Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 69 (2023) 155–162

Transportation Research Procedia

www.elsevier.com/locate/procedia

AIIT 3rd International Conference on Transport Infrastructure and Systems (TIS ROMA 2022), 15th-16th September 2022, Rome, Italy

Measuring Safety Performance in the extra-urban Road Network of Lombardy Region (Italy)

Michela Bonera[a], Martina Carra[b], Roberto Ventura[b], Benedetto Barabino[b]*, Giulio Maternini[b]

[a]*Research and Development - Brescia Mobilità SpA - Via Leonida Magnolini, 3, 25135 Brescia, Italy*

Department of Civil, Environmental, Architectural Engineering and Mathematics (DICATAM), University of Brescia (IT), Via Branze 43, 25123 Brescia, Italy

Abstract

Road Network Screening (RNS) is a process to evaluate the safety performance of the whole road network and identify worst performing roads. Currently, literature provides many models and methods for RNS. Moreover, several frameworks of RNS were issued at the European National Level over time. However, even if sophisticated models and methods could be preferable for their computational accuracy, they may be far from the capabilities of practitioners. In addition, other issues such as availability of operative attributes and data quality and processing persist. For instance, accurate crash location, which is crucial for detailed analyses of high crash rates at some locations, is still an issue: many road administrations pointed out that coordinates miss or are inaccurate in many cases. Within this context, this paper proposes a straightforward operational framework to evaluate safety performance for RNS, using a flexible rationale that integrates crash, traffic, and road data, respectively. More precisely, this framework: (a) handles crash location data without using spatial coordinates; (b) computes the crash rate index at different administrative levels; (c) shows results by Geographic Information System (GIS) maps. This framework is applied to the whole extra-urban road network of the Lombardy Region (Northern Italy) using 30.000+ crash data provided by the Regional Institute for Lombardy Policy Support (PoliS). Road authorities could adopt this framework to perform an accurate safety screening on the road network aimed at rational planning of safety interventions.

Keywords: Road network screening; Crash Location; Crash rate

* Corresponding. Tel.: +39 030 3711306.
E-mail address: benedetto.barabino@unibs.it

10.1016/j.trpro.2023.02.157

1. Introduction

Over the last decades, road safety has improved in Europe, and EU roads are among the safest in the world (Eurostat, 2020). However, road safety still represents a major social and health issue, as too many people still lose their life or get injured on EU roads. New targets have been set for the decade 2020-2030, and a reduction of 50% in both road deaths and serious injuries was expected (European Commission, 2019). Therefore, Member States must implement further strategies to achieve those targets at any level. At the high level, Ministries of Transports delineate the main strategies to improve road safety (e.g., road infrastructure safety, driving regulation, enforcement) and allocate funds. Regions support the Central Government at the intermediate level in coordinating, monitoring, and assessing such strategies. Road Authorities (RAs) and Municipalities and/or Local Administrations (LAs) implement specific safety projects and initiatives at the local level. Therefore, all these subjects would benefit from having available effective tools to measure road safety performance within their jurisdictions, to better recognize safety problems, and monitor safety improvements more efficiently. The Road Infrastructure Safety Management System (RISMS) is an effective tool for this purpose. Indeed, it provides a set of managerial tools (or procedures) to help evaluate road safety performance over the entire life cycle of road infrastructures (European Union, 2019; Persia et al., 2016). Each tool is conceived for a specific stage (e.g., project, operation), aim (e.g., monitoring, auditing), and level (e.g., network-wide, site-specific). While the RISMS procedures must be implemented on all roads belonging to the TEN-T network, Member States are warmly recommended to implement them also on other roads, which are classified as primary in the national network (European Union, 2019; Elvik et al., 2009). In this context, Road Network Screening (RNS) is the first step of the whole RISMS procedure. It is applied on a wide scale to assess the safety performance of the overall road network and identify the worst performing roads (or sites) before in-depth analyses to assess specific concerns and set effective enhancement actions (Park and Sahaji, 2013; Stipancic et al., 2019).

