worst performing continent in road safety (Figure 4-11). In the same way, in Africa there is an observable difference between middle-income countries, which have a rate of death of 23.6 per 100,000 population and low-income countries, where the rate is 29.3 per 100,000 population.

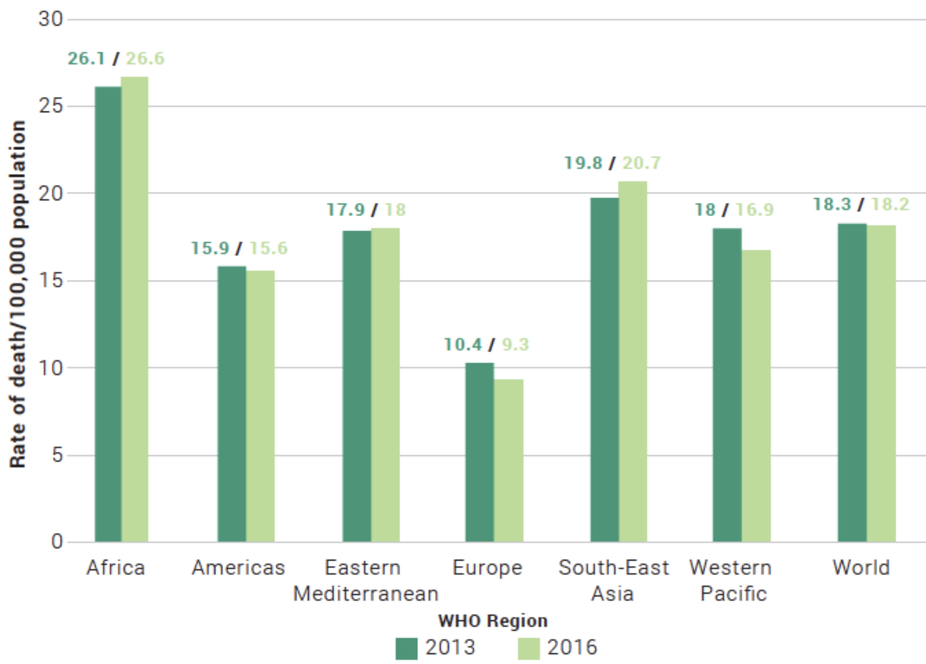


Figure 4-11 Rates of road traffic death per 100,000 population by WHO regions:2013, 2016 (WHO, 2018)

In order to improve road safety performance in African countries, many barriers need to be overcome. Among them stands the substantial lack of detailed knowledge on road casualties in terms of their number as well as associated factors leading to road accidents or affecting their consequences. There is a serious lack of road safety data in African countries, and even when data are available (e.g. through the reports of WHO, International Road Federation - IRF, etc.), little is known about data collection systems, data definitions, etc. (Thomas et al., 2017)

In 2011 the Africa Road Safety Action Plan (ARSAP) established an Action Plan to meet the objective of reducing road traffic crashes by 50% by the year 2020. Despite this initiative, the situation worsens year after year. To contribute reverse this trend, the *SaferAfrica* project, a joint effort of 16 partners from Africa and Europe, was launched in 2016. The *SaferAfrica* project was founded by the European Commission under the Horizon 2020 Mobility for Growth, carried out between October 2016 and September 2019. The project aims at establishing a Dialogue Platform between Africa and Europe focused on road safety and traffic management issues. It will represent a high-level body with the main objective of providing recommendations to foster the adoption of specific initiatives, properly funded.

The overall concept of *SaferAfrica* is depicted by a pyramid articulated in three levels, shown in Figure 4-12. The top of the pyramid represents road safety and traffic management actions oriented to the “Safe System approach”. The other two levels represent the Dialogue Platform (DP). Of these two levels, the higher one is a decision-making level, namely the Institutional level, while the lower one constitutes the Technical level. These two levels are closely interconnected to foster the appropriate match between African road safety policy evolution, application, knowledge enhancement and institutional delivery capacity.

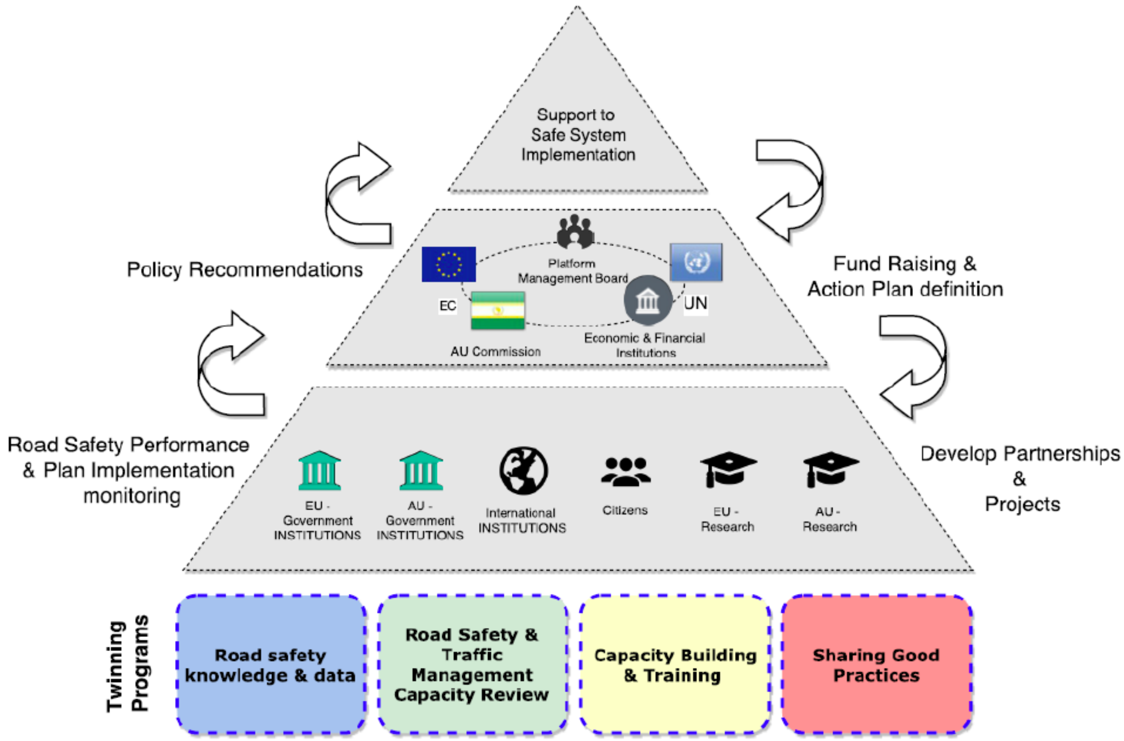


Figure 4-12 SaferAfrica overall concept (SaferAfrica, 2016)

The pyramid is based on the four building blocks, defined according to the priorities highlighted by the Africa Road Safety Action Plan:

1. Road safety knowledge and data with the specific objective of setting up the African Road Safety Observatory;
2. Road safety and traffic management capacity reviews;
3. Capacity building and training;
4. The sharing of good practices.

In order to assess the needs of stakeholders involved in road safety in terms of knowledge and information tools and convey a clear view of current road safety practices followed in Africa, two-fold surveys as well as existing road safety analysis documents were exploited. The surveys consisted of a brief questionnaire in order to point out the current status in each country in terms of basic road safety aspects and definitions, followed by an extensive one where, besides other concerns, detailed demands and views of road safety stakeholders, not necessarily directly involved in decision-making, in each examined African country were recorded. Furthermore, existing road safety analysis documents were exploited; namely the Global Status Report on Road Safety (WHO, 2015) and the IRF World Road Statistics 2016 (IRF, 2016) reports (Thomas et al., 2017).

This first survey addressed an initial approach to identify per country the current status in terms of basic road safety management and data collection practices. Representatives from 20 African countries, mainly from the West, East and South regions of the African continent took part in this survey. Most of the respondents had a significant experience in the field of road safety (over 10 years), thus the information they provided is considered accurate and reliable.

Experts from all countries stated emphatically the high importance of data and knowledge to support road safety activities. This is a clear indication of the urgent need for the improvement of data and information availability with regard to the improvement of road safety in African countries.

The second survey included questions on road safety management and data collection practices, road safety resources and basic road safety data developed appropriately to reflect the conditions in Africa. This survey was filled-in by 29 stakeholders from 21 African countries. The majority of the replies were received by governmental representatives.

All the information presented in the following section (2.1.1) is from Deliverable 4.1: Survey results: road safety data, data collection systems and definitions (2017) of *SaferAfrica* project.

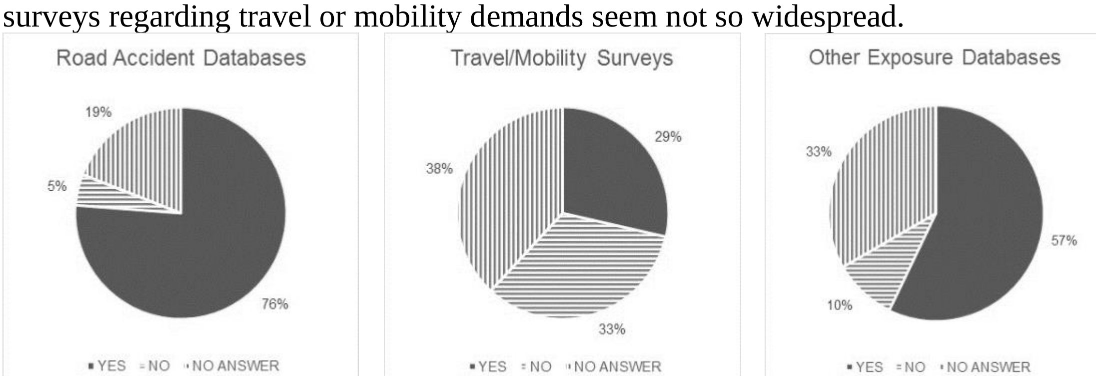
4.7.1 Road safety data collection systems in Africa countries

4.7.1.1 General

The present section aims in clarifying the current status in terms of the existence, extent and level of road safety data collection systems in African countries.

As an initial approach the existence of road safety databases and information at national level in the examined countries was explored through question: "Do you use any national databases/information sources? a. Road accident databases; b. travel/mobility survey results; c. other exposure databases (e.g. vehicle fleet); d. other, please specify". Alternative answers for each database/source: yes, no, don’t know).

From Figure 4-13 it can be seen that in most examined countries there are formal systems in place for recording road accidents. Also, it is interesting to know that other exposure databases are utilized in more than 50% of the countries. On the other hand, surveys regarding travel or mobility demands seem not so widespread.



(a) (b) (c)

Notes: a: No feedback provided from Kenya, South Sudan, Senegal and Tunisia
b: No feedback provided from Benin, Kenya, Sierra Leone, South Africa, South Sudan, Senegal, Tanzania and Tunisia.
c: No feedback provided from Gambia, Kenya, Sierra Leone, South Sudan, Senegal, Tanzania and Tunisia.

Figure 4-13 Existence and use of databases – information at national level

As a second approach, core road safety management concerns related to data collection practices in the examined African countries, were addressed from the road safety monitoring and evaluation points of view. The replies per country for these basic aspects, are shown in Table 4-5. In the first column of Table 4-5, shortcuts of the questions on availability of road safety management items are shown. The alternative answers were: yes, no, don't know.

Table 4-5 Basic aspects in monitoring and evaluation of road safety data collection practices in African countries

		Eastern Africa					Central Africa		Southern Africa				Western Africa									Northern Africa
		KENYA	MALAWI	MAURITIUS	SOUTH SUDAN	TANZANIA	CAMEROON	DR CONGO	BOTSWANA	LESOTHO	SOUTH AFRICA	SWAZILAND	BENIN	BURKINA FASO	THE GAMBIA	GUINEA	MALI	NIGERIA	SENEGAL	SIERRA LEONE	TOGO	TUNISIA
1	Sustainable systems to collect/manage data on road accidents, fatalities and injuries	√	√	√	N/A	√	√	√	√	√	√	√	U/K				√	√	√	√	U/K	√
2	Sustainable and reliable in-depth accident investigations for road safety purposes		√				√	√		√							√	√	√		√	N/A
3	National Observatory centralizing data systems for RS		√				√	√		√	√		U/K	√			√	√			√	√
4	Reporting process been set up to monitor road safety interventions	N/A	√	U/K			√	√			√			√			√	√				√
5	"Benchmarking" used to monitor progress in the road safety situation			U/K	N/A			√			√			√			N/A	√	N/A	√		√

Notes: √: Yes, Empty cell: No, N/A: No Answer, U/K: Unknown.

Experts revealed that sustainable and reliable systems (durable, funded and maintained) to collect and manage data on road accidents, fatalities and injuries are available for a number of African countries. On the other hand, sustainable in-depth accident investigations for road safety purposes seem to be conducted for 8 out of 21 examined countries (Malawi, Cameroon, D.R. of the Congo, Lesotho, Mali, Nigeria, Senegal and Togo). A national observatory centralizing the data systems for road safety is available in almost 50% of the responding countries. On the whole, the same countries also have a reporting procedure to monitor road safety interventions in place. Last but not least, benchmarking is not really utilized in most countries except for D.R. of the Congo, South Africa, Burkina Faso, Nigeria, Sierra Leone and Tunisia.

4.7.1.2 Road accident data

As seen through Table 4-5, for 10 countries a national observatory is available for centralizing the data systems for road safety. For these countries, different types of data included in the national observatory were further specified through question: "Is there a national Observatory centralizing the data systems for road safety? If yes, does it include data on: accidents; fatalities or injuries; in-depth accident investigations; behavioural indicators; exposure (traffic); violations or fines; driver licensing; vehicle registration; other data (please specify)". Alternative answers were: yes, no, don't know.

Although in general such data vary, all 10 countries incorporate in their observatories data on accidents, fatalities and injuries, 50% of them incorporate data regarding in-depth accident investigations, and also 50%, data on behavioural indicators.

Monitoring road safety interventions through a reporting process is available for 8 of the examined African countries (Table 4-5) (Question: "Has a reporting procedure been set up to monitor the road safety interventions carried out in the country?"). Aiming to further understand such practices in these countries, further questions were addressed and the results are presented below.

The reporting of monitoring road safety interventions is mostly linked to intermediate phases of the country's national road safety programme as found in 4 out the 8 countries of Table 4-5 (Question: "Is the reporting: periodical; linked to intermediate phases of the RS programme?").

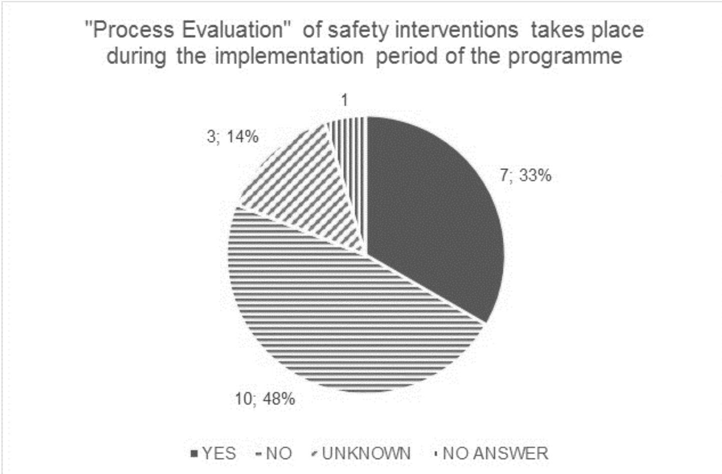
On the other hand, the most common areas of intervention to which the reporting procedure applies are driver training, campaigns, enforcement and vehicle related measures (Question: "Does reporting apply to all areas of intervention: Engineering measures on rural roads; Planning and engineering interventions in urban areas; Enforcement operations; Traffic education; RS campaigns; Driver training; Vehicle related measures; Others (please specify").