RNS is not a novelty in the road safety community. The literature is quite rich, and several models and methods are applied for RNS (e.g., Ghadi & Török, 2019; Stipancic et al., 2019). On the one hand, the research has developed sophisticated mathematical models. They relate specific attributes (e.g., road design and functional features) to the response variable (e.g., crash frequency, severity) using historical crash data and different modelling forms, such as Negative Binomial, Empirical Bayesian Methods, Poisson Log-Normal models (Mannering & Bhat, 2014; Bonera et al., 2022). However, knowledge and expertise are required to develop, perform, and interpret such models as well as specific software or coding skills might be required too. Moreover, these models may require much data to be effectively implemented and are far from the capabilities of practitioners (Ambros et al., 2016). In addition, many of such existing models need for accurate crash location that are still not fully available. For instance, in Italy, 36% of crashes in rural roads miss from accurate coordinates (Montella, 2010). Therefore, these models are not of immediate use in operations because of the possible lack of trained personnel and the inability to consider other issues (e.g., statistical significance, best-fit evaluation). Moreover, usually, the LA and/or RA managers might not be willing to run models and accept the results passively. On the other hand, many Member states proposed specific RNS methods. These methods are based on computing simple or composite indices (e.g., crash frequency, crash rate) to identify the worst-performing road network elements. Moreover, their simple properties make these methods the most adopted by many road safety experts (e.g., SETRA, 2006; Elvik, 2007; MIT, 2012; EuroRAP, 2020). However, methodological issues such as data availability, data processing and integration with other data sources have not been fully addressed, especially in case of mis-recorded and misreported data. All these issues are fundamental matters for the applicability and replicability of each method and are the *conditio sine qua non* any data-driven model can be performed (Schlögl & Stütz, 2019). Moreover, these methods do not consider dynamic maps showing the safety performance for administrative levels.

This study aims to fill the previous gaps by proposing a straightforward framework to perform RNS at different administrative levels. Specifically, it integrates three data sources and presents four steps: (i) flexible network rationale segmentation; (ii) road, traffic, and crash attributes assignment; (iii) screening index computation; (iv) safety performance ranking and visualization (by easy-to-read Geographic Information System dashboards). A total of 30000+ crash data occurred between 2014 and 2018 from the whole non-urban road network of the Lombardy Region (Northern Italy) was adopted to show the feasibility of this framework in a real (and relevant) case study.

The remaining paper is organized as follows. Section 2 presents the methodological framework to measure safety performance. Section 3 presents the experimental results and related discussion. Finally, Section 4 concludes the study and provides research perspectives.

2. Methodological framework

Building on EuroRAP (2020), this framework is organized in four steps and provides a feasible and flexible structure to integrate raw traffic, road, and crash data to provide enough spatial resolution. Two main assumptions support this framework: first, RNS should almost include road crashes frequency and exposure measures (*e.g.*, length of road segments and traffic volumes). Therefore, crash, road and traffic data should be linked to perform such assessment. Second, a spatial resolution that does not rely on crash spatial coordinates should be defined: coordinates may not always be available or correctly recorded. Therefore, an integration among all the involved data sources is required to provide such a spatial resolution. Fig. 1 shows the scheme of the framework that mainly includes (i) data sources and (ii) procedure steps. The overall framework is summarized in what follows.

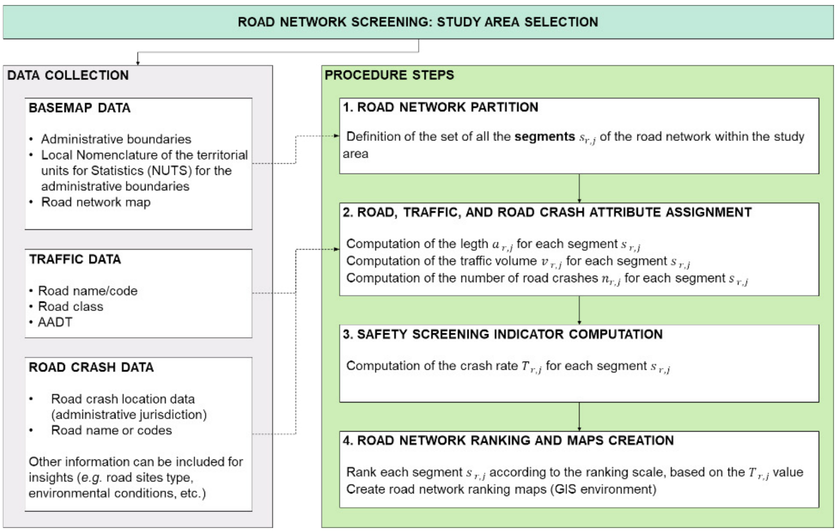

Fig. 1 - Operational framework scheme

2.1. Data collection

Once the study area has been defined for RNS, the related information from different data sources should be gathered. Specifically, the "*Data collection*" box contains the three main sources where data should be gathered. These are: (i) **base map data**, *i.e.*, the main maps, GIS-based data, and the related spreadsheets, which refer to the administrative partition of the selected area; (ii) **traffic data**, *i.e.*, road identification and traffic volumes data. Specifically, road name or code are necessary to identify the route, whereas traffic volumes quantify an exposure measure. Both data should be considered according to a link-node configuration and are generally provided as a GIS-based file, but also the related spreadsheets are available. Moreover, data on road class should be gathered, as it would be required to differentiate the screening for different classes; (iii) **road crash data**, *i.e.*, the number of road crashes that occurred within the area and the number of road deaths and injuries as well. The crash location is required to match crashes to the considered roads (*e.g.,* jurisdiction, road name or code); other data (*e.g.,* road site type, environmental conditions) might be useful for specific insights. Such data are generally provided as spreadsheets and are retrieved from national statistics templates or other sources. Because all data can be provided in different formats, some preparation could be necessary to refine data and make them consistent for the next steps of the framework.

2.2. Procedure steps

Step 1 - Road network partition

Usually, road safety data are expressed according to the nature of the related information. For instance, crashes are points on the road network, as they represent a single event with specific characteristics, whereas roads (and the related attributes) are sequences of links (and intersections) with specific design and traffic attributes. Hence, a road network unit should be defined to enable a unique correspondence between crashes and road segments. This unit should work as a "*least common multiple*" of the location attributes of all the data sources available, on which the road network can be partitioned. Therefore, all location attributes must be identified among the different data sources. Then, only the common attributes among the different data sources should be considered. Unlike spatial coordinates and road chainage, the road name or code (which identifies a specific route) and the administrative location (or jurisdiction) are usually reported in these sources. Usually, this information is already registered in the road traffic data source. However, if not, such information could be integrated by overlapping the road network layer with the administrative boundaries map (*e.g.,* country, region, province, metropolitan areas, municipality) layer to perform a more detailed road network partition. Thus, the "*least common multiple*" among location attributes is the portion of a generic road within the boundaries of the lowest territorial jurisdiction, which is referred to as a **segment**.

Such network partition enables flexibility to investigate each road thoroughly according to the territorial jurisdiction of interest: the denser the network partition, the more accurate the RNS analysis. Specifically, let: J be the set of the administrative location within the study area, and $j \in J$ be a generic location; $R(j)$ be the set of roads crossing the jurisdiction $j \in J$, and $r \in R\ (j)$ be a generic road; $L(r,j)$ be the set of road links of road $r \in\ R(j), j \in J$, and $l \in L(r,j)$ be a generic link; $S_{r,j}$ be the set of all links $l \in L(r,j)$ of road $r \in\ R(j),\ j \in J,$ and $s_{r,j} \in S_{r,j}$ be a generic **segment**. Then, $s_{r,j}$ is defined as:

$$s_{r,j} = \{l \in L(r,j): r \in R(j) \text{ and } j \in J\} \tag{1}$$

Step 2 – Road, traffic, and road crash attributes assignment

Step 2 assigns length and traffic attributes to each segment. Because these attributes are reported on a link-node basis, each link is associated with its length and the related Average Annual Daily Traffic (AADT). Next, the length and AADT of $s_{r,j} \in S_{r,j}$ can be easily computed as the sum of the length and AADT of each link of $s_{r,j} \in S_{r,j}$, respectively. Formally, let: a_l be the length of a generic link l; v_l be the AADT of a generic link l. Then, the length ($a_{r,j}$) of the segment $s_{r,j} \in S_{,j}$ of $r \in\ R(j)$ within, $j \in J$ is defined as:

$$a_{r,j} = \sum_{l \in L(r,j)} a_l \qquad \forall\, r \in R, \forall\, j \in J \tag{2}$$

The AADT ($v_{r,j}$) of the segment $s_{r,j} \in S_{,j}$ of $r \in\ R(j)$ within, $j \in J$ is defined as:

$$v_{r,j} = \frac{\sum_{l \in L(r,j)} a_l \cdot v_l}{a_{r,j}} \qquad \forall\, r \in R, \forall\, j \in J \tag{3}$$