Another interesting fact of the reporting process to monitor road safety interventions is related to the level at which this is performed, which is mostly performed at regional/local (60%) level and only in 3 countries at national level (covering ministries, government agencies, etc.) as well (Questions: "Is reporting performed “horizontally” at the national level (covering ministries and government agencies)?" and "Is reporting performed “vertically” to cover activities at the regional and/or the local level?").

However, the information of this process is addressed mainly to the road safety lead agency or the government itself (Question " Is the information addressed to?: the Lead Agency; the high level inter-sectoral decision-making road safety institution; the technical inter-sectoral road safety institution; the government; the Parliament?".

An additional but also important issue of concern is whether certain actions have been taken based on the information collected through the reporting process and towards which direction (Question: Has some action been taken on the basis of the outcome of this information: limited changes in the action programme; allocation of funds or human resources; training; others (please specify)) It was found that these actions in most cases (75%) concern training as well as slight changes in the action programme, while allocation of funds or human resources take place in less than 50% of these 8 countries.

Safety interventions need time to show results. However, it is important to check whether such measures work as expected and do not generate undesired side-effects (Question: "Does some "process evaluation" of safety interventions take place during the implementation period of the programme (i.e. checking that measures work as expected and do not generate undesired side-effects)?". It was found that such a process is undergoing in approximately 35% of all the examined countries (Figure 4-14). Additional responses from these 7 countries which provide further insight into this process are summarized below.



Notes: The number of respondents and the respective percentage per answer alternative are shown in the graph. No feedback provided from South Sudan.

Figure 4-14 Existence of process evaluation for Safety interventions

It was found that in all 7 countries the evaluation for interventions addresses road safety campaigns, in approximately 70% it addresses enforcement and vehicles and in around 50% other areas (Question: "Is the evaluation for interventions addressing: all areas; infrastructure; vehicles; enforcement; road safety campaigns; other areas (please specify)?").

The evaluation is performed using observations and/or field surveys or measurements in 5 of the countries, whilst, for this task, safety performance indicators are utilized by 4 countries. (Question: "Does it involve: performance indicators; observations and/or field surveys or measurements?").

Scientific expertise seems to be present in performing process evaluation in more than 50% of the countries (Question: "Are scientific expertise involved in performing process evaluation?") while the evaluation results are available to all stakeholders in 70% of the countries (Question: "Are the evaluation results available to all stakeholders?").

Finally, actions taken on the basis of the evaluation process results for most of these 7 countries involve both improvements of the implementation conditions and well as partial changes in the action programme (Question: "Has some action been taken on the basis of the outcome of this information such as: partial changes in the action programme; improvement of implementation conditions?").

Furthermore, a process to assess the effects on accidents and injuries or socio-economic costs of certain policy components seems to be available in 6 (29%) of the examined 21 countries (Question: "Has an evaluation process been planned to assess the effects on accidents and injuries or socio-economic costs of some policy components (“product” evaluation)?").

For these 6 countries the areas of interventions covered by the evaluation plan are mainly enforcement and vehicle related measures, while infrastructure is slightly less covered (Question: "Which areas of intervention are covered by the evaluation plan: infrastructure; enforcement; vehicle related measures; others (please specify)?").

4.7.1.3 Risk exposure

The amount of travel in each country is one of the main determinants of road fatality risk. However, traffic measurements are not systematically carried out in all countries. In general, the lack of sufficient and reliable exposure data is still a major limitation of road safety analyses and may significantly affect the potential for evidence-based policy making in the African countries, regions and cities.

In terms of data collection systems, availability of exposure indicators was found in the examined countries' national observatories. As already discussed (Table 4-5), a national observatory for centralizing the data systems for road safety seems to be available in 10 countries. From these 10 countries managing national observatories, approximately 50% (5 countries) seem to include exposure data in them.

4.7.1.4 Road safety performance indicators

In order to develop effective measures to reduce the number of accidents/injuries it is necessary to understand the processes that lead to accidents. Safety Performance Indicators (SPIs) can serve this purpose since by providing information, they serve as a link between the casualties from road accidents and the measures to reduce them.

Road users' behavioural aspects are a vital field of safety performance indicators. The collection and management of such information are assessed through certain behavioural indicators, such as speeding, drinking and driving, use of protection systems, distraction, etc.

Concerning data on behavioural indicators (Question: Are sustainable and reliable systems in place to collect and manage data on behavioural indicators: vehicle speeds; safety belt wearing rates; alcohol-impaired driving; others, please specify), a sustainable system for their collection and management is in place for less than 50% of the 21 questioned countries. For example, safety belt wearing rates are systematically collected and managed in fewer countries (7 countries) compared to speeding and alcohol impaired driving (9 countries).

During the implementation period of a country's national programme or policy, it is very important to assess its safety performance (Question: Has a procedure been set up to evaluate safety performances of the national programme or policy? If yes, are the performances assessed on the basis of performance indicators; against national quantitative targets?). Unfortunately, such a process is currently available in only 4 countries (19%), where the safety performance is assessed based on national quantitative targets as well as on performance indicators.

5 METHODOLOGY

This chapter gives an overview of the methodology proposed, in order to develop and pilot a new simplified methodology for road infrastructures' safety assessment.

This research was based on the following aspects and criteria with which were compared and analyzed different Road Assessment Program (RAP) methodologies in section 2.6: theoretical approach; road segmentation; road users, qualifications of safety personnel, data source and way(s) of data collection; key parameters; method calculation; and geographical implementation and validation.

The main steps of the methodology and their interrelation is shown in Figure 5-1. This is structured in the following four main components: (1) methodology-related information, (2) data-related information, (3) new simplified methodology, and (4) piloting and validation.

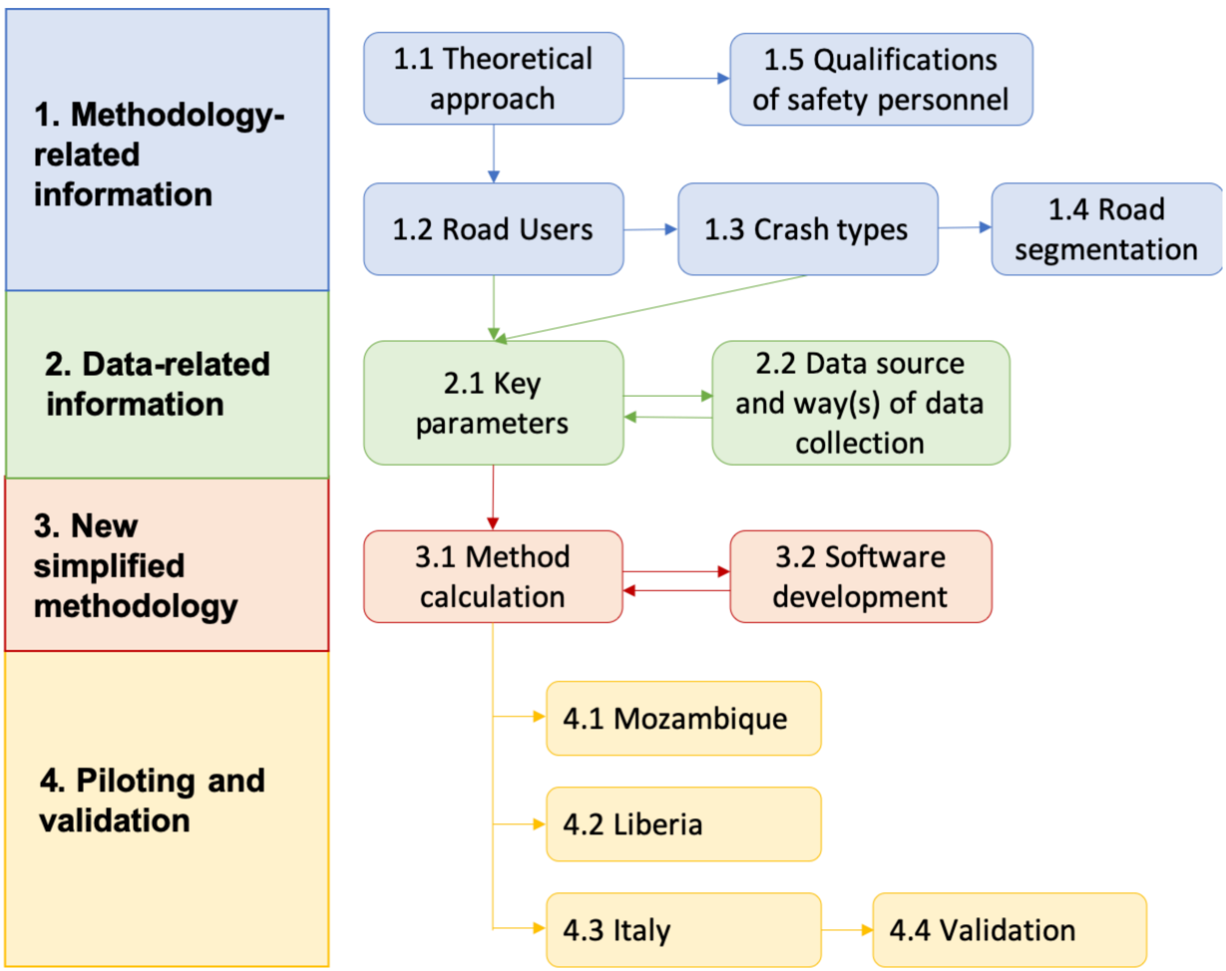


Figure 5-1 Main steps of the methodology

5.1 Methodology related-information

The proposed methodology is based on the concept of Crash Modification Factor (CMF): a multiplicative factor used to compute the expected number of crashes after modifying the road characteristics at a specific site (e.g. by implementing a given countermeasure). A CMF higher than one is assumed to increase the likelihood or severity of a target accident type, while if lower than one it decreases accident likelihood/severity.

Thus, the common definition given by the combination of key factors such as Danger (likelihood that a crash can happen), Vulnerability (risk of injury of road users given a crash occurred) and Exposure (amount of "activity" a user is exposed to a risk), to calculate a risk index based on the physical characteristics of the road was used.

The resulting formula for risk assessment is thus as follows
Risk=Danger**Vulnerability*Exposure*
(19):

$$Risk = Danger * Vulnerability * Exposure \quad (19)$$

Likewise, the proposed methodology allows the automatic recognition of road attributes from video images, as well as the calculation of the risks of road users automatically through software.

Starting from the formula above, some road user categories were considered for the risk assessment. Examples of road user categories universally recognised as being at risk of road traffic crash are:

- car drivers and passengers;
- heavy vehicles;
- vulnerable road users such as motorcyclists, bicyclists and pedestrians.

Some other road user categories could be considered due to their high vulnerability, such as children and elderly.

Initially, the following road users were considered:

- Passenger car occupants
- Heavy vehicles
- Motorcyclists
- Cyclists
- Pedestrians

The capabilities of recognition of features in an image or video have increased significantly over the last years. However, during the preliminary test carried out in order to adjust the algorithms related to the video performances, problems were identified regarding the counting of passenger vehicles, heavy vehicles and motorcycles. Furthermore, in the current state of the art on CMFs, there are no relevant references regarding heavy vehicles and motorcycles. Therefore, it was decided to group all motorized vehicles as a single user of the road.

In this way the following three road user categories were defined:

- Motor-vehicles (passenger car, heavy vehicles, motorcyclists)
- Cyclists
- Pedestrians

For each of these categories, different crash types were considered, the following are connected to more frequent road traffic crash occurring:

- Head-on collisions of two vehicles (typically car to car (Figure 5-2a), car to motorcycle, motorcycle to motorcycle).
- Lateral collisions of two vehicles (typically at intersections (Figure 5-2b) or access points (Figure 5-2c)).
- Lateral collision of a vehicle with a road user travelling along the road (typically a cyclist (Figure 5-2d) or a pedestrian (Figure 5-2e)).
- Single vehicle crash, such as running-off the road (Figure 5-2f) of collision with obstacle.

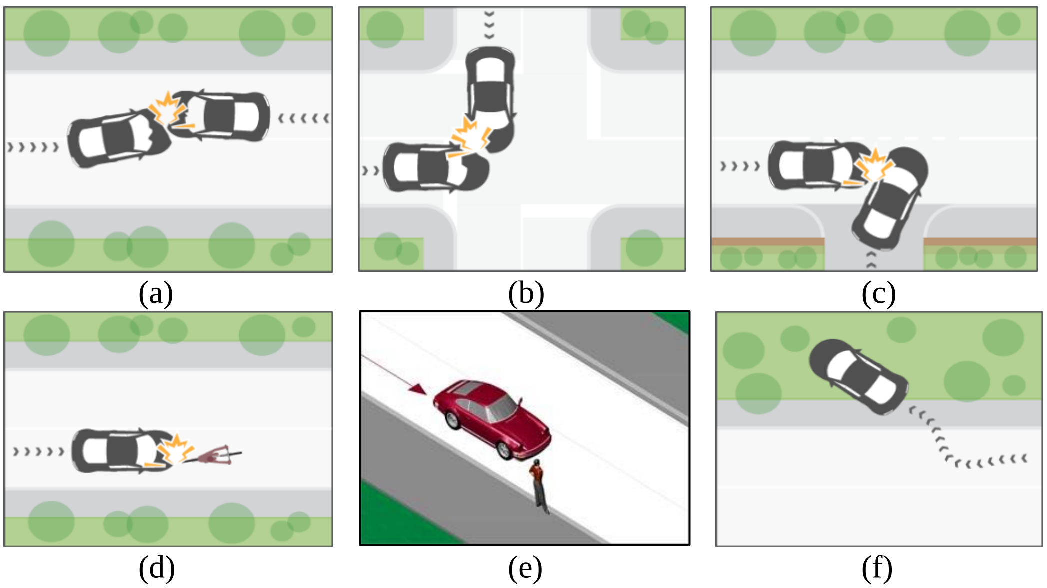


Figure 5-2 Examples of crash types

These crash types have been grouped. Thus, the following three road conditions were defined:

- Along the road (i.e. when a road user is travelling or walking along the road)
- At intersections (i.e. when a road user is crossing an intersection while travelling along the road – valid for motor-vehicles and bicycles)
- While crossing a road (valid for pedestrians)

After this, the homogeneous road segments were defined. As shown in the literature review, this is one of the key steps in assessing road safety risk.

The length to be considered for road sections was decided during the preliminary test carried out in order to adjust the algorithms related to the video performances, so that the entire process could be automated with a software solution. As first orientation, road lenghts of 100 m were considered, providing a good balance between computational difficulties and precision of results.