Next, each segment must be assigned the related number of crashes. The crash data source contains all the crashes that occurred over the road network of the study area considered. Specifically, the road and the jurisdiction where the crash occurred are registered for each element. Hence, the number of crashes of $s_{r,j} \in S_{r,j}$ of $r \in\ R(j)$ within, $j \in J$ can be defined as the sum of the crashes having the same road and the jurisdiction attributes. Specifically, let: $N\ (r,j)$ be the set of road crashes that occurred on the route $r \in\ R(j),\ j \in J,$ and $n_{r,j} \in N_{r,j}$ be a generic crash. Then, the number of crashes of a generic segment $s_{r,j} \in Sr,j$ of $r \in\ R(j)$ within $j \in J$ is defined as:

$$n_{r,j} = \{n \in N(r,j): r \in R\ (j) \text{ and } j \in J\} \tag{4}$$

Step 3 - Safety screening indicator computation

Step 3 computes the safety indicator for each segment. Valuable indicators could be employed in road safety analysis to evaluate road safety performance. However, European and national recommendations are considered in this work. Thus, we compute the straightforward and well-known crash rate index as the ratio between the number of crashes at a given site over a specified period and the segment length per the related traffic volume (expressed in billion km travelled). Although this index is simple to compute, it is chosen because widely accepted and used among administrators and technicians (Borghetti et al., 2021). More formally, let *f* be a correction factor that homogenizes the quantities involved in the computation of the crash rate (e.g., the number of days in a year to be considered). By joining Eqn. (2), Eqn. (3), and Eqn. (4) the crash rate for each segment is computed as follows:

$$T_{r,j} = \frac{10^6 \cdot n_{r,j}}{f * a_{r,j} * v_{r,j}} \qquad \forall\, r \in R, \forall\, j \in J \tag{5}$$

Step 4 - Road network ranking and maps creation

Step 4 ranks all the segments consistent with a specific scale and shows results according to dynamic maps. There are many methods to develop a ranking scale: in this study, a five-level scale is adopted based on the distribution quartiles of $T_{r,j}$, as proposed by Bonera et al. (2022). First, once the $T_{r,j}$ values have been computed for each segment, they are ordered from the lowest to the highest. Then, thresholds are set based on the lower, middle, and upper quartiles (Q1 = 25th percentile, Q2= 50th percentile, and Q3 = 75th percentile, respectively). Next, the interquartile range (IQR) of the distributions of the ordered $T_{r,j}$ is also introduced to identify the most critical segments. Indeed, the IQR is adopted to better emphasize 'outliers' values (in terms of high critical values) rather than remove them from the distribution. Therefore, the extension of Q3 (Q1) above 1,5*IQR defines thresholds, enabling the ranking scale to a five-level scale (Table 1) and identifying the segments with the highest crash rate. Table 1 shows this scale and reports the lower and upper limits for each level, which defines the range values.

The ranking results provide specific maps, where each segment is represented with a colour corresponding to the related safety ranking level. These maps can be produced in a GIS environment, following the segment construction rationale, and uploaded on a territorial information system to be consulted by the interested users (e.g., LAs and Ras), who can also have a clear overview of the overall safety performance of the road network of interest. Moreover, the flexibility of the proposed road network partition (*i.e.,* a segment of each road within a specific territorial jurisdiction) enables elaborating the RNS in different scales. Specifically, the overall computation procedure can adapt itself to the territorial jurisdiction chosen. For instance, if provinces are considered territorial jurisdictions, the procedure will return a crash rate weighted over the provincial boundaries for each road, thus a unique value without distinguishing from municipalities.

Table 1 – Definition of the ranking scale for the crash rate distribution.

Level	Ranges values		Colour
	Lower limit	Higher limit	
1	(Q1-1,5 IQR) > 0	Q1	
2	Q1	Q2	
3	Q2	Q3	
4	Q3	(Q3 + 1,5 IQR)	
5	(Q3 + 1,5 IQR)	MAX	

3. Real experimentations

3.1. The context

The road network of the Italian Lombardy Region (LR) was investigated for the experimentation of the framework. LR is the most populated region in Italy (10+ million inhabitants), and it is considered the commercial and industrial hub of the entire Country. Its road network is wide and dense and comprises 700+ km of motorways, 10.000+ km of provincial roads, and about 1.000 km of state roads, besides 58.000 km of local roads. LR yearly records 30.000+ road crashes, 400+ deaths and 40.000+ injuries, that is one of the highest records in Italy. To summarise, LR is like several

European and Italian Regions, apart from being very large in implementation scale and representativeness. Thus, this experiment will provide a good case study of RNS from which lessons can be learnt for other similar European (Italian) Regions.

3.2. Experimental Setup

Base maps data were retrieved from the open-access regional topographic database in a shapefile format and contained the administrative boundaries of the whole Region, provinces, and municipalities. The regional Directorate General provided traffic data for road safety in a shapefile format that contained the road network graph. Each link of the graph was assigned with the road name, road type and the AADT. Finally, crash data that occurred in RL over the five years 2014-2018 were provided by Polis-Lombardia, i.e., the Regional Institute for Policy Support. Data were provided in the spreadsheet format and reported all the main attributes of the national statistical road crashes template that mainly contains crash data and location (i.e., province and municipality codes, road name or code), road type, location attributes (e.g., segment and/or intersection type, pavement type), number of people involved (ISTAT, 2019). Noteworthy, 21% of the crash records missed of spatial coordinates. A total of 34.000+ crashes and 24.000+ road links were included in the analysis, after some data pre-processing.

3.3. Framework development and results

The framework was implemented according to Section 2.2. Specifically, Step 1 was performed in a GIS environment, given that traffic and geographical basemap data were available in this format. The open-access QGis software was used. Steps 2, 3, and 4 were performed in MS Excel, as formulas computation was easier to perform there. Finally, Step 4 was also refined in QGis for maps creation and visualisation. To define the road network segments according to Eqn. (1) road names and municipalities boundaries were considered in this work. To make Eqns. (2) and (3) easier to compute, segment codes were created into the road network basemap by simply merging the variable "road code" and "boundaries" of the data source for each segment of the network. In such a manner, each link was attributed a new variable, which indicated the segment association. For instance, the BreBeMi highway has the road code "A35". Each link $l \in L(r,j)$ is associated with the related segment code, defined according to different jurisdictions, i.e., municipalities, provinces, and region. Boundaries of the different jurisdictions are identified by a 5-digit code (*e.g.,* "17029") and a 2-digit code (*e.g.,* "17") for municipalities and provinces, respectively. The Nomenclature des Unités Territoriales Statistiques (NUTS) code for the Region was not assigned, as it represents the study area; hence, each road is considered in its full extension.

Next, the computation of the crash rate was performed separately for motorways, state roads and provincial roads. Their selection was mainly based on the administrative road classification, as insufficient information on the functional attributes were included in the road data source. Noteworthy, state roads were separated from provincial roads because they are managed by different RAs and for their different relevance in the whole road network.

Fig. 2 shows the capability of the procedure to adapt itself at a different level of screening, thus at the regional (i.e., entire routes within the regional boundaries), provincial (i.e., routes within the provincial boundaries), and municipality level (i.e., routes within the municipalities boundaries). For clarity, results are reported for the state roads only. In these maps, jurisdiction boundaries are reported to emphasize the screening capability of such a procedure. In Fig.2 (a), the screening at the regional level is represented: the segments are defined considering the whole regional jurisdiction; hence, the segment corresponds to the overall road. At such screening level, the crash rate is computed weighted over the route independently from the provinces or municipalities traversed.

In Fig.2 (b), the screening at the provincial level is represented: the segments are defined considering the provincial jurisdictions; hence, the crash rates are computed for the same road depending on the province traversed. In Fig.2 (c), the screening at the municipality level is represented. Each road is segmented based on the municipality boundaries, and the crash rate is computed within the municipality jurisdiction for each segment. To summarise, this flexible structure enables an RNS at both wider and in-depth levels. Therefore, owing to the scarcity of resources, such flexibility can help prioritise actions.

Notably, EuroRap (2020) is like our method, because it provides a crash rate computed as the ratio between the number of crashes and the billions of vehicles*km travelled. However, it returns results for the overall road, without distinguishing between paths and administrative levels and level of traffic. These properties cannot be considered as constant because they could variate among road segments that could have different characteristics. Moreover, that ratio is compared against a gradual scale with fixed (predefined) thresholds to identify black spots needing priority. That is the scale is not built using specific context data. Therefore, although an adjustment factor is provided, since the classification scale is fixed and more countries-comparison-oriented, it might not be fully representative of the specific network analysed.