Thus, two different road sections were defined:

- 100m road sections
- 100m road sections where intersections and/or access points are present

The proposed methodology mainly focuses on rural two-lane highways. However, it should also be considered that, in most of developing countries, national highways often cross built up (urban) areas. In this way, during the pilot in Mozambique and Liberia the methodology was applied in built-up areas.

The experience and skills of the technical team play an essential role in the process. The proposed methodology requires a team of a least 2 people. A road safety expert/auditor and a driver. The road safety expert/auditor must have university-level preparation and demonstrated experience in road highway design, accident analysis, traffic engineering, or other activities related to road safety, according to the procedures defined in the Italian road safety audit guidelines (Public Works Ministry of Italy, 2001).

5.2 Data related-information

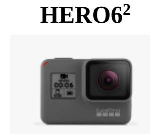
During this section on data related-information, the data sources and ways of data collection are described, as well as the key parameters selected for the proposed simplified methodology. As mentioned earlier in Chapter 2, during the data collection process each methodology considers different attributes affecting risk safety on roads. Additionally, most of the existing methodologies perform the data collection process manually.

5.2.1 Data source and way(s) of data collection

One of the main objectives of this research was to choose a set of attributes to be used for the simplified methodology, considering the impact on road safety risk and the feasibility of automated image analysis.

For the above, three different cameras (dashboard and sport cameras) from several well-known manufacturers were compared (Table 5-1). A set of six preliminary main criteria (image resolution, geo-referenced videos, connection to a computer/table, storage needs, power needs, and others) has been considered to carry out a first assessment of a brunch of low-cost cameras available in the market.

Table 5-1 Digital cameras and equipment characteristics

Manufacturer		NEXTBASE	GOPRO	GARMIN
Model		**612GW[1]** 	**HERO6[2]** 	**65W[3]** 
Type		Dash cam	Sport cam	Dash cam
Image resolution	**Photo resolution**	---	12 Mp/30 fps	2.1 Mp
	Video resolution	4k Ultra HD 3840x2160p @30 fps	4K @60 fps 2.7K @120 fps 1080p @240 fps	1920 x 1080p @30fps
	Low light conditions	Yes	Yes	Yes

[1] https://www.nextbase.co.uk/dash-cams/612gw-4k-dash-cam/ [accessed on 3 April 2018]
[2] https://shop.gopro.com/EMEA/cameras/hero6-black/CHDHX-601-master.html [accessed on 3 April 2018]
[3] https://buy.garmin.com/en-US/US/p/587334 [accessed on 3 April 2018]

Manufacturer		NEXTBASE	GOPRO	GARMIN
	Wide viewing angle	150º	170º	180º
	Windscreen glare removing	Yes	Not	---
Geo-referencedvideos	**GPS integrated**	Yes (location + speed)	Yes	Yes
Connection to a computer/ tablet	**Wi-fi / cable**	Wi-Fi	Wi-Fi / Bluetooth	Wi-Fi
Storage needs	**External storage support**	Up to 64 GB Micro SD card	Up to 128 GB Micro SD card	Micro SD card
Power needs	**Battery autonomy**	Always connected to the power	It depends on video recording resolution	30 min. Possibility to be connected to the power
	Connection to car power	12/24V Vehicle power cable	USB cable	12/24V Vehicle power cable
Others	**Display screen**	3" HD screen	2" HD screen	2" HD screen
	Voice control	Not	Yes	Yes
	Price	300 €	430 €	250 €

All analysed cameras offer a minimum video resolution of 1920 x 1080p at 30 frames per second (some of the assessed cameras offer higher image resolution), with a wide viewing angle ranging from 150 to 180 grades. The majority are equipped with polarizing filters or lenses to remove windscreen glare, and are able to record videos at low light conditions.

All cameras are equipped with an integrated GPS in order to geo-reference the road travelled, but no specifications about the GPS accuracy have been found. 612GW camera from Nextbase is the only one specifying that its GPS is able to record location and speed data.

All cameras can be connected via Wi-Fi with a mobile device (mobile phone or tablet) in order to play back footage quickly and easily on the device. All cameras offer specific software with full editing capability to edit and share video files, but no specifications about the video format were found.

All cameras need micro SD cards (from 32 Gb to 128 Gb) to store the video files. Duration of video recording are mainly linked to the capacity of micro SD cards. All cameras, but Hero6 from Go-Pro, can be directly connected to the power of the vehicle, avoiding the limitation of batteries.

5.2.1.1 Preliminary test

The equipment for video recording has been preliminary tested on short roads in Rome (Italy) and Roquetas (Spain) in April of 2018, with the main objective of defining the main operating conditions for videos and establishing the procedures to adjust the algorithms. During the three inspections variable weather conditions were encountered, generally cloudy with isolated episodes of rain that, however, did not affect the tests. Traffic was generally ranging from low to very low.

The first road section inspected (Via di Tor Cervara) is in a peripheral area of Rome, in the east part of the city. The length of this road was about 3.3 km (see map in

Figure 5-3). It is a single carriageway with two lanes. Even if inside the urban area of Rome, this road was selected due to its characteristics in some extend similar to that of Mozambique and Liberia. This rural road is currently not well maintained (e.g. the marking and road surface are often poor along the road). Its lanes are narrow (about 2.8 meters each) and the road side conditions are poor (

Figure 5-3b,c).

The test on this road was executed using the **Garmin 65W** camera. Two different resolutions were tested (720p / 30fps and 1080p / 60fps). The road was driven several times in the two directions, using the two resolutions. In both cases the quality of the videos was judged good and certainly sufficient for the image analysis.

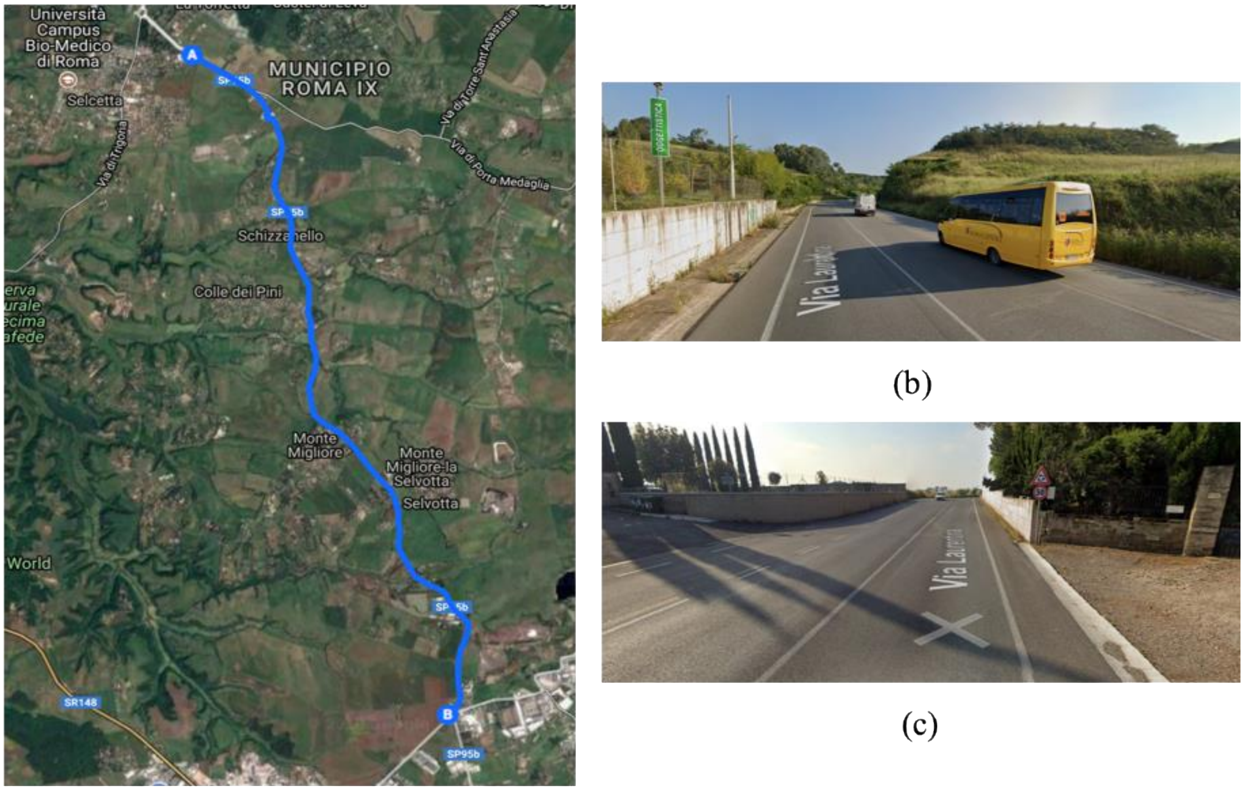
(a)

(b) (c)

Figure 5-3 First road tested - Via di Tor Cervara in Rome, Italy. Source: Google Maps

A second test was carried out in a rural road south of Rome (Via Laurentina). This road has a particular cross-section, with one lane in one direction and two in the opposite (one only for buses, Figure 5-4b, c). The alignment is rather rolling. The length of the inspected road section is about 10.5 km (Figure 5-4).

The camera used was the **Nextbase 612GW** set initially with maximum resolution (4K). The resulting video had excellent quality, but, on the other hand, the resulting files were very heavy (1 GB per 3 min video), making their storage and processing rather difficult. Then the 1080p 30fps resolution was tested, with a better result in the weight of the files, 273 MB per 3 min video.



(a)

Figure 5-4 Second road tested – Via Laurentina in Rome, Italy. Source: Google Maps

A third road section was also inspected in Spain (Camino de las Salinas). It is a suburban road that links two urban areas of Roquetas de Mar city. The length of this road was about 2.4 km (Figure 5-5a). The typical cross section is composed by a single carriageway with two 3.5 m width lanes and small shoulders (Figure 5-5b, c). The road section has similar characteristics to the ones of Mozambique and Liberia.

The test on this road was executed using the **Hero 6 GoPro** camera. Just one resolution was tested (1080p/ 30fps). The road was driven once in the two directions. The quality of the videos was judged good and certainly sufficient for the image analysis.

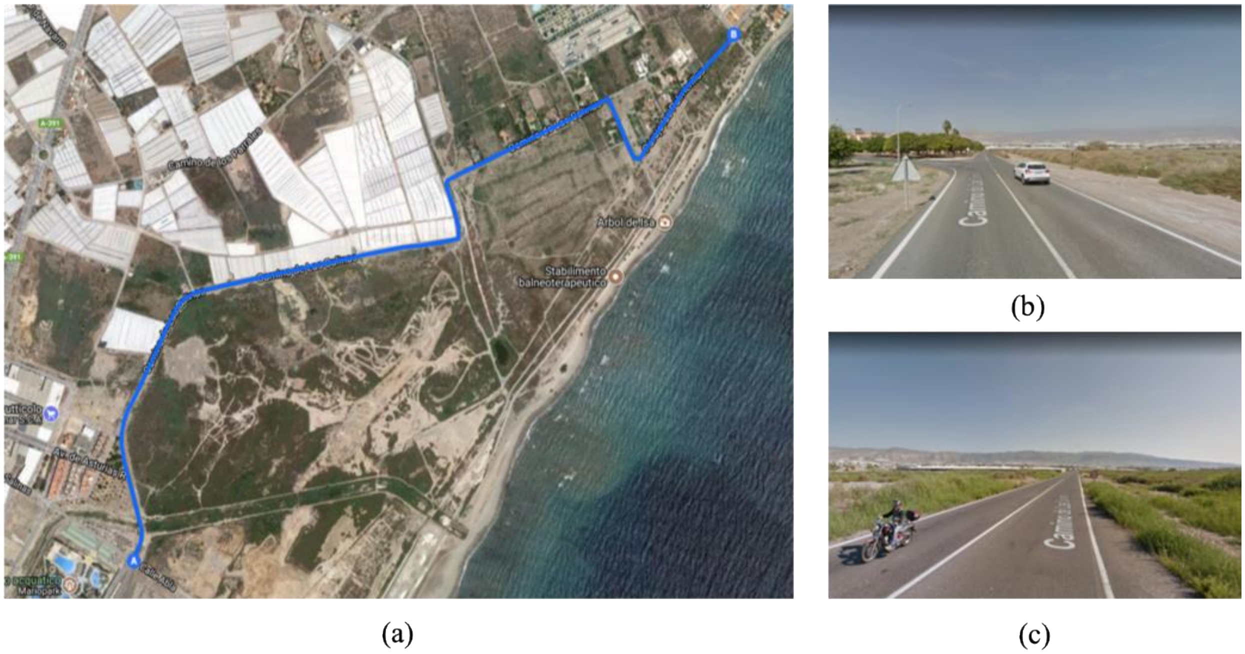


Figure 5-5 Third road tested – Camino de las Salina, Spain. Source: Google Maps

5.2.1.2 Comparison of the cameras

After the three tests carried out, it was possible to make a reasoned comparison of the three cameras. The used cameras are shortly described in Table 5-2.

Table 5-2 Assessment of cameras and videos according to test setting

Model	Garmin 65W	GoPro Hero 6	Nextbase 612GW
Thumbnail			
MicroSD card	64 GB, U3 type	128 GB, U3 type	128 GB, U3 type
File format	MP4	MP4	MP4
Resolution[4]	720p 30fps	1080p 30fps	1080p 30fps
Video length	1 min	16 min	3 min
File size	42 MB	4 GB	273 MB
Operating time[5]	≈ 23 h	≈ 8 h	≈ 22 h

The analysis, including a list of pros and cons of each device, is summarised in the Table 5-3. It should be noted that all the cameras have more than enough video quality for video recognition analysis, even if the resolutions set are different from the maximum possible. In the

[4] It refers to the resolution set during the tests; higher resolutions can be also set.
[5] It refers to the operating time using the SD cards used during the tests; of course, it can be increased using more SD cards.

tests, the handling of files was therefore preferred over the quality of video. Smaller files, in fact, pose fewer difficulties in terms of storage and, above all, of computing power necessary for their post-processing.

Table 5-3 Pros and Cons of the cameras

Model	Garmin 65W	GoPro Hero 6	Nextbase 612GW
Pros	– Small dimensions – Connects to vehicle power supply – Voice commands are available	– Can be installed outside the vehicle and thus provide a ‘cleaner’ image – Provides 16 min video output, making the post-processing less laborious – Can be easily installed with a professional suction cup, which can also be used on the front bonnet or other positions outside the vehicle – Voice commands makes it easy to use	– Can be easily installed with a suction cup on the windscreen – The menu is very intuitive and easy to navigate (touchscreen) – The software for video analysis is very well done and provides several information including the location on a map (Google Map or Open Street Map) – Connects to vehicle power supply
Cons	– Manual start/stop of recording is not possible (starts automatically when switched on) – Each recording is divided into 1 min video each, making rather laborious the preparation of the video for post-processing – There is no suction cup available for installation; therefore, the support provided must be glued to the windscreen, making it difficult to use the camera with several vehicles	– It is not possible to connect the camera to the car power supply, so that a battery change is necessary every 1.5/2 h of recording – Several batteries (at least 3) are necessary for a day inspection	– If the power supply is connected to the vehicle, recording starts automatically each time the vehicle is started; this requires manual intervention to avoid unwanted recording

After the analysis of the three preliminary tests, the Nextbase 612GW camera was considered the best option in terms of technical features, versatility and easiness of use. Video management software is also a significant added value.