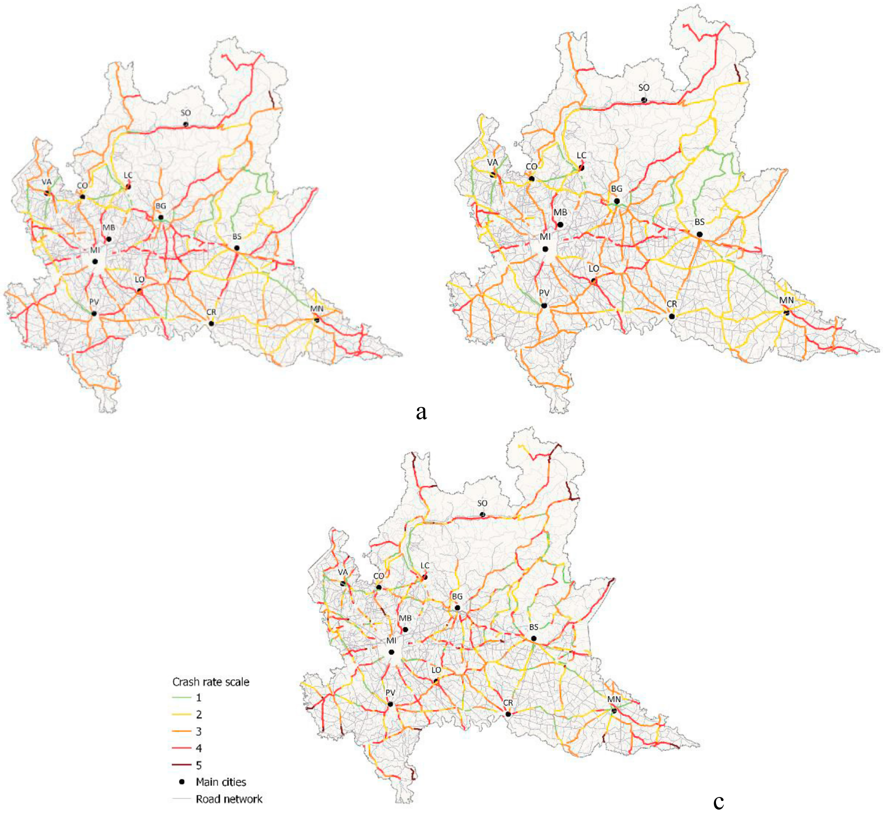

Fig. 2. - Road safety network screening maps over different jurisdictional level for state roads: (2a) regional level, (2b) provincial level, and (2c) municipality level.

4. Conclusions

Despite improvements that have been registered over the last decade, road safety Europewide still represents a major social and health issue to be overcome. Road Network Screening (RNS) may be a useful tool for safety performance measurements because it helps detect the most critical road crashes routes. On the one hand, most of the RNS approaches rely on models, and they might be far from the capabilities of practitioners, who may not have enough knowledge or competencies to implement them. On the other hand, RNS methods were proposed by several national safety guidelines. These methods are straightforward, but they are needed for accurate crash location and presented results using fixed maps for visualisation. This study covered some previous gaps by integrating existing techniques and tools into an operational framework to perform RNS. Specifically, this paper contributed to the literature by: (i) providing a replicable and flexible framework to manage crash location data without relying on spatial coordinates; (ii) proposing a 5-level ranking scale based on the quartiles of the crash rate values distribution, where the interquartile range is used to emphasise criticalities rather their removal; (iii) enabling a general and flexible RNS, as the computational process can adapt itself according to the territorial jurisdiction considered.

The framework is based on an easy-to-implement four-steps procedure and uses a straightforward index for the RNS. This enables high degree of replicability and adaptability above all among practitioners. The 5-level ranking scale enables a clear identification of the most critical paths, and this is essential to direct strategies and allocate funds more efficiently. Specifically, this rank helps prioritise interventions. The higher the risk, the higher the priority. The flexibility of this framework at different administrative levels enables to obtain diverse level of network screening. Thus, road authorities and administrations can approach differently to the road network they manage.

The whole procedure was applied to the main non-urban road network of the Lombardy Region, and it was found that more than half of the network resulted in being quite safe, as it reported a low or medium-low value of crash rate. Moreover, the results can be applied in similar contexts characterized by comparable elements such as road network characteristics and related functionalities and crash data. Conversely, the methodology implemented presents general validity and, providing new input data which refers to the context at hand, the model can be applied elsewhere, provided that data on crashes, roads and traffic volumes will be available.