5.2.1.3 White sheet calibration

In addition to testing technology tools, a video calibration procedure was developed during inspections, which is necessary for the video image recognition algorithm to transform pixels into real distances.

In practice, it consists of shooting a sheet[6] of known dimensions[7] (2m x 2m) before driving along the road to be inspected (Figure 5-6). The sheet, which is white in order to effectively contrast with the colour of the pavement, is placed in front of the vehicle at the start of the inspection at approximately 4 meters far from it.

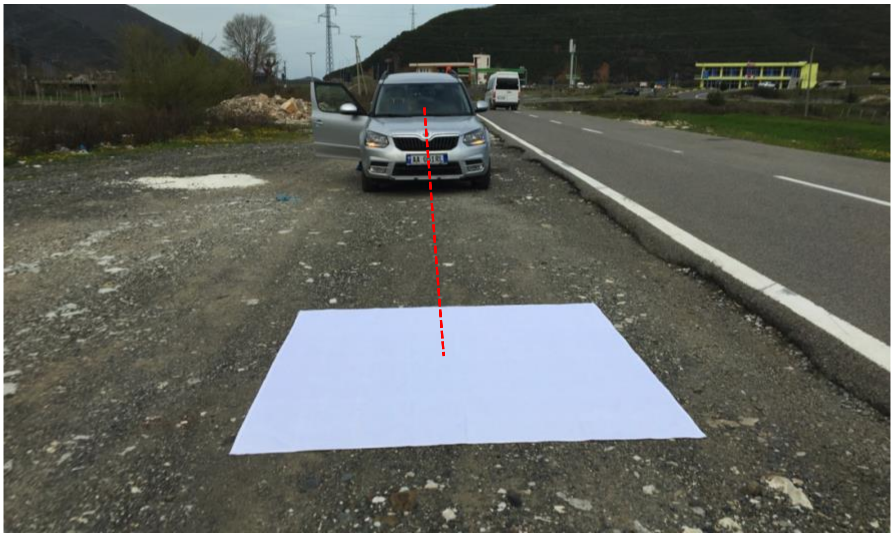


Figure 5-6 Example of white sheet calibration

This video calibration procedure allows to use any kind of vehicle for the field survey and also to install the camera at any position of the windscreen, but close to the back mirror. It is important to note that the video calibration procedure is required every time the camera is installed in the windscreen of the vehicle and/or the vehicle used for the survey is changed.

5.2.1.4 RoadLab Pro App

In addition to the cameras, RoadLab Pro app installed on smartphone was also tested. Road Lab Pro is designed as a data collection tool for engineer by the World Bank in collaboration with Beldor Center, Softteco and Progress Analytics LLC (Figure 5-7).

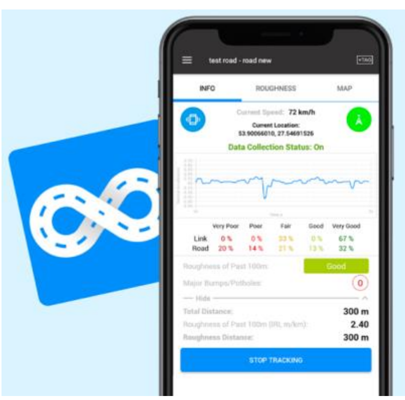


Figure 5-7 RoadLab Pro app. Source: https://softteco.com/projects/roadlab

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[6] Any type material can be considered for this element (ex. fabric, plastic, etc.). Nevertheless, it is recommended to consider a strong and flexible fabric for a better utilization and transportation, such as sailcloth.
[7] The dimensions of this element must be always 2.00 x 2.00 meters. A maximum tolerance of +/-1 cm is possible.

According to the developer[8], the App allows to autonomously collect, analyse and transfer data while driving. The possibility of using data from the gyroscope (acceleration vector) and GPS chip (latitude, longitude and altitude at sea level) for performing IRI calculations together with an option of introducing road sections adjustments makes this app an efficient and a cost-effective tool for road engineering agencies. All received data can be uploaded to dedicated servers for further analysis or can be exported in various geo-formats. the application is specifically tailored to road engineering agencies for providing accurate road quality reports in developing countries.

To use the app, the mobile device has to be placed on a stable surface in the vehicle, preferably mounted vertically and tightly to the vehicle windshield. It is available free of charge for all Android and iOS devices (both smartphones and tablets). The App was launched in 2016 and later updated in 2018.

After the RoadLab Pro App was tested during the preliminary testing carried out on the three short sections of roads in Italy and Spain, the following was concluded:

- The application is easy to use
- RoadLab Pro provides qualitative results on the condition of the pavement
- Its use is recommended and necessary to complete the set of information needed for the road safety assessment

5.2.1.5 Final considerations

From the preliminary tests carried out, it was possible to identify different attributes that can be collected automatically (Table 5-4). This automatic recognition is carried out from the videos recorded during the inspection of the road sections.

Table 5-4 List of automatic recognition attributes

Road attributes	Recognition method
Number of lanes	Image analysis
Lane width	Image analysis
Curvature	Image analysis
Grade	Image analysis
Delineation	Image analysis
Inspecting vehicle speed	Image analysis
Roadside severity - distance	Image analysis
Pedestrian crossing	Image analysis
Pedestrian observed flow	Image analysis
Bicycle observed flow	Image analysis
Road surface conditions	RoadLab Pro App
Area type	OpenStreetMap
Intersection type	OpenStreetMap
Access points	OpenStreetMap

Even if some attributes cannot be automatically recognized, they should be appraised anyway as they are necessary for a methodologically coherent assessment. Especially with regard to vulnerable road users. Consequently, collection of the following attributes using manual post-processing recognition have been considered:

[8] https://softteco.com/projects/roadlab [accessed on 6 May 2019]

- Median type
- Speed management / traffic calming
- Paved shoulder width
- Sidewalk
- Facilities of bicycling
- Motorcycle dedicated lane

In conclusion, according to the findings in the literature review, road attributes have been considered and selected based on the following criteria:

1. Consistency with the general approach; i.e. the selected attributes must describe both the likelihood and the severity of a crash. The exposure of vulnerable road users was also considered.
2. Feasibility of attribute recognition through video image analysis; i.e. reduce as much as possible the number of attributes to be collected manually.
3. Provision of a minimum set of attributes guarantying the reliability of the risk assessment.

5.2.2 Key parameters

Several studies have been performed to estimate the safety impact of various types of road infrastructure improvements. Many existing CMFs are derived from these evaluation studies, like before-and-after analysis, of actual countermeasures implementation.

In the following, for each attribute considered in the simplified methodology, affecting accident likelihood, CMFs are reported. Each category of the attribute is associated to a CMF affecting the probability of an injury accident. The CMFs are presented according to the availability of the literature for the following three previously defined road users:

- Crashes involving only one or more motor vehicles (MV)
- Crashes involving at least a cyclist
- Crashes involving at least a pedestrian

5.2.2.1 Number of lanes

The impact of number of lanes on collision rates depends on whether the road is located in an urban or a rural area. In rural areas, accident rate declines as road width (i.e. number of lanes) increases, whereas in urban areas, collision rate increases as road width (number of lanes) increases. Differences in speed and the mix of traffic using the road may account for this difference in the effect of number of lanes. In general, the higher the number of lanes is, the higher is the pedestrian exposure to crashes when crossing the road. The main references used for determining Number of lanes CMFs was Elvik et al., 2009.

Table 5-5 CMF values of number of lanes by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
1 lane			1.00			1.00
2 lanes			1.90			0.90
3+ lanes			3.20			0.90

5.2.2.2 Lane width

Widening lanes reduces the occurrence of run-off road crashes, head-on, sideswipe collisions same and opposite direction crashes. The main references used for determining Lane width CMFs was AASHTO (2010).

Table 5-6 CMF values of lane width by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Narrow (< 2.75 m)					1.50	1.50
Medium (2.75 - 3.25 m)					1.20	1.20
Wide (> 3.25 m)					1.00	1.00

5.2.2.3 Grade

For intersections there are more crashes at intersections with steep gradients than at junctions with no or small gradients. The opposite is valid for crashes along the road. The main references used for determining Grade CMFs was Elvik et al., 2009.

Table 5-7 CMF values of grade by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
≥ 7.5%					1.10	0.80
< 7.5%					1.00	1.00

5.2.2.4 Curvature

Collision rate increases as curves get sharper. The main references used for determining Curvature CMFs was Elvik et al., 2009.

Table 5-8 CMF values of curvature by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Very sharp (< 200 m)		2.35		2.35		2.35
Sharp (200 - 400 m)		1.85		1.85		1.85
Sharp (400 - 600 m)		1.55		1.55		1.55
Moderate (600 - 1000 m)		1.30		1.30		1.30
Straight or gently curving (1000 - 2000 m)		1.10		1.10		1.10
Straight or gently curving (> 2000 m)		1.00		1.00		1.00

5.2.2.5 Delineation

This attribute measures the presence of clearly visible markings along a road or at an intersection (i.e. edge lines and centre line). Placing edge lines and centre line markings where no markings exist decreases injury collisions of all types. Reference for CMF values was AASHTO (2010).

Table 5-9 CMF values of delineation by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Adequate delineation		1.00		1.00		1.00
Poor delineation		1.25		1.25		1.25

5.2.2.6 Roadside severity – distance

Increasing the distance to fixed obstacles was found to decrease the number of injury collisions. The main references used for determining increasing the distance to fixed obstacles type CMFs was Elvik et al., 2009.

Table 5-10 CMF values of roadside severity – distance by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
< 1 m						1.45
1 – 5 m						1.20
≥ 5 m						1.00

5.2.2.7 Pedestrian crossing

Appropriate pedestrian crossings may improve pedestrian safety; however, motor vehicle collision rates appear to increase due to a possible increase of rear-end accidents. The main references used for determining Intersection type CMFs was Elvik et al., 2009.

Table 5-11 CMF values of pedestrian crossing by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Pedestrian crossing			0.90	0.90	1.10	1.10
No crossing facility			1.00	1.00	1.00	1.00

5.2.2.8 Road surface conditions

It is estimated that increasing unevenness and rut depth lead to an increase in accidents. Reference for determining road conditions CMFs were based on AASHTO (2010).

Table 5-12 CMF values od road surface conditions by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Poor		1.40				1.40
Poor-Medium		1.30				1.30
Medium		1.20				1.20
Medium-Good		1.10				1.10
Good		1.00				1.00

5.2.2.9 Area type

Some treatments have a different impact according to the specific traffic conditions. A roundabout in an urban context lead to a different safety effect when compared to a rural roundabout. Area type attribute affects the value of specific CMFs, as specified in the attribute tables.

In general, crashes per million vehicle kilometers of travel varies greatly between different types of traffic environment, based on the average collision rates on rural and urban roads the values shown in Table 5-13 are considered in the methodology. The main references used for determining area type CMFs was Elvik et al. (2009).

Table 5-13 CMF values of area type by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Urban		2.00		2.00		2.00
Rural		1.00		1.00		1.00

5.2.2.10 Intersection type

Studies mostly show that intersections with four or more legs are associated with more crashes compared to 3-leg intersections. Compared to roundabouts, intersections are associated to more crashes. Main reference used for determining Intersection type CMFs was Elvik et al., (2009).

Table 5-14 CMF values of intersection type by crash type and location

Attribute category	Area type	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
		Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
No intersection	rural	0.00		0.00		0.00	
	urban	0.00		0.00		0.00	
Roundabout	rural	1.00		1.00		1.00	
	urban	1.00		2.50		2.50	
3-leg	urban	1.36		2.50		2.50	
	rural	1.36		2.50		2.50	
4-leg	urban	1.45		2.67		2.67	
	rural	1.64		3.00		3.00	
5+ legs	rural	1.82		3.33		3.33	
	urban	1.82		3.33		3.33	

5.2.2.11 Access points

The number of access points has a major impact on collision rate. The main references used for determining Access points CMFs was Elvik et al., 2009.

Table 5-15 CMF values of access points by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Access 3+	1.50		1.50		1.50	
Access 1 or 2	1.30		1.30		1.30	
No access points	0.00		0.00		0.00	

5.2.2.12 Median type

Medians have been found to reduce crashes in most situations according to Elvik et al., 2009.

Table 5-16 CMF values of median type by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Physical median						0.85
Centre line						1.00

5.2.2.13 Speed management/traffic calming

Traffic calming and speed-reducing devices are generally found to reduce the number of crashes. The main references used for determining Intersection type CMFs was Elvik et al., 2009.

Table 5-17 CMF values of speed management by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Traffic calming on main urban roads	0.90	0.90	0.90	0.90	0.90	0.90
No Traffic calming	1.00	1.00	1.00	1.00	1.00	1.00

5.2.2.14 Paved shoulder width

A value higher than 0 meters identifies the presence of a paved shoulder. Paving and increasing shoulder width has been found to reduce the number of injury collisions. The main references used for determining Paved Shoulder Width CMFs was AASHTO (2010).

Table 5-18 CMF values of paved should width by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
None		1.50		1.50		1.50
Narrow (< 1.0 m)		1.30		1.30		1.30
Medium (1.0 - 2.4 m)		1.00		1.00		1.00
Wide (≥ 2.4 m)		0.80		0.80		0.85

5.2.2.15 Sidewalk

Sidewalks carry pedestrian traffic and sometimes bicycle traffic in both directions. Research results show that collision rates are lower on roads with sidewalks than on other roads for pedestrians and for cyclists, and higher for motor vehicles. The main references used for determining Intersection type CMFs was Elvik et al., 2009.

Table 5-19 CMF values of sidewalk by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Sidewalk >= 1 m from roadway	0.95			0.95		1.15
Sidewalk <1.0 m from roadway	1.00			1.00		1.00
No sidewalk	1.10			1.10		1.10

5.2.2.16 Facilities of bicycling

Cycle lanes and cycle tracks are found to reduce the total number of injury collisions. For bicycle crashes, the reduction of the total number of collisions is smaller than for other road users. Possible explanations are increased numbers of cyclists and increased speed among cyclists (Elvik et al., 2009). The main references used for determining Intersection type CMFs was Elvik et al., 2009.

Table 5-20 CMF values of facilities of bicycling by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
On-road lane	0.75	0.80	0.75		0.50	0.75
No facility	1.00	1.00	1.00		1.00	1.00

5.2.2.17 Motorcycle dedicated lane

No relevant CMF was found, it is assumed a motorcycle dedicated lane leads to similar effects as a cycle lane.

Table 5-21 CMF values of motorcycle dedicated lane by crash type and location

Attribute category	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
On-road lane	0.75	0.80			0.50	0.75
No facility	1.00	1.00			1.00	1.00

5.2.2.18 Inspecting vehicle speed

The inspecting vehicle maximum speed observed within a 100 m road section have been used as a proxy of the operating speed along a road section.

5.2.2.19 Bicycle observed flow

Bicycle observed flow records the number of cyclists observed within a 100 m road section. This attribute has been used as a proxy of the exposure of cyclists to road hazards. It is intended to highlight those road sections which are likely to be used by cyclists, the aim is not to reflect a bicycle volume.

5.2.2.20 Pedestrian observed flow

Pedestrian observed flow records the number of pedestrians observed (both crossing and walking along the road) within a 100 m road section. This attribute has been used as a proxy of the exposure of pedestrians to road hazards. It is intended to highlight those road sections which are likely to be used by pedestrians, the aim is not to reflect a pedestrian volume.

6 NEW SIMPLIFIED METHODOLOGY

As previously mentioned, the proposed methodology is based on the concept of Crash Modification Factor (CMF), and the common definition given by the combination of key factors such as Danger (likelihood that a crash can happen), Vulnerability (risk of injury of road users given a crash occurred) and Exposure (amount of "activity" a user is exposed to a risk), to calculate a risk index based on the physical characteristics.

The resulting formula for risk assessment is thus as follows (Risk=Danger*Vulnerability*Exposure (*20*)):

*Risk=Danger*Vulnerability*Exposure* (20)

In the following table the attributes identified as relevant for the risk assessment are classified according to their purpose under the formula.

Table 6-1 Classification of attributes proposed

Attributes	**Factor**		
	Danger [likelihood]	**Vulnerability [severity]**	**Exposure**
Operating speed	X	X	
Median type	X	X	
Intersection type	X		
Area type	X		
Access points	X		
Number of lanes	X		
Lane width	X		
Curvature	X		
Grade	X		
Road conditions	X		
Delineation	X		
Pedestrian crossing	X		
Speed management/traffic calming	X		
Paved Shoulder Width	X		
Roadside severity - distance	X	X	
Sidewalk	X		
Facilities of bicycling	X		
Motorcycle dedicated lane	X		
Bicycle observed flow			X
Pedestrian observed flow			X

6.1 Danger or crash likelihood Assessment

A road can be considered as the result of a “base case” road plus a number of changes (i.e. treatments) implemented on this base road. These changes can improve or reduce the road safety performance. A CMF value equals to 1 corresponds to the base case road, while a lower/higher value represents a risk factor/treatment affecting its performance.

Currently, the most common method for estimating the combined effect of several treatments is the method of “common residuals” (Elvik, 2009):

$$\text{Combined effect} = CMF1 * CMF2 \ldots *CMFn \tag{21}$$

Where: CMF1, CMF2, … CMFn are CMF affecting the injury crashes likelihood. The method assumes that the effects of treatments are independent and remain unchanged when other road safety measures are introduced.

The danger (or injury crash likelihood) assessment is applied to two different road sections:

- 100m road sections
- 100m road sections where intersections and/or access points are present.

For each of these road sections, three different crash types are considered, accounting for most of the road crashes with deaths and serious injuries:

- Crashes involving only motor vehicles (MVs).
- Crashes involving cyclists.
- Crashes involving pedestrians.

For each crash type, a Danger score can be calculated according to the above-mentioned combined effect formula as follow:

$$Dcr = CMF1 * CMF2 \ldots * CMFn \tag{22}$$

Where: *Dcr* = danger score at a 100m road section for a crash type.

The formula applied to road sections with intersections/accesses is slightly different. It is assumed that along a 100 m road section an intersection plus a number of access points are applicable. To consider risks affecting locally both the intersection and the access points, a modified version of the common residuals’ formulation is proposed as follow:

$$Dci = (Aint + Aacc) * CMF1 * CMF2 \ldots * CMFn \tag{23}$$

Where: *Dci* = danger score at a 100m road section with an intersection/access point for a crash type; *Aint* = attribute “Intersection type”; *Aacc* = attribute “Access points”; and *CMF1 * CMF2 … *CMFn* = CMF values affecting safety performance at an intersection/access point.

Table 6-2 provides the list of road attributes to be considered for each crash type at a road intersection/access or at a road section.

Table 6-2 Road attributes considered for crash type

Attribute	Cycle crashes		Pedestrian Crashes		Motor Vehicles crashes	
	Intersections	Along the road	Crossing	Along the road	Intersections	Along the road
Median type						X
Intersection type	X		X		X	
Area type		X		X		X
Access points	X		X		X	
Number of lanes			X			X
Lane width					X	X
Curvature		X		X		X
Grade					X	X
Road conditions		X				X
Delineation		X		X		X
Pedestrian crossing			X	X	X	X
Speed management/traffic calming	X	X	X	X	X	X
Paved Shoulder Width		X	X			X
Roadside severity - distance						X
Sidewalk	X			X		X
Facilities of bicycling	X	X	X		X	X
Motorcycle dedicated lane	X	X			X	X

6.2 Vulnerability or crash severity assessment

Vulnerability is given by the road attributes referring to the predisposition of the users to suffer damage caused by a crash. Three main factors are considered within the methodology: Operating speed, Median type and Roadside severity.
For each road section Vulnerability is calculated as follow:

$$V = SW * CMF1 * CMF2 \ldots * CMFn \qquad (24)$$

Where: *V*= Vulnerability; *SW*= attribute related to speed; and *CMF1 * CMF2 … *CMFn* = CMF values affecting crash severity (Median type and Roadside severity).

SW is obtained using a continuous function of the operating speed (Figure 6-1). Especially, Sigmoid functions are used as follows:

- Motor vehicles

$$SW = exp(0.1524*SPEED/1.609 -8.2629)/(1+ exp(0.1524*SPEED/1.609 -8.2629)) +1 \qquad (25)$$

- Cyclists and pedestrians

$$SW = 1/(1 + exp(5.549 - 0.1035*SPEED)) + 1 \qquad (26)$$

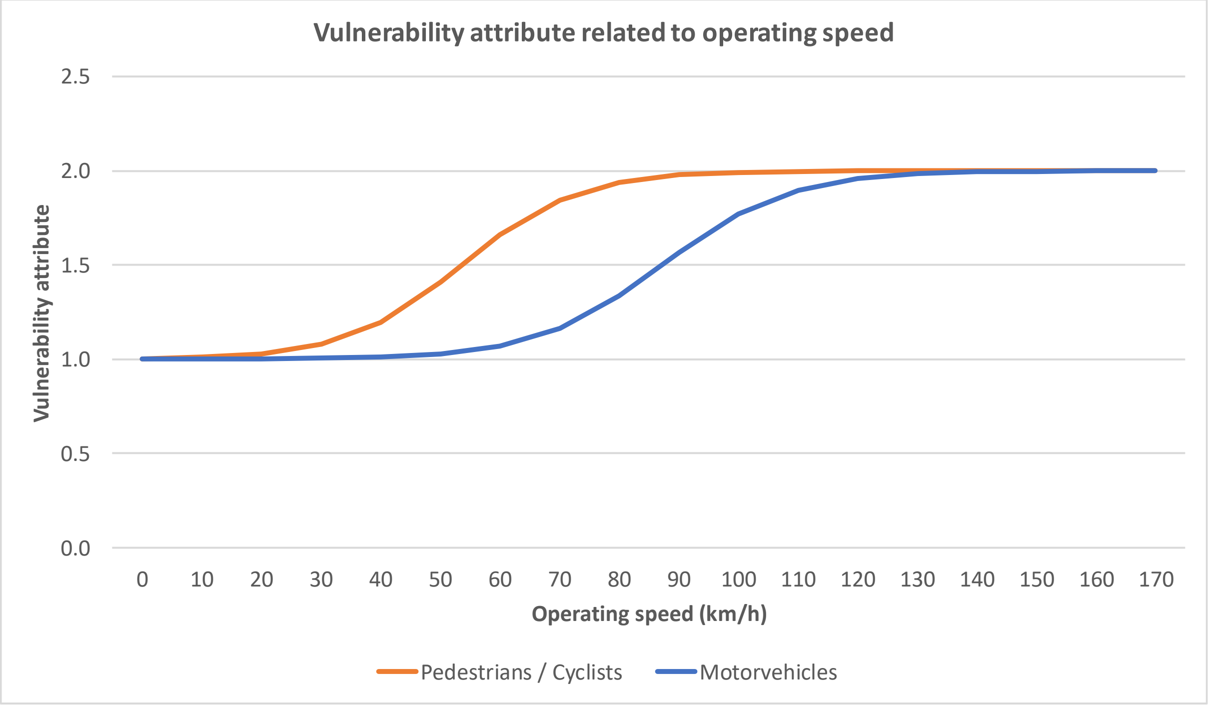

Figure 6-1 Vulnerability attribute related to operating speed

The attribute is equal to one at low operating speeds and can double at high operating speed (i.e. the road user vulnerability can double). The curves for motor-vehicles, cyclists and pedestrians change depending on the operating speed, so that lower speeds are more dangerous for vulnerable road users, compared to motor-vehicles. With this approach it is possible to consider the higher danger for pedestrians and cyclists arising from higher traffic flow speed. The vulnerability for pedestrians and cyclists is designed to have a higher value (compared with the motor-vehicles) in the speed range between 20 and 120km/h. This is due to the higher expected road crash severity for these users.

6.3 Total risk score

The final score for each crash type is obtained as the sum of the Risks related to the road section and to the road intersection/access points multiplied by the Vulnerability, as follow:

$$S\_CT = (Dcr + Dci) * V \qquad (27)$$

Where: *S_CT*= Score crash type; *Dcr*= Danger related to the road section; *Dci*= Danger related to the road intersection/access point; and *V*= Vulnerability.

Thus, the methodology provides three separate risk scores for each of the three road user categories considered.

It is worth mentioning that the “road user risk scores” are independent of the vehicle flows (i.e. exposure to risk).

Based on the three “road user risk scores” calculated, a **Global Risk Score (GRS)** for each 100 m road section is calculated. This risk score allows to consider the pedestrian and cyclist flows and thus the risk exposure.

The basic assumption is that, due to high speeds and road characteristics, a motorway should be unsafe for pedestrians. However, motorways are not allowed to pedestrians and cyclists and thus should have intrinsically a low global risk score (if they are correctly designed). Thus, if pedestrians or cyclists are not counted on a motorway, the GRS will be close as value to the motor-vehicles' risk scores (*S_MV*).

On the contrary, on other roads where pedestrians and cyclists are allowed to travel, the global risk score must be correlated to the effective presence of these road users. On roads where pedestrians or cyclists are counted, the GRS will be close as value to the pedestrians' and / or cyclists' risk scores (*S_PED* / *S_CYC*).

GRS is given by:

$$GRS = (S\_PED * w\_PED + S\_CYC * w\_CYC + S\_MV) / (w\_PED + w\_CYC + 1) \qquad (28)$$

Where: *S_PED* = total risk score for pedestrians; *S_CYC* = total risk score for cyclists; *S_MV*= total risk score for motor vehicles; *w_PED* = weight calculated based on the pedestrians' flow on the assessed road (recognized automatically by the video analysis); and *w_CYC* = weight calculated based on the cyclists' flow on the assessed road (recognized automatically by the video analysis).

The weights are proportional to the probability of crossing pedestrians and / or cyclists on the analyzed road.

The preliminary assumption is that the probability of crossing pedestrians and / or cyclists follows a Gamma distribution with parameters "*a*" and "*b*" meaning that it expects to cross "*a*" pedestrians or cyclists in "*b*" 100m road sections.

These parameters by default are equal to:

- Rural area: $a = 0.5$ and $b = 2$
- Urban area: $a = 1$ and $b = 2$

The parameters are then corrected based on the number of pedestrians and cyclists counted by the software. The weights are thus adjusted through a Bayesian inference. The new parameters obtained will be:

$$a' = a + k \qquad (29)$$

$$b' = b + N \qquad (30)$$

Where: k= number of pedestrians or cyclists counted in the whole video; and N= number of 100m road sections in the same video.

The weights are then:

$$W = a' / b' \qquad (31)$$

Where: W= weights.

6.4 Risk scores categorization

The risk scores related to the three road user categories (i.e. motor-vehicles, pedestrians and cyclists) are basically random variables obtained by the combination of multiple parameters. Thus, their values range between a minimum and a maximum which is dependent on the parameters' distribution.

Generally, it is not possible to know a priori the distribution of those parameters. In fact, they are related to the road characteristics, thus their distribution will be based on the road network on which the algorithm is applied.

Stated this, a range evaluation was performed on the set of values which the three main variables (i.e. the risk score of the three analysed categories) can assume. Since the score values are computed as a product of evenly distributed variables, their values will reach their peak when all the parameters take their maximum values and, on the other hand, will reach their lower point when all the parameters assume their minimum value. The minimum and the maximum value of each parameter was set according to the section 3.2.2 Key parameters and noted in

Table 6-3 below. The combination of those values is shown in Table 6-4.

Road User	**Bicycles**				**Pedestrians**				**Motor-Vehicles**			
Attribute	Intersections		Along the road		Crossing		Along the road		Intersections		Along the road	
	min	max	min	max	min	max	min	max	min	max	min	max
Area type			1.00	2.00			1.00	2.00			1.00	2.00
Median type											0.85	1.00
Intersection type	0.00	1.82			0.00	3.33			0.00	3.33		
Access points	0.00	1.50			0.00	1.50			0.00	1.50		
Number of lanes					1.00	3.20					0.90	1.00
Lane width									1.00	1.50	1.00	1.50
Curvature			1.00	2.35			1.00	2.35			1.00	2.35
Grade									1.00	1.10	0.80	1.00
Road conditions			1.00	1.40							1.00	1.40
Delineation			1.00	1.25			1.00	1.25			1.00	1.25
Pedestrian crossing					0.90	1.00	0.90	1.00	1.00	1.10	1.00	1.10
Speed management/traffic calming	0.90	1.00	0.90	1.00	0.90	1.00	0.90	1.00	0.90	1.00	0.90	1.00
Paved Shoulder Width			0.80	1.5	0.80	1.50					0.85	1.50
Roadside severity - distance											1.00	1.45
Sidewalk	0.95	1.10					0.95	1.10			1.00	1.15
Facilities of bicycling	0.75	1.00	0.80	1.00	0.75	1.00			0.50	1.00	0.75	1.00
Motorcycle dedicated lane	0.75	1.00	0.80	1.00					0.50	1.00	0.75	1.00
Total	**0.00**	**3.00**	**0.46**	**12.34**	**0.00**	**23.98**	**0.77**	**6.46**	**0.00**	**9.06**	**0.26**	**33.95**

Total	**0.00**	**3.00**	**0.46**	**12.34**	**0.00**	**23.98**	**0.77**	**6.46**	**0.00**	**9.06**	**0.26**	**33.95**

Table 6-3 Minimum and maximum values of attributes

Table 6-4 Minimum and maximum risk's values by speed

Road User	**Cyclists**		**Pedestrians**		**Motor-vehicles**	
Speed (km/h)	**min**	**max**	**min**	**max**	**min**	**max**
0	0.39	23.27	0.66	43.15	0.22	61.95
10	0.40	23.44	0.66	43.45	0.22	61.97
20	0.40	23.88	0.67	44.27	0.22	62.04
30	0.42	25.04	0.71	46.42	0.22	62.20
40	0.47	27.74	0.78	51.43	0.23	62.63
50	0.55	32.63	0.92	60.51	0.23	63.70
60	0.65	38.47	1.09	71.34	0.24	66.29
70	0.72	42.78	1.21	79.31	0.26	72.06
80	0.76	44.95	1.27	83.35	0.30	82.68
90	0.77	45.85	1.29	85.00	0.35	96.93
100	0.78	46.18	1.30	85.62	0.40	109.62
110	0.78	46.30	1.31	85.85	0.42	117.44
120	0.78	46.35	1.31	85.93	0.44	121.20
130	0.78	46.36	1.31	85.96	0.44	122.80
140	0.78	46.37	1.31	85.97	0.45	123.45
150	0.78	46.37	1.31	85.97	0.45	123.70
160	0.78	46.37	1.31	85.97	0.45	123.80
170	0.78	46.37	1.31	85.97	0.45	123.84

The data show a minimum value which ranges between 0.39 and 0.78 for cyclists, 0.66 and 1.31 for pedestrians and 0.22 and 0.45 for motor-vehicles. The minimum values are essentially what is called "intrinsic risk" (i.e. the risk originated by the action of moving on a public road which is not related to the infrastructure condition but only to the presence of other road users and of the motor-vehicles flow speed).