Further research can improve this framework by embracing and modelling the concept of risk to provide a more refined crash rate indicator as already applied in public transport (e.g., Barabino et al., 2021;).

Acknowledgements

This work has been supported by Polis-Lombardia and the Safety General Directorate of the Lombardy Region within the Agreement on road safety studies to support the Road Safety Regional Monitoring Centre of the Lombardy Region (CMR).

References

Ambros J., Jurewicz C., Turner S., Kieć M. (2018). An international review of challenges and opportunities in development and use of crash prediction models, Eur. Transp. Res. Rev. 10.

Barabino, B., Bonera, M., Maternini, G., Olivo, A., & Porcu, F. (2021). Bus crash risk evaluation: An adjusted framework and its application in a real network. Accid. Anal. Prev., 159, 106258.

Borghetti, F., Marchionni, G., De Bianchi, M., Barabino, B., Bonera, M., & Caballini, C. (2021). A new methodology for accidents analysis: the case of the State Road 36 in Italy. International journal of transport development and integration, 5(3), 278-290.

Bonera, M., Barabino, B., & Maternini, G. (2022). Road Network Safety Screening of County Wide Road Network. The Case of the Province of Brescia (Northern Italy). In International Road Federation World Meeting & Exhibition (pp. 525-541). Springer, Cham.

Bonera, M., Barabino, B., & Maternini, G. (2022). A Straightforward Framework for Road Network Screening to Lombardy Region (Italy). Sustainability, 14(19), 12424.

ISTAT, Incidenti stradali. Anno 2019, 2020.

Elvik R., Vaa T., Hoye A., Sorensen M. (2009). The handbook of Road Safety Measures, Emerald Group Publishing, Burlington, MA,

European Commission, EU Road Safety Policy Framework 2021-2030 - Next steps towards "Vision Zero," 2019.

European Road Assessment Program, RAP Crash Risk Mapping: Technical Specification, 2020.

European Union, Directive 2019/1936 of the European Parliament and of the Council amending Directive 2008/96/EC on Road Infrastructure Safety Management, 2019.

Eurostat, Eurostat regional yearbook - 2020 edition, 2020. https://ec.europa.eu/eurostat/web/products-statistical-books/-/ks-ha-20-001.

EuroRAP. (2020). RAP Crash Risk Mapping: Technical Specification (Issue January).

Ghadi, M., & Török, Á. (2019). A comparative analysis of black spot identification methods and road accident segmentation methods. Accid. Anal. Prev., 128, 1–7.

Mannering, F. L., & Bhat, C. R. (2014). Analytic methods in accident research: Methodological frontier and future directions. Analytic Methods in Accident Research1, 1-22.

Montella, A. (2010). A comparative analysis of hotspot identification methods. Accid. Anal. Prev., 42(2), 571–581.

MIT. (2012). Linee guida per la gestione della sicurezza del- le infrastrutture stradali. Art. 8 del decreto legislativo 15 marzo 2011, n. 35.

Park P.Y., Sahaji R. (2013) Safety network screening for municipalities with incomplete traffic volume data, Accid. Anal. Prev. 50 1062–1072. https://doi.org/10.1016/j.aap.2012.08.012.

Persia L., Usami D.S., De Simone F., La Beaumelle V.F.D., Yannis G., Laiou A., Han S., Machata K., Pennisi L., Marchesini P., Salathè M., (2016) Management of Road Infrastructure Safety, Transp. Res. Procedia. 14, 3436–3445. https://doi.org/10.1016/j.trpro.2016.05.303.

Porcu, F.; Olivo, A.; Maternini, G.; Barabino, B. Evaluating bus accident risks in public transport. Transp. Res. Procedia 2020, 45, 443–450.

Schlögl M., Stütz R. (2019) Methodological considerations with data uncertainty in road safety analysis, Accid. Anal. Prev. 130 136–150. https://doi.org/10.1016/j.aap.2017.02.001.

SETRA (2006). Démarche SURE - Étude d'enjeux de sécurité routière pour la hiérarchisation des itinéraires.

Stipancic J., Miranda-Moreno L., Saunier N., Labbe A. (2019) Network screening for large urban road networks: Using GPS data and surrogate measures to model crash frequency and severity, Accid. Anal. Prev. 125, 290–301. https://doi.org/10.1016/j.aap.2019.02.016.