As shown in Table 6-4, this value is not significantly affecting the risk score range (the variability is not remarkable), hence only the right side of the interval (i.e. the maximum) was considered from now on. Considering data shown in Figure 6-2, it is clear that the three categories might assume values significantly different (e.g. at 80 km/h cyclist's risk score ranges up to around 45 while pedestrian and MV up to 83 – 84). For this reason, it was not possible to define a unique set of risk levels. On the contrary, a multiple set system was chosen. Each one of these sets was tailored on the risk score range of the related road users' categories.

Five colours are used to represent the risk levels for each road user category (and for the GSR):

- Green = very low risk.
- Yellow = low risk.
- Dark orange = medium risk.
- Red = high risk.
- Black = very high risk.

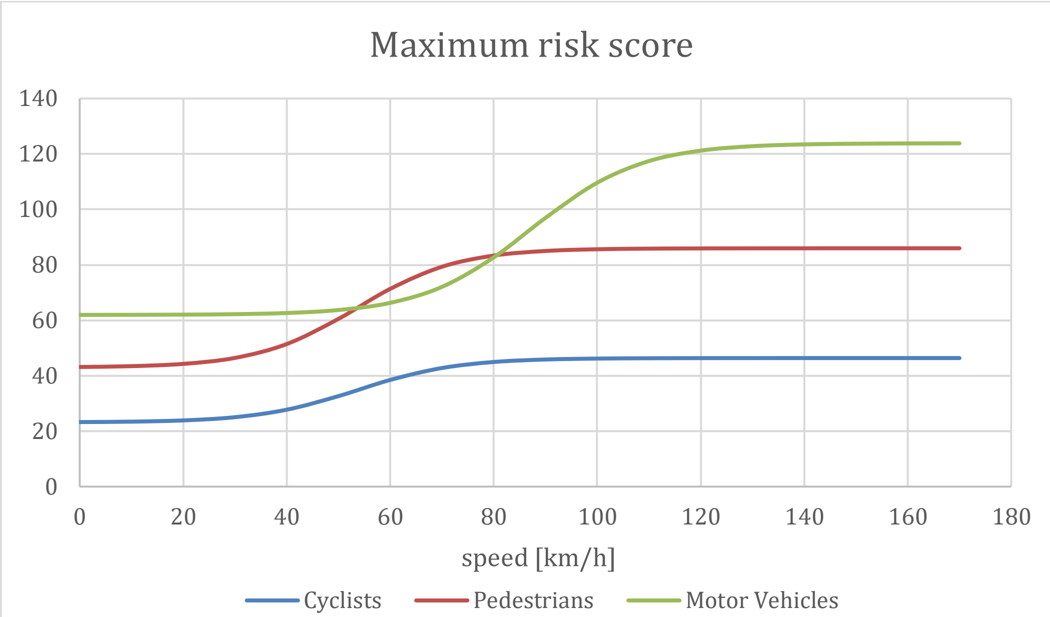

Figure 6-2 Maximum risk's values by road user

The risk is generally considered as the combination of two factors: the event likelihood and the severity of the consequences. Both these factors have already been considered in the risk score formula, nevertheless it was deemed unrealistic to have a low risk at high motor-vehicle flow speed for pedestrians and cyclists. On the other hand, a possible scenario could be travelling on a motor-vehicle at high speed and recording a low risk (of course this depends on the characteristics of the infrastructure). For this reason, two different kinds of risk levels were considered:

- for pedestrians and cyclists, the set of risk level assumes intervals ranging with the motor-vehicles' flow speed (Figure 6-3 and Figure 6-4);
- for the motor-vehicles, those intervals are fixed (Figure 6-5).

The coloured lines in the figures indicate the limits for changes from a score range to another, so that:

- Scores values under the green line represent a low risk (green area).
- Scores values between the yellow and green lines represent a medium-low risk (yellow area).
- Scores values between the dark orange and yellow lines represent a medium risk (dark orange area).
- Scores values between the red and dark orange lines represent a high-medium risk (red area).
- Scores values above the red line represent a high risk (black area).

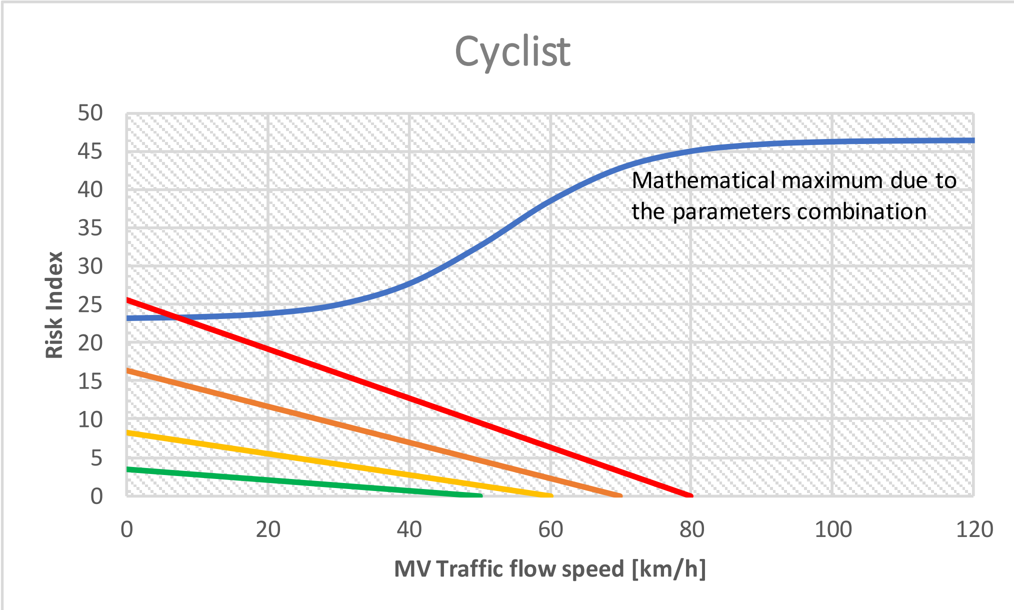

Figure 6-3 Cyclists' risk range variation

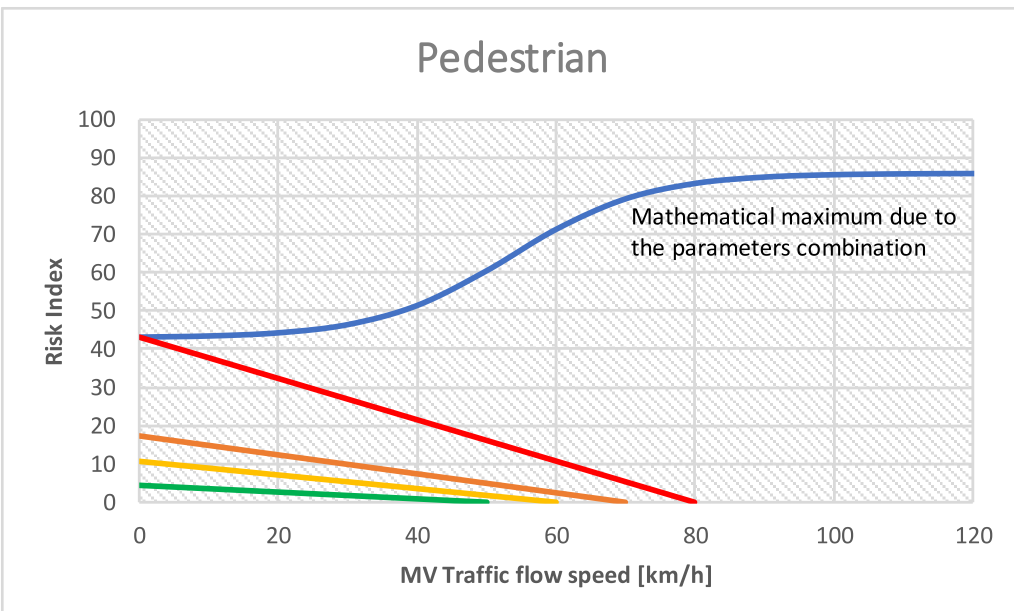

Figure 6-4 Pedestrians' risk range variation

Using a risk level system for cyclists and pedestrians which is more restrictive when the traffic flow speed increases is coherent with the purpose of safeguarding the vulnerable road users. Besides, when pedestrians or cyclists flow promiscuously with the motor-vehicles (e.g. there are no dedicated and protected lanes or sidewalks), it is not realistically possible to achieve a "risk-free" status, hence once more it is coherent to have a system which excludes a priori the possibility of low risk level scenarios for vulnerable road users after a certain motor-vehicles' flow speed.

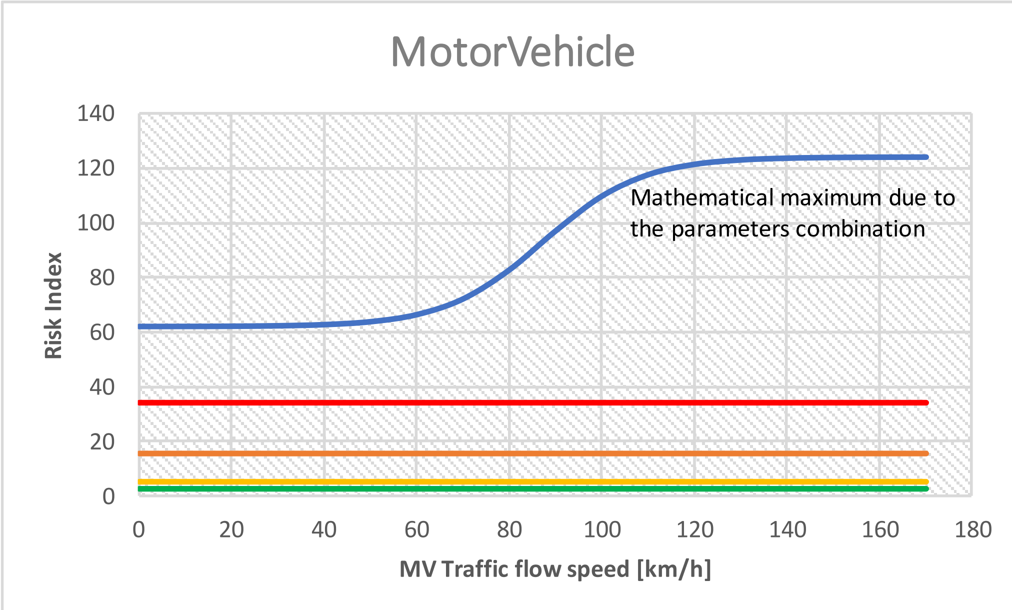

Figure 6-5 Motor-vehicles' risk range variation

The risk levels for the GSR have been obtained similarly, by considering fixed intervals calibrated on a real case scenario of roads in Mozambique (Figure 6-6).

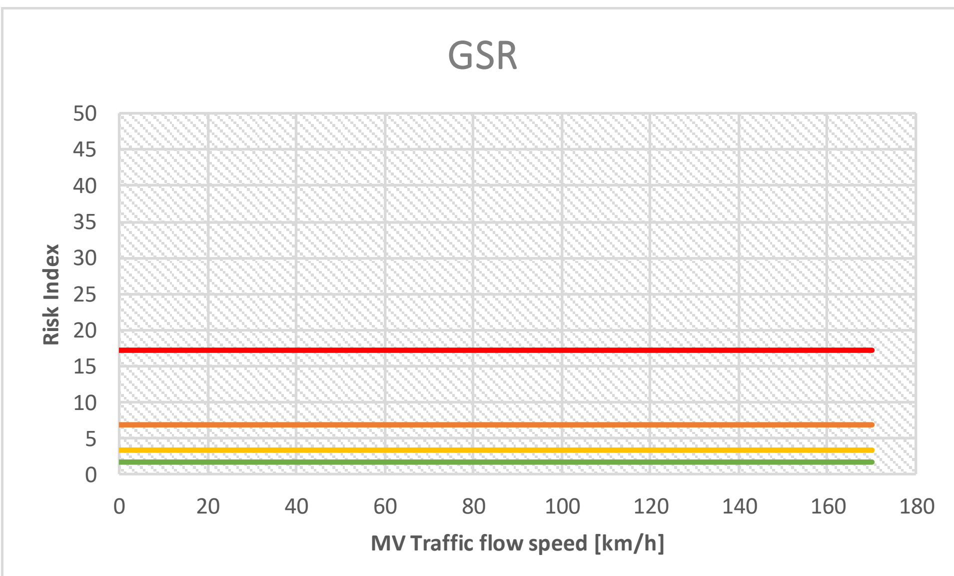

Figure 6-6 GSR risk range variation

6.5 Software developed

After the definition of the simplified risk assessment methodology, it has been implemented into a software for automatic road risk assessment. The software can be installed on personal computers using Windows or Apple.

It allows to input manually some road attributes, while all the others are automatically calculated thanks to automatic video analysis. After calculation of the road attributes, the software automatically implements the above described methodology to calculate the crash risk for the three road user categories considered, as well as the Global Risk Score. Results of the risk assessment are provided on map for 100 meters road sections, as well as on tables.

It is worth mentioning that since software development is an activity that requires specific programming skills, this activity has been carried out by the company *Pangea Formazione* and not by the author of this research work.

The use of the software is described below.

6.5.1 Preparing for assessment

The software starts with an interface for input of the following assessment information:

- Video to be analyzed. It highly recommended to perform the assessment step by step for short videos. The recommended camera for video recording (Nextbase 612GW) already provides videos of short length (about 3 minutes) that can be inputted directly in the software.
- Photo of the blank sheet (needed for video calibration).
- Output file of the RoadLabPro App. There is no need to separate the output file according to the video length. The software automatically recognises the parts of the file to be treated based on the GPS positions. The entire file can thus be inputted into the software.

Below the steps for preparing the assessment are described. Some road attributes cannot be extracted from the video and must be inputted manually. All the information needed can be inputted using the commands on the right side of the application interface.

i. As first step, it is important to watch the video being analyzed. This will allow:

   -To verify the road characteristics to be inputted manually into the software.
   -To verify that all along the road, the characteristics are homogeneous.

ii. The software also provides a module for checking of data consistency. It allows to verify if the GPS coordinates are missing in some videos and thus, eventually, to correct the videos or to discard them. By clicking on “Browse” one or more videos can be selected for verification (Figure 6-7).

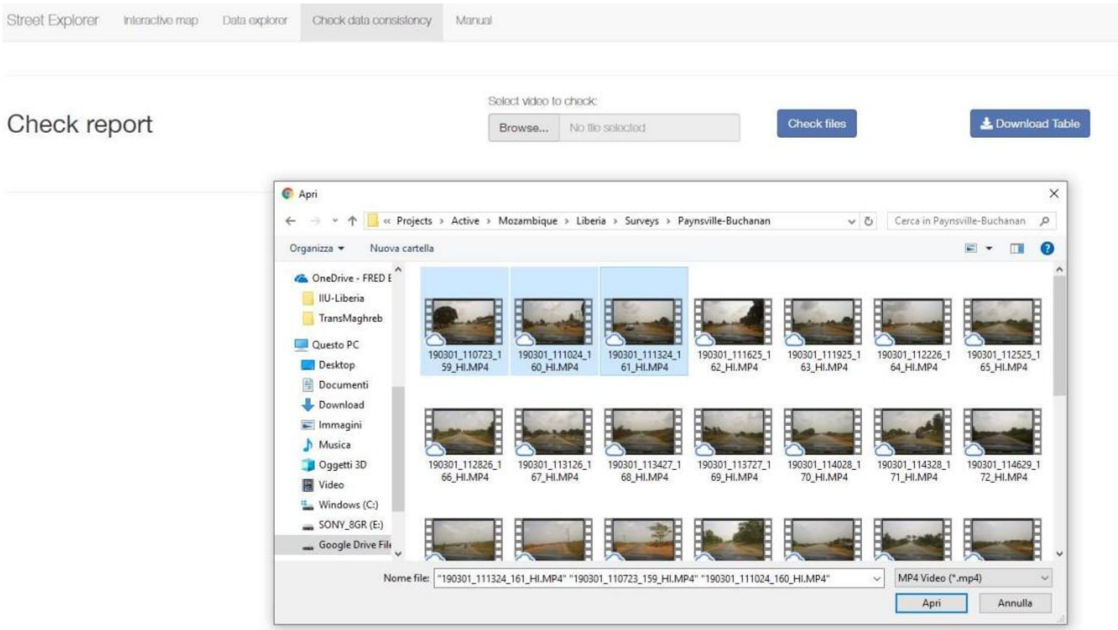

Figure 6-7 Example of select video to analyze

After the upload, by clicking on "Check files", the results of verification appear both on table and on map (Figure 6-8). The road sections for which the GPS coordinates are missing are highlighted in red. The map shows the road sections checked. The maps can also be used to retrieve the road name to be used successively used as input for the risk assessment.

The table with all the verification data can be downloaded by clicking on "Download Table".

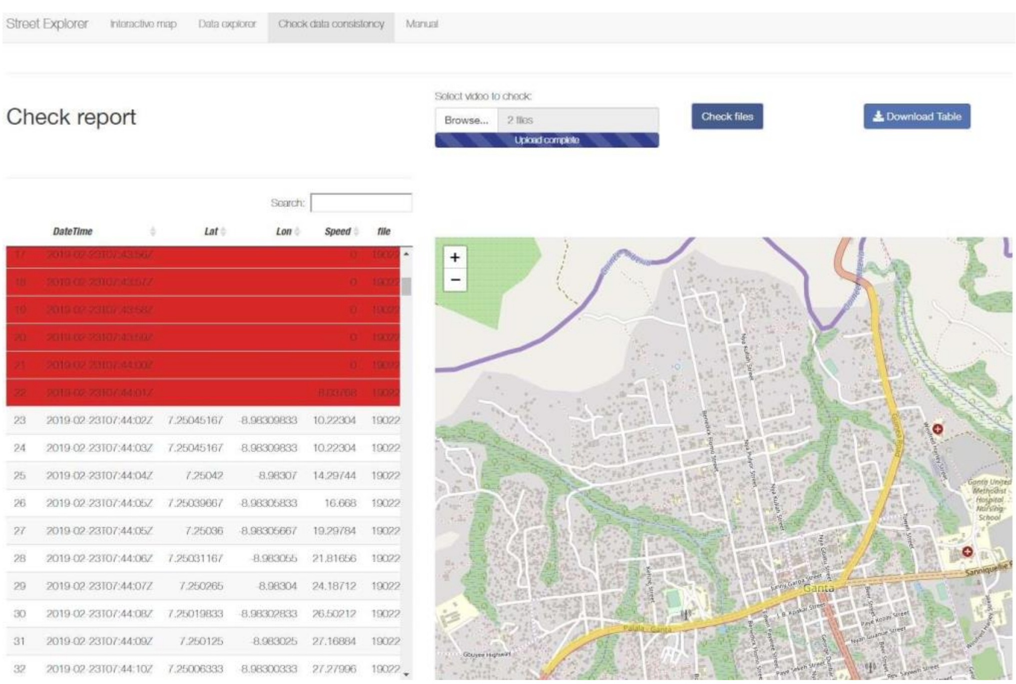

Figure 6-8 Example of check files

iii. The software allows to upload multiple videos all together (Figure 6-9). All the videos will be assessed together.

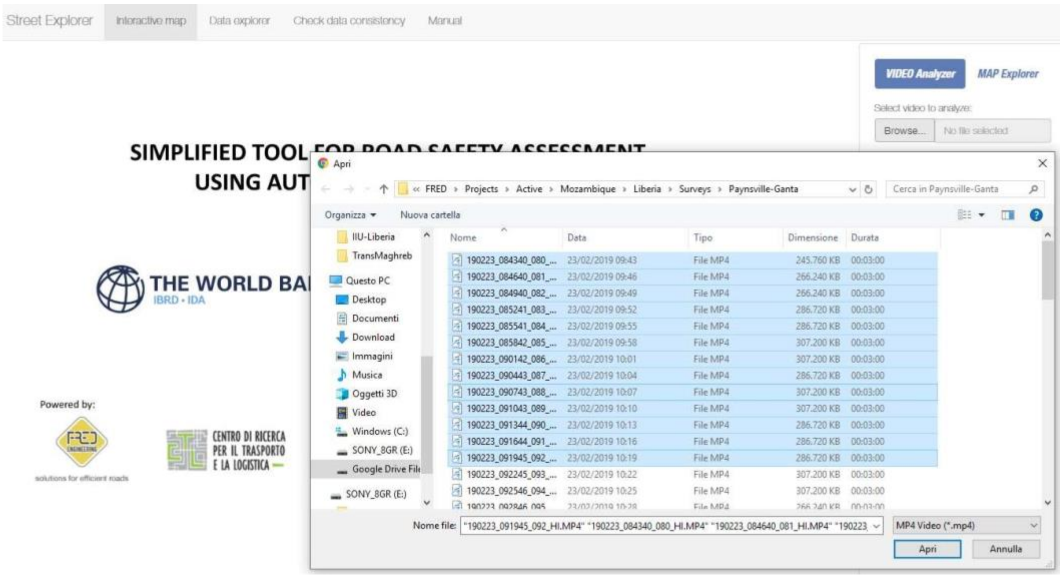

Figure 6-9 Example of multiple videos upload

iv. The calibration image and the RoadLabPro output file must be uploaded. By clicking on "Browse" it is possible to upload the files from the folder where they have been saved. It is recommended to save the three files in the same folder (Figure 6-10).

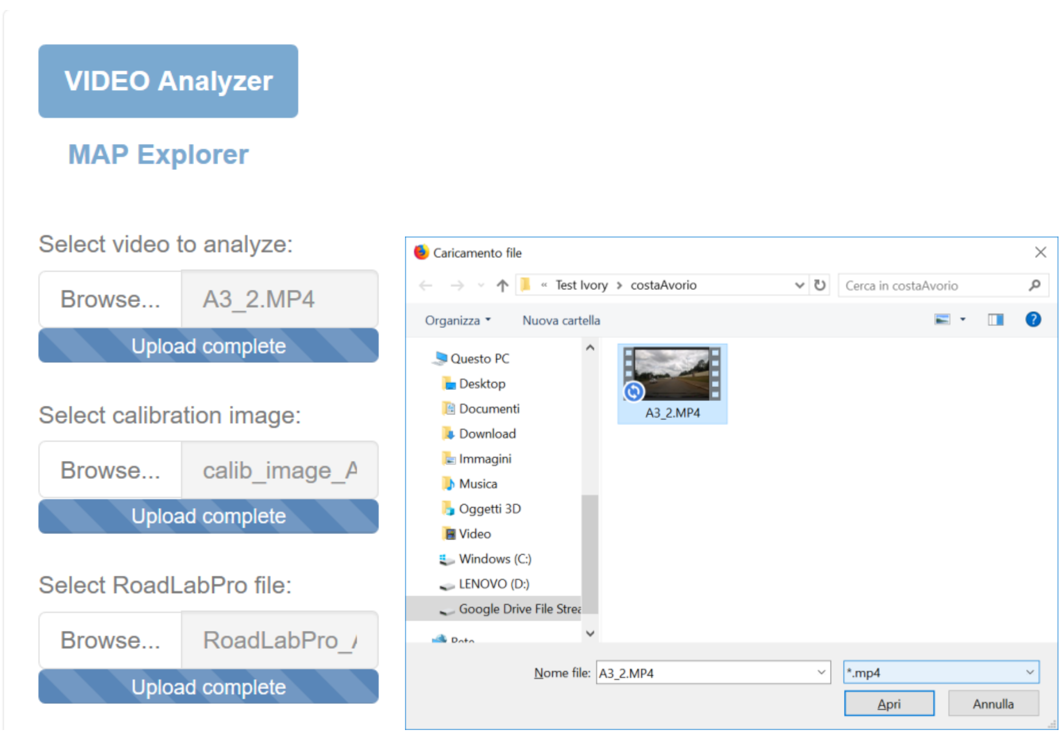

Figure 6-10 Example of files selected to analyze

v. Then all the other manual inputs can be provided selected from lists of variables. A name to the road section being assessed must be provided manually. The street name must be the same name used in “OpenStreetMap” website (https://www.openstreetmap.org). After opening OpenStreetMap, search for one of the locations where the video has been recorded and read the name of the road indicated (Figure 6-11).

The road name to be used in the software must be identical to the one used in OpenStreetMap (e.g. “n1” referring to the Figure 6-11). No capital letters must be used (e.g. “N1” must be written “n1”).

The driving side used in the country where the video has been done must also be provided manually (right or left driving side) (Figure 6-11).

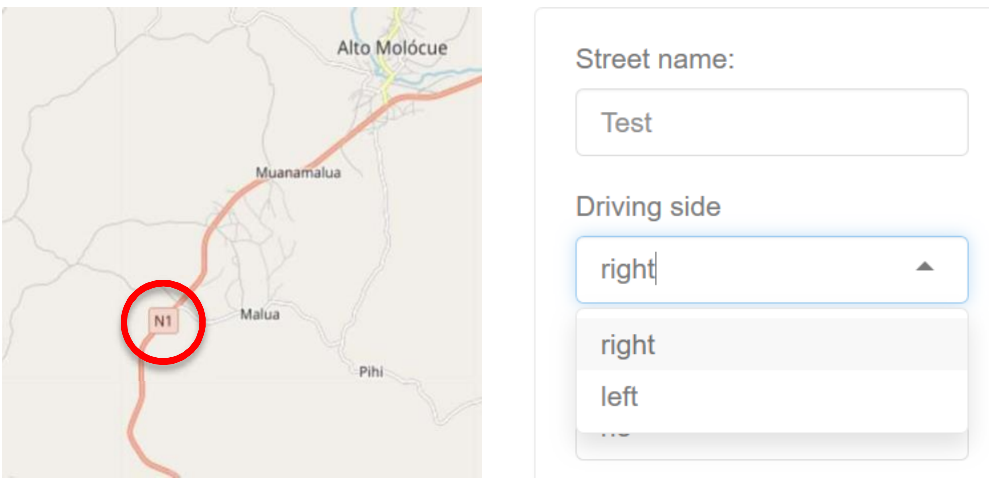

Figure 6-11 Example of street name and driving side input

vi. The following information must be provided manually using the lists available in the software interface (Figure 6-12):
- Type of carriageway (one-way or two-ways).
- Type of median (physical or line marking).
- Presence and width of sidewalk (no sidewalk, sidewalk shorted than 1 meter, sidewalk larger than 1 meter).
- Presence and width of paved shoulder (no shoulder, narrow, medium or wide shoulder).
- Presence of traffic calming (yes / no).
- Presence of motorcycle lane (yes / no).
- Presence of bicycle lane (yes / no).

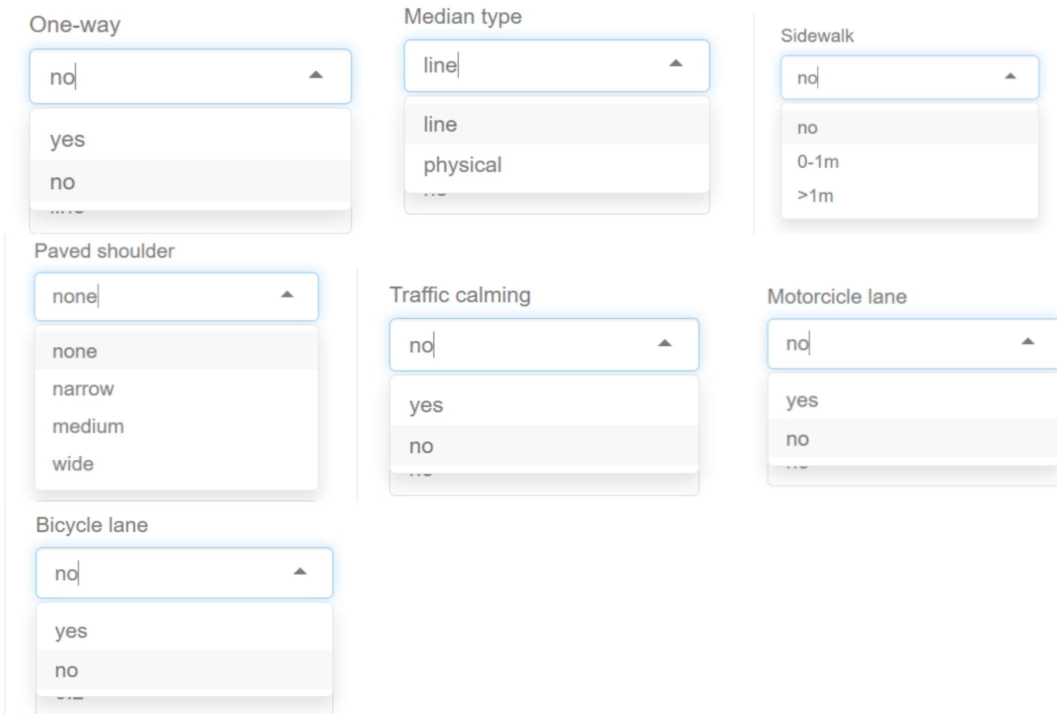

Figure 6-12 Input variables

vii. Some settings can be provided regarding the dimension of the video analyzed by the software. Especially it is possible to change:

-Bottom cut of the video

-Warp cut of the video

Changing these values allows the user to calibrate the videos. Initially it is recommended to maintain the default values (Figure 6-13). These values should be changed only if the calibration of video is not positive (see next step).

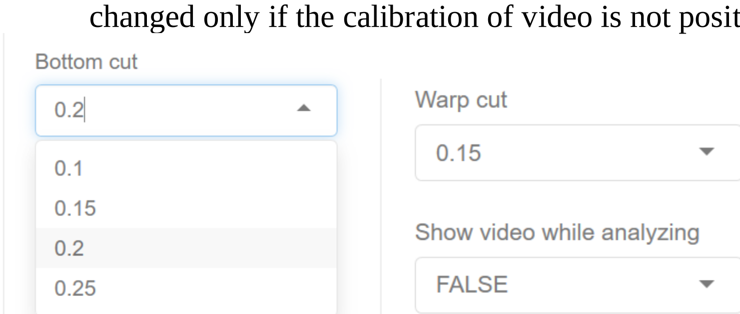

Figure 6-13 Video calibration values

viii. Once all the input information has been provided, click on “Run analysis”. A window appears asking to evaluate the video calibration. If the blank image is clearly visible and not separated, the calibration is positive. In this case click on “Good calibration” to launch the analysis (Figure 6-14).

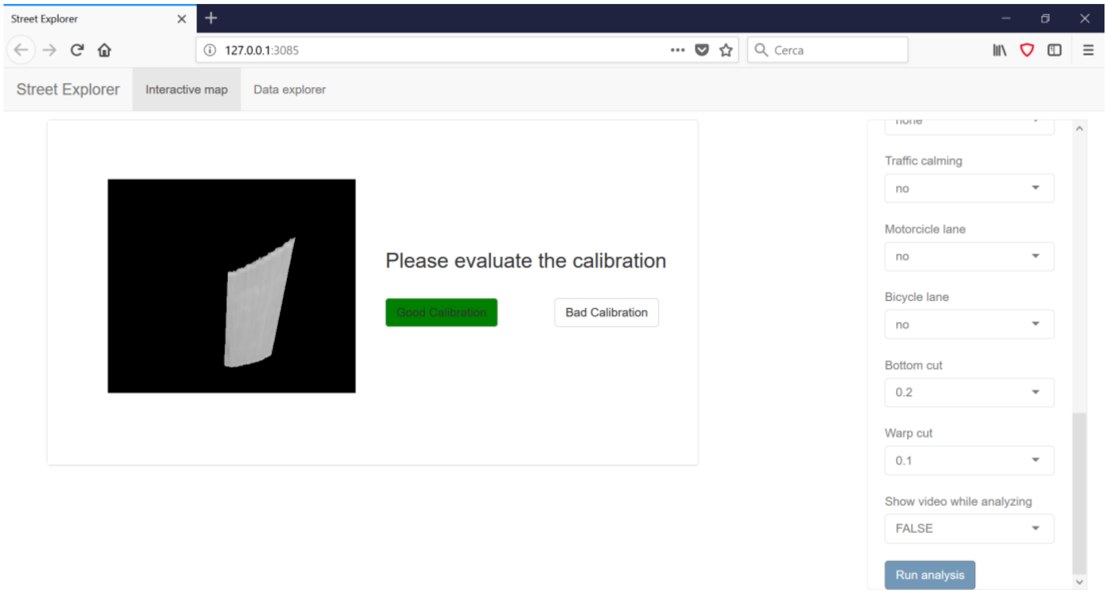

Figure 6-14 Example of good calibration

If the blank image is not clearly visible and / or separated, the calibration is negative. In this case click on "Bad calibration" (Figure 6-15). You can now adjust the calibration values "Bottom cut" and "Warp cut". Try different values and click on "Run analysis". This procedure has to be done until a good calibration is found.

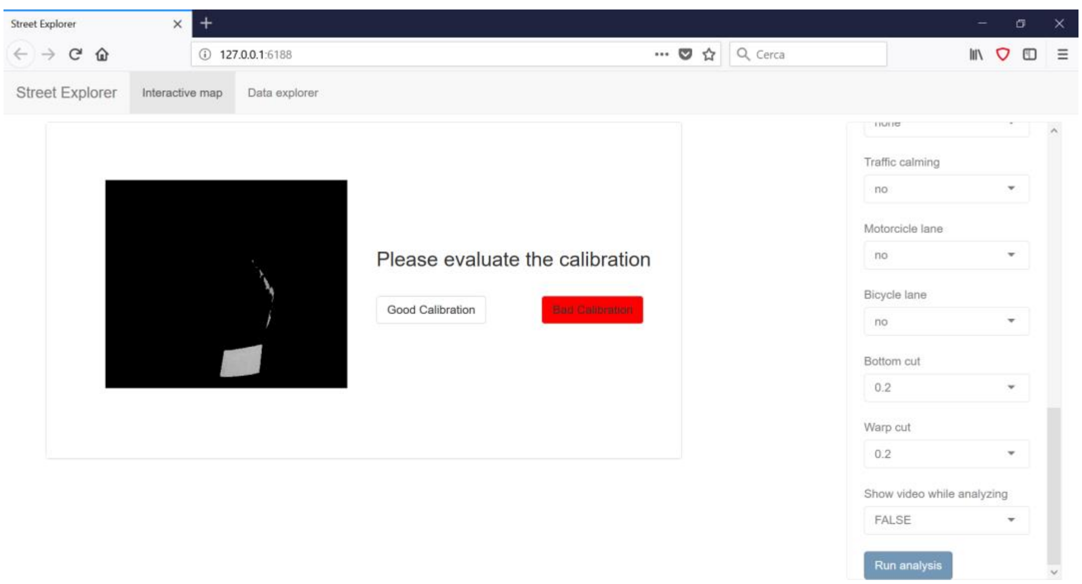

Figure 6-15 Example of bad calibration

The software will automatically perform all the analysis based on the risk assessment methodology. The running time for the analysis could take some time depending on the dimension of the video to be analyzed.

6.5.2 Working with outputs

Once the video analysis and risk assessment are completed, the software automatically shows the result on a map (on OpenStreetMap). By default, the software provides the result of the “Global Risk Score” (Figure 6-16).

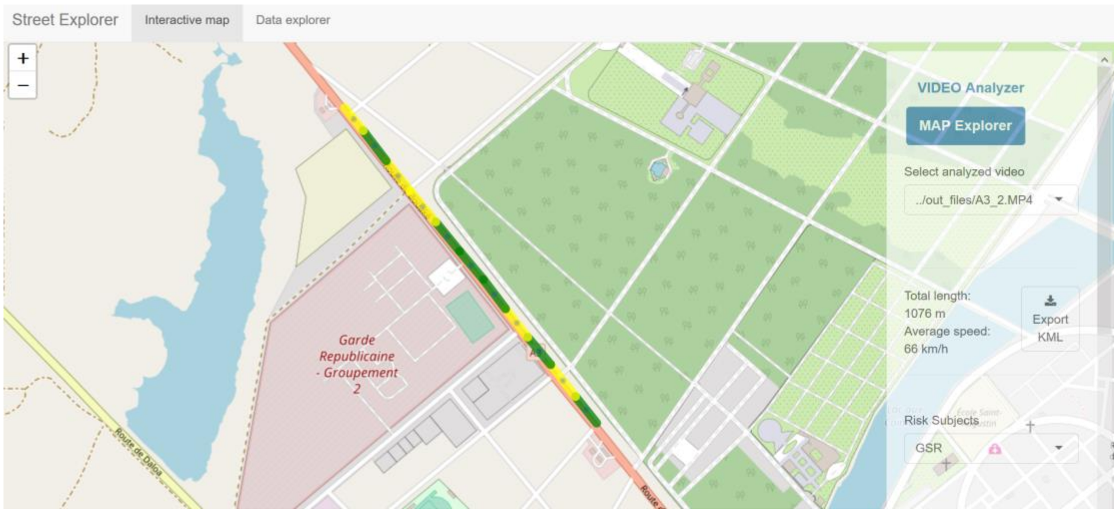

Figure 6-16 Example of Global Risk Score on a map

On the right part of the software interface some buttons and information are available. On the top part the user can chose between “Video analyzer” and “Map explorer” (

Figure 6-17). The first allows to come back to the interface to input data and run analysis. The second is the interface for assessing results.

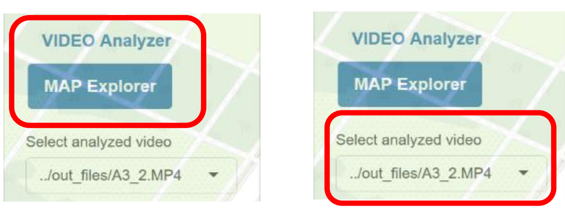

Figure 6-17 Video analyzer and Map explorer options

Below this section the user can select a video among those analyzed, of which the results can be assessed. This function allows to easily come back to results of previous analysis.

This part of the interface also provides some basic information about the road section length analyzed and about the average speed of the vehicle used for video recording. The user can download a “KML” file of the result map just by clicking on “Expert KML” (Figure 6-18). The software will open a window to select the folder in which the file must be saved.

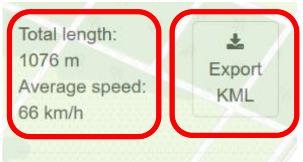

Figure 6-18 Total length and average speed information

The user can select the results to be visualized on the map through the drop-down menu "Risk Subjects". The following options are available:

- Global Risk Assessment
- Motor vehicles
- Pedestrians
- Bicycles

A pie graphic is also shown providing information on the percentages of road sections of 100 meters having a certain risk. Like for the map, the information about risk are provided through colors:

- Green = low risk
- Yellow = low-medium risk
- Dark orange = medium risk
- Red = medium-high risk
- Black = high risk

When one of the risk subjects is selected the colors shown on the map are automatically changed based on the calculated risk. Similarly, the colors in the pie graphic are automatically changed.

In the top part of the results interface, the user can choice between "Interactive map" (described above) and "Data explorer", through which detailed information about the risk assessments can be obtained (Figure 6-19).

The "Data explorer" provides two tables: "Overall Summary" and "Risk Summary".

The "Overall Summary" shows every 100 meters the values of the road attributes provided as input by the user and calculated by the software.

Street Explorer | Interactive map | Data explorer

Overall Summary

Download

Show 30 entries

Search:

	interval	lanewidth	roadside	speed	curvature	roadconditions	access	intersections	zebra	area	grade	persons	bicycle
1	100	2.8	0.6	65	1140	fair	0	0	0	rural	0	0	0
2	200	2.8	0.7	64	2028	poor	0	2	0	rural	1	2	0
3	300	3.8	0.9	68	3404	fair	1	0	0	rural	1	0	0
4	400	2.6	0.8	70	2928	very poor	1	1	0	rural	3	0	0
5	500	2.6	0.9	71	3024	fair	0	0	0	rural	4	0	0
6	600	2.7	0.8	71	2986	fair	1	0	0	rural	1	0	0

Figure 6-19 Overall summary table

By clicking on "Download", the user can obtain a ".csv" file containing all the information listed in the table. The users can choice the folder in which the file must be saved (Figure 6-20).

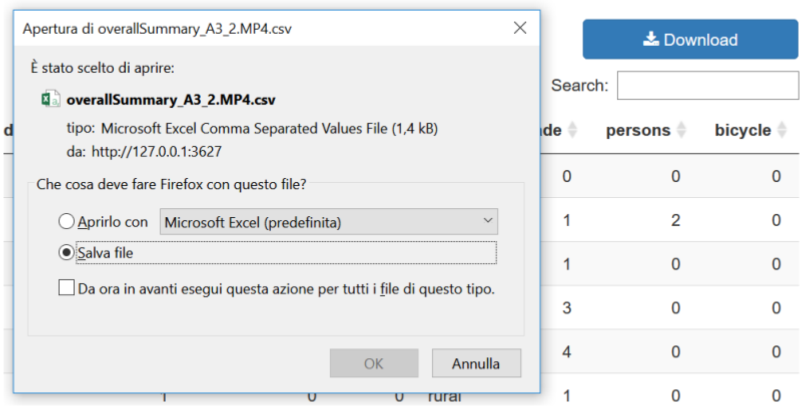

Figure 6-20 Example of download overall summary table

The "Risk Summary" table shows all the results of the risk assessments (GRS, motor vehicles, pedestrians, ciclysts).

Risk Summary

Download

Show 30 entries

Search:

	interval	StartLat	StartLon	EndLat	EndLon	vulnerability_mv	vulnerability_ped	roadDanger_mv	intersectionDanger_mv	risk_mv
1	100	6.82521833	-5.28688833	6.82586167	-5.2874	1.61	2.56	3.41	0	5.48
2	200	6.82586167	-5.2874	6.82661333	-5.28801	1.59	2.53	3.36	3.6	11.1
3	300	6.82661333	-5.28801	6.82727667	-5.28855667	1.65	2.63	3.59	1.3	8.08
4	400	6.82727667	-5.28855667	6.82796833	-5.2891	1.69	2.68	4.52	5.7	17.24
5	500	6.82796833	-5.2891	6.82866833	-5.28964667	1.71	2.69	3.88	0	6.61
6	600	6.82866833	-5.28964667	6.82934833	-5.29021833	1.71	2.69	3.88	1.95	9.94

roadDanger_ped	intersectionDanger_ped	risk_ped	roadDanger_bic	intersectionDanger_bic	risk_bic	gsr
1.21	0	3.1	1.98	0	5.07	5.1
1.1	5.7	17.21	1.95	1.8	9.5	12
1.38	1.3	7.04	2.25	1.43	9.69	7.97
1.1	7.54	23.12	2.1	2.93	13.45	18.04
1.1	0	2.96	1.8	0	4.85	5.98
1.1	2.47	9.62	1.8	1.43	8.7	9.85

Figure 6-21 Risk summary table

For each 100 meters of road section the following information are provided:

- StartLat = Latitude of the starting point of the 100 meters road section.
- StartLon = Longitude of the starting point of the 100 meters road section.
- EndLat = Latitude of the ending point of the 100 meters road section.
- EndLon = Longitude of the ending point of the 100 meters road section.
- vulnerability_mv = calculated value for the vulnerability of motor vehicles
- vulnerability_ped = calculated value for the vulnerability of pedestrians and of cyclists
- roadDanger_mv = calculated value for the danger for motor vehicles on road sections
- intersectionDanger_mv = calculated value for the danger for motor vehicles at intersections
- risk_mv = calculated risk for motor vehicles
- roadDanger_ped = calculated value for the danger for pedestrians on road sections
- intersectionDanger_ped = calculated value for the danger for pedestrians at intersections
- risk_ped = calculated risk for pedestrians
- roadDanger_bic = calculated value for the danger for cyclists on road sections
- intersectionDanger_bic = calculated value for the danger for cyclists at intersections
- risk_bic = calculated risk for cyclists
- GRS = Global Risk Score calculated for the 100 meters road